

Rapid advancements in technology have responded to and pioneered changes in our state and across the world.

Often these resources and technologies are critical to the function of our society while also helping us work better and faster. Sometimes they also enable us to adapt — the onset of a global pandemic in 2020 has now made virtual meetings commonplace and changed how Oregonians conduct business. The resources and technologies presented in this section cover the spectrum of traditional to innovative, and demonstrate the breadth of technology that is integral to the production and management of our energy system.

Electricity generation technologies, such as wind and solar, are becoming more widely used and in many cases are now lower cost than more traditional technologies. And some newer technologies may be just around the corner while researchers, scientists, and businesses work to make them commercially viable. Tomorrow's energy resources may include electrolyzers to generate hydrogen fuel, offshore wind turbines, fuel cell electric vehicles that run on hydrogen and emit only water, or carbon capture and sequestration technologies that help industries capture and store harmful greenhouse gas emissions.

Automated metering infrastructure enables utilities to evaluate real-time data on customer electricity use so that they can optimize their systems and provide better value to their customers. Electric vehicles, battery storage, and smart appliances create opportunities for electric utilities to communicate with devices in homes and businesses to better balance new electricity loads while avoiding investments in expensive electricity generation. In some areas of Oregon, utilities are already communicating with customers and their smart devices to help better manage the grid.

There are trade-offs with these technologies. Some operate without emitting greenhouse gases or other air pollutants, but there are often emissions and environmental impacts associated with building and transporting them. For example, how do we plan for and manage the waste streams of new technologies when they reach the end of their useful life? Technologies like smart thermostats and rooftop solar can reduce energy costs or the effects of energy use for consumers, but not all Oregonians have access to these technologies — a significant equity issue that requires deep partnership with currently and historically underrepresented communities.

The technologies examined in the following pages are those that are prevalent in Oregon and of interest to stakeholders that ODOE heard from when putting together this report. Many of these technologies place Oregon and its communities on the forefront of a cleaner, more sustainable future. They help Oregon meet its climate and energy goals by enabling cleaner and more efficient fuels and resources. They offer opportunities to invest in Oregon's economy by creating energy-related jobs to maintain our energy system and develop new projects. They can make us more resilient by enabling us to maintain or restore our energy systems when disruptions occur. And beyond these opportunities and benefits — they are just so cool.

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Resource Review: Hydropower



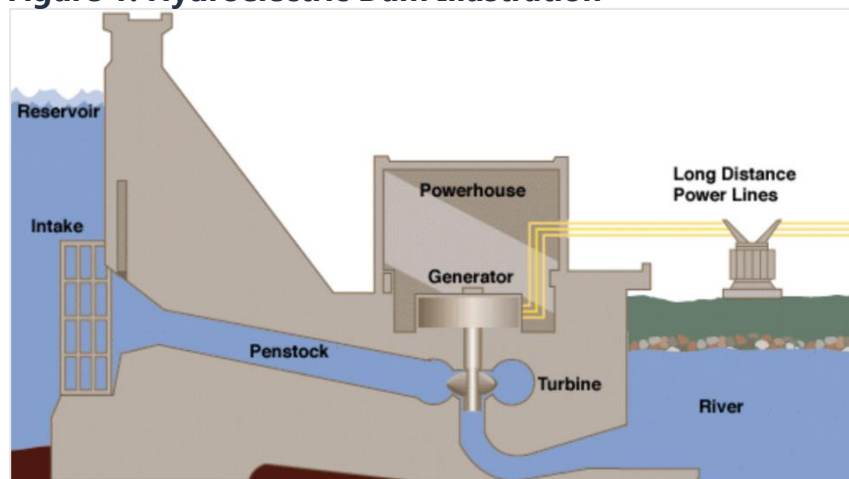
• Total Capacity in Oregon (2019):	8,303 MW
• Facilities in Oregon (0.03 to 2,160 MW)	94*
• Total Generation (2018):	35,442,773 MWh
• Total Consumption (2018):	22,125,769 MWh
• Total Exports (2018):	13,317,004 MWh

*Seven hydropower facilities cross state borders.

Hydropower (or hydroelectric power) is a renewable energy resource that generates electricity from moving water. Because water can be stored behind dams, hydropower facilities can provide firm, or consistent, electricity output and can also ramp up or down quickly to provide grid balancing services. Hydropower projects are an important resource in the Pacific Northwest, providing low-cost, reliable power as well as other benefits like flood control and irrigation. Hydropower is the largest electricity generation source in Oregon and the largest source of electricity consumed in Oregon.¹

Hydropower uses the movement of water powered by gravity to run electricity generator turbines; water flows downward through a pipe or channel called a penstock and pushes against the blades of a turbine to spin a generator. There are two main types of hydropower facilities: “run-of-river” systems that use the force of a river or stream’s natural current to run hydro turbines, accounting for over two-thirds of hydropower in Oregon, and “storage systems,” which use dams on rivers or streams to store water that can be released to run hydro turbines when needed.² Alternative hydropower projects are also in use that capture energy in irrigation or water supply pipes (see the conduit hydropower Technology Review). Hydropower generation is highly dependent on precipitation levels which can vary season to season and year to year.

Figure 1: Hydroelectric Dam Illustration²



Trends and Potential in Oregon

In 2018, ninety-four hydropower facilitiesⁱ in Oregon generated over 35,000,000 MWh of electricity, accounting for 55.3 percent of generation³ and 43.3 percent of consumption in Oregon.⁴ Oregon is the second-largest hydropower producer in the U.S., behind Washington state. The state is also home to the oldest operational hydropower facility, the T.W. Sullivan facility on the Willamette River, which became operational in 1895.⁵

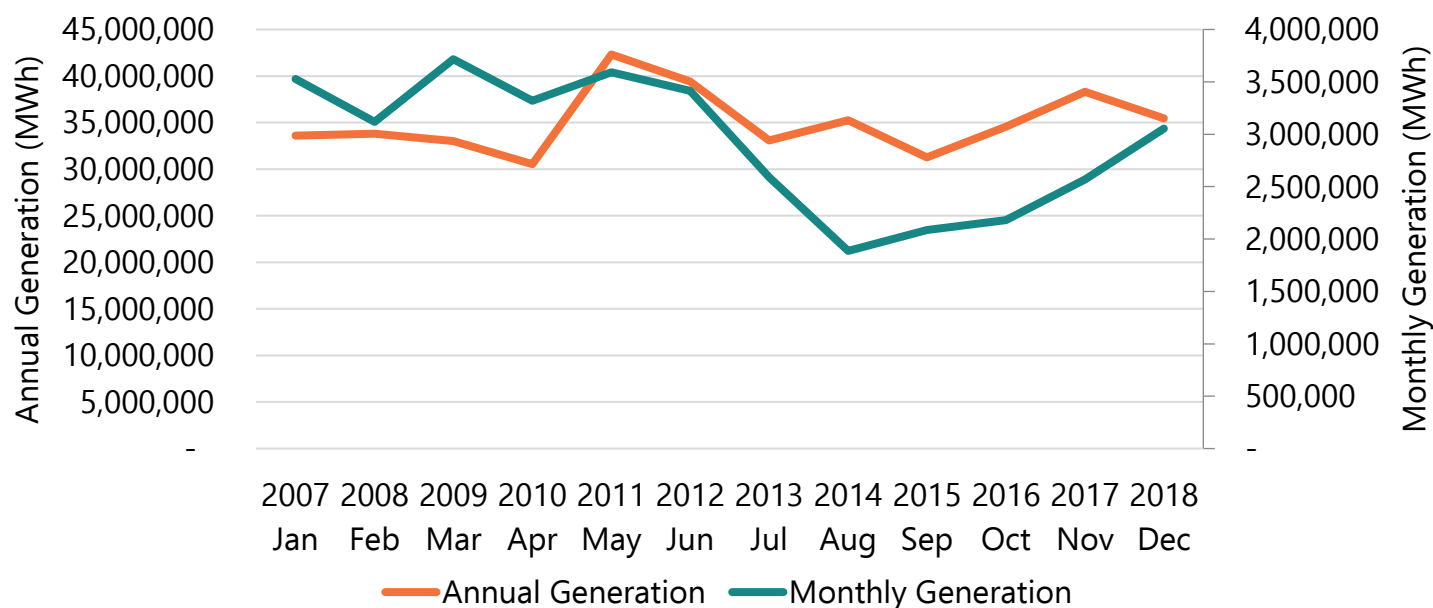
ⁱ The 94 facilities include 7 dams that span Oregon’s border with neighboring states. Six of these dams serve customers in multiple states, but the dams are attributed solely to Oregon by the USDOE Energy Information Administration.

The majority of hydropower capacity (6,514 MW) in Oregon comes from 13 federal dams operated by the US Army Corps of Engineers and marketed by the Bonneville Power Administration (BPA), including nine that are wholly within Oregon and four facilities that span the Oregon and Washington border.⁶ Four of these federal dams on the Columbia River, Bonneville, John Day, McNary, and The Dalles generated almost 27,000,000 MWh in 2018 accounting for 76 percent of Oregon hydropower generation.ⁱⁱ One additional federal facility, the 17 MW Green Springs facility is operated by the US Bureau of Reclamation. Investor-owned utilities operate a further 28 facilities with over 1,499 MW capacity, including two facilities owned by Idaho Power that border Oregon and Idahoⁱⁱⁱ.⁷ Independent power producers or consumer-owned utilities like the Eugene Water and Electric Board (EWEB) own the remaining 52 facilities that have a combined capacity of 273 MW, including one facility owned by Northern Wasco County People’s Utility District at the Dalles Dam that borders Washington and Oregon; 26 of these facilities are under 1MW.⁸

Consumer-owned utilities including electric cooperatives, peoples’ utility districts, and municipal utilities have a legal right of first refusal to purchase federal power at cost (which is called “preference”).⁹ The 39 consumer-owned utilities serving Oregonians largely rely on hydropower from BPA for a majority of their power, with most of them (referred to as full requirements customers) obtaining 100 percent of the power they sell to customers from BPA. These utilities have some of the lowest retail power rates in the country. Oregon’s IOUs also deliver hydropower to their customers and to the wholesale market.

Oregon’s hydropower capacity has not changed substantially in the past fifty years, with a majority of hydropower capacity developed before 1970.¹⁰ As shown in Figure 2, hydropower generation varies annually, as well as seasonally within the year, largely due to changes in annual precipitation levels.

Figure 2: Oregon Annual and Monthly Average Hydropower Generation by Year



ⁱⁱ The EIA attributes all generation from these four federal dams to Oregon even though they border both Washington and Oregon. Not all electricity generated from these dams serves Oregon consumers.

ⁱⁱⁱ A third dam, the Brownlee Dam, a 585.4 MW facility, borders Oregon and Idaho on the Snake River. EIA and the owner Idaho Power attribute all generation from this facility to Idaho so it is not included in the Oregon count of facilities.

Hydropower has been a primary source of electricity generation in Oregon for over a century. While no new large-scale hydropower projects have been developed for several decades, efficiency upgrades to existing hydroelectric plants continue to increase the generation of existing projects. New applications of hydropower technology, such as “micro-hydro” projects like in-pipe conduit turbines, are also being deployed. Hydropower can play an important role in integrating more solar and wind energy in Oregon as it is a stable and flexible power source that can be ramped up and down quickly and at low cost. This can help balance the variability of those other renewable resources. Although the resource is considered renewable, most generation from projects built before 1995 – often called “legacy hydro” – are not eligible for participation in the Oregon Renewable Portfolio Standard; only the incremental increase in generation attributable to efficiency upgrades can be used by utilities to meet renewable portfolio standard obligations.¹¹

Non-Energy Implications

Hydropower is a carbon free renewable resource with a low lifecycle carbon footprint, with embedded greenhouse gas emissions from processes over the facility’s lifecycle such as raw materials extraction, construction, and small ongoing emissions from operations.

Hydropower facilities provide significant benefits beyond zero emission electricity generation including: flood control, navigation, irrigation, and water supply, as well as providing recreational opportunities.¹² Local economic benefits from hydroelectric facilities come in the form of increased tax revenues and jobs.

Hydropower facilities have negative environmental impacts, including: changing stream flow and temperature which can negatively affect fish and wildlife habitat; altering sediment and nutrient regimens; and affecting the ability of anadromous fish to migrate from the river to the ocean and back.¹³ Construction of dams inundates upriver land, potentially damaging cultural resources and agricultural lands. Operations of the dams also change natural water levels throughout the year.¹⁴

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Technology Review: Conduit Hydropower



Conduit hydropower¹ refers to electricity generating systems that are incorporated into an existing diversion from a river or stream where the diversion is for a purpose other than generating electricity, such as watering crops or providing drinking water. The addition of generating capacity does not affect the delivery of water for the primary purpose. Conduit hydropower is distinguished from both impoundment systems, which rely on a dam and often a reservoir, and run-of-the-river systems in which a portion of a river's flow is diverted into a separate channel and run through a turbine before being returned to the river again. Because conduit generation systems are small relative to traditional hydropower generation resources such as the Columbia River dams, they are often grouped with other small impoundment and run-of-the-river systems under the term "micro hydropower."

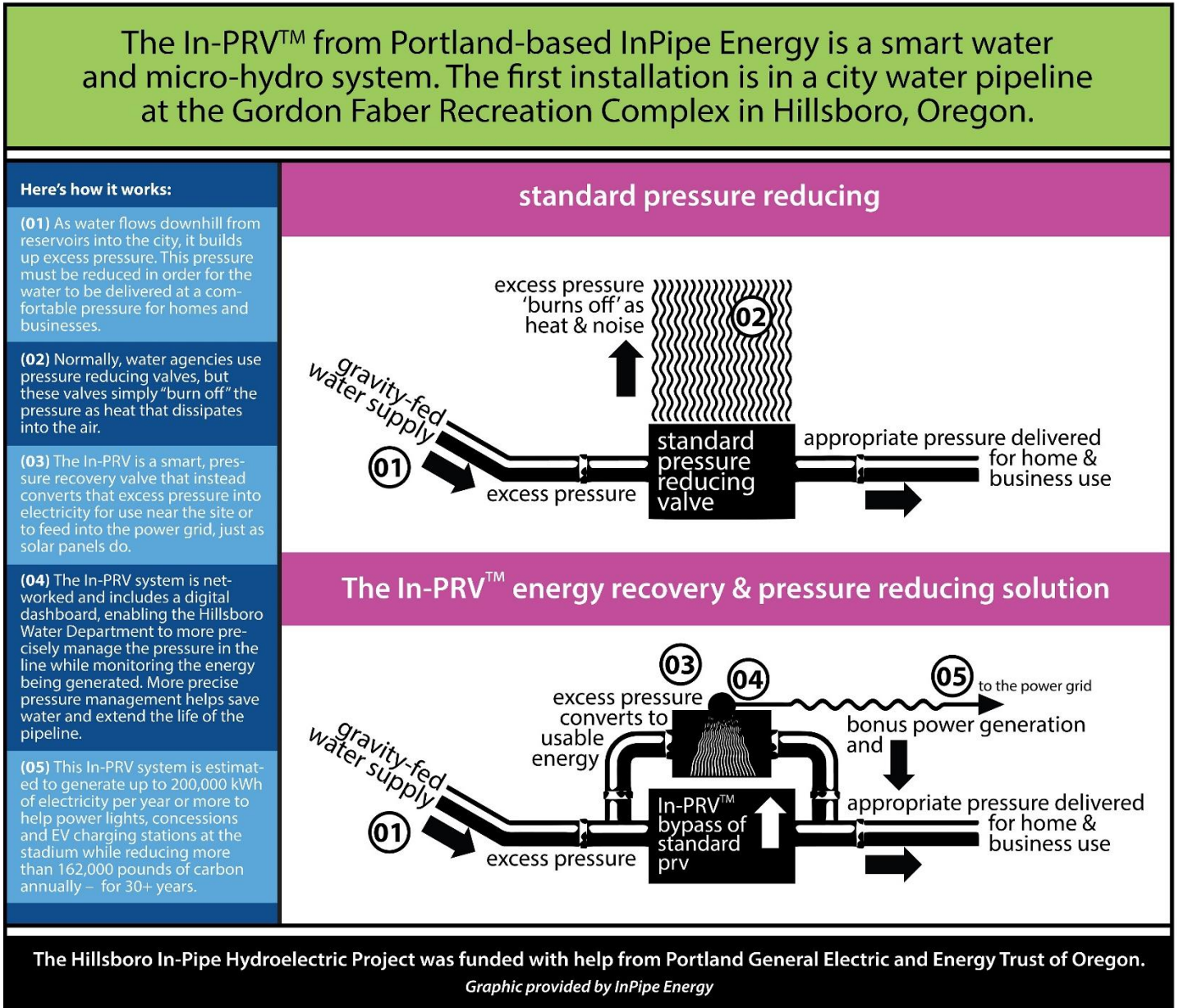
Adding conduit hydropower is relatively straightforward for piped delivery systems that already use pressure-release valves to step down the pressure as water gets closer to its final delivery point. Routing water flow through turbines rather than pressure-release valves in order to generate electricity can be an attractive option for both municipal drinking water systems whose water originates at a higher elevation than where it is delivered, and for farmers who receive piped water from an irrigation district and need to reduce the pressure of the water before it enters their irrigation systems.

Alternatively, conduit hydropower can be part of a more complicated system design or redesign. For example, irrigation modernization projects in Oregon may include the installation of several elements: fish screens, piping to replace existing irrigation canals or ditches, irrigation pivots to replace flood irrigation at the farm level, and turbines for generating electricity both at the irrigation district level and the farm level.

Trends and Potential in Oregon

Conduit hydropower uses existing, well-developed technologies, and has been developed or is under consideration in many locations around the state, including at municipal water facilities and as part of several irrigation modernization projects. Due to Oregon's geography, many irrigation districts and municipal water districts rely on mountain-fed rivers and streams. Therefore, many of these districts have the potential to generate energy by taking advantage of pressurization as water moves from higher elevations within their existing water delivery infrastructure, with additional engineering sometimes needed for districts with significant seasonal and daily variations in flow. As municipalities pursue climate and clean energy goals, interest is growing in exploring opportunities to install energy generation at locations where water districts currently use pressure release valves.

Figure 1: In October 2020, Hillsboro, Oregon celebrated its first electricity-generating water pipeline.²



Generating electricity is a secondary benefit, not the primary driver, for irrigation modernization projects; rather, the priorities center around water: increasing stream flows, improving water quality, and ensuring that farmers receive water allocations throughout the growing season. Irrigation modernization projects are complex: they have multiple goals, include multiple components and typically happen in stages over several years; they involve multiple stakeholders, funders, and funding mechanisms; they are expensive due to the scale of the infrastructure involved; and they offer several economic, environmental and social benefits. Farmers Conservation Alliance, a non-governmental organization based in Hood River, has been working with irrigation districts on modernization projects for several years and has developed a strategy for bringing together a variety of stakeholders and funders to plan and help fund these projects.³

While the generation potential for conduit hydropower is modest compared to utility-scale generation facilities, irrigation modernization projects save energy on the farm by delivering pressurized water to farmers and reducing or even eliminating the need for pumps. Energy savings accompany pressurization from piping even when generation turbines are not installed as part of a project; FCA's analysis finds that energy savings for irrigation modernization projects typically exceed the generation potential.⁴ Reducing electricity use associated with irrigation pumping could be helpful for rural utilities struggling to meet peak demands during summer heatwaves. Conduit hydropower is mostly located in rural areas and small communities of the state and has the potential to provide pressurized water and electricity when the grid is down, providing resilience benefits to local communities. Finally, conduit hydropower generation has few if any negative environmental impacts, as this form of generation causes no greenhouse gas emissions and irrigation modernization reduces energy use for pumping, which reduces emissions. Piping irrigation canals does not involve new water diversions or impoundments that block fish passage or negatively affect habitat.

Opportunities

Many of Oregon's irrigation districts are in some stage of implementing district-wide modernization projects; 25 Oregon irrigation districts are currently participating in Farmers Conservation Alliance's Irrigation Modernization Program. In a recent evaluation of 15 participating districts, FCA found that fully piping and pressurizing their systems would add 32 MW of electricity generation, in addition to generation capacity that is already installed in several districts. FCA's analysis found 101 potential hydroelectric sites across these 15 districts, 68 of which are under 100kW in size.⁵ Oregon is one of a handful of states where a local entity has assessed the undeveloped resource potential for conduit hydropower, along with California, Colorado, and Massachusetts. According to the U.S. Department of Energy, a broad assessment of conduit hydropower opportunities is "difficult to perform because of the highly individual nature of each project."⁶

Energy Trust of Oregon works closely with both municipal water districts and irrigation districts on conduit hydropower projects. As part of a partnership with Farmers Conservation Alliance, Energy Trust provides technical and financial support for irrigation modernization projects in order to leverage other funding sources. Energy Trust has designated irrigation hydropower as one of its

Figure 2: Energy Trust of Oregon and Farmers Conservation Alliance Illustrate Irrigation Modernization Option for In-Conduit Hydropower



focus areas under non-solar renewable energy, spending over \$1.7 million to support 19 irrigation hydropower projects in 2019.⁷

A variety of state, federal, and non-governmental entities also provide funding to assist with irrigation modernization projects that include conduit hydropower. For example, the USDA Natural Resources Conservation Service is currently supporting irrigation modernization projects in Wallowa and Deschutes counties under the Regional Conservation Partnership Program,⁸ and the 2019 Oregon Legislative Assembly appropriated funds for the Wallowa Lake Dam project.⁹

Barriers

Piping irrigation canals, which makes conduit hydropower possible for irrigation districts, is complex and expensive. Generation costs for conduit hydropower are often higher than the cost of other renewable energy resources, or of the cost of incumbent generation technologies. The avoided cost prices in power purchase agreements under the Public Utility Regulatory Policies Act (see Chapter 3 of ODOE's 2018 *Biennial Energy Report* for more information about PURPA) have decreased over time, which in turn decreases the amount of revenue for municipal water and irrigation districts wishing to sell power to an electric utility. Avoided costs do not take into account the energy resilience benefits, or non-energy conservation and economic development benefits to local communities.^{10 11} Many potential conduit hydropower projects are in remote locations, which means that additional transmission investments are often needed to interconnect to the utility grid. Additionally, projects located within consumer-owned utility service territories will need to pay wheeling charges if they wish to sell the electricity to an investor-owned utility. Costs associated with transmission, interconnection, and wheeling charges challenge the economic feasibility of many conduit hydropower projects.



See Energy 101 section for more about transmission and wheeling charges.

Energy generation is not the primary business for the entities who own the existing water infrastructure, which means a water or irrigation district may not recognize opportunities in their system or will need to hire external expertise to assist with hydropower system design and the electrical grid interconnection process. Conduit hydropower projects are much more common in Europe and Asia than in the U.S., and although Oregon is in the forefront of states working on irrigation modernization, in the case of water districts there are relatively few existing installations to use as examples.¹² While municipal water system conduit projects can achieve a positive net present value, in some cases the pay-back periods may be too long to compete successfully with other demands for scarce local government funds.¹³

Non-Energy Implications

For irrigation districts, conduit hydropower is often part of larger infrastructure projects that districts pursue primarily for other reasons, such as keeping more water in the stream to enhance or protect habitat for aquatic species or to improve the district's ability to deliver water to all of its members in low water years. Many irrigation districts in Oregon rely on aging infrastructure like open canals or ditches, which are vulnerable to water loss through evaporation and seepage, or to contamination

from trash or animal waste. Piping irrigation canals can improve water quality both in-stream and on-farm for the farmers receiving piped water. On the other hand, replacing irrigation canals with buried pipes has been controversial in some communities which regard irrigation canals as scenic amenities. Switching from flood irrigation to pivots can cause changes to local hydrology by reducing or shifting the runoff that flows off one farmer's fields to another's fields, or into streams or aquifers.¹⁴

Conduit hydropower generation, whether installed in a drinking water system or as part of irrigation modernization, can produce more electricity than is needed on site. Power sales can provide a revenue stream that enables additional system improvements.¹⁵ The energy savings and habitat improvements associated with irrigation modernization projects also provide economic benefits for the local community. By pressurizing the water that arrives on-farm, these projects reduce on-farm energy expenditures, which enables farm businesses to make investments to expand or improve their operations and helps to make farm businesses more economically sustainable for current and future generations. Proponents of irrigation modernization projects tout the potential benefits to the community from improving outdoor recreational opportunities on local streams and rivers.

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Resource Review: Natural Gas



Natural gas is a versatile fossil fuel resource that can be used for generating electricity, heating residential spaces and water, cooking, transportation, and commercial and industrial processes. Technology advancements have led to increased production of natural gas, particularly from shale gas, and lower natural gas prices, which in turn has led to more natural gas electricity generation.¹ In 2019 in the United States, natural gas made up 32 percent of all energy use and 38 percent of all electricity generation, making it the most-used resource or fuel for electricity production.² In Oregon, natural gas is second to hydropower in electricity generated. In electricity consumed, natural gas is third to hydropower and coal because of natural gas electricity exports and coal-based electricity imports.³

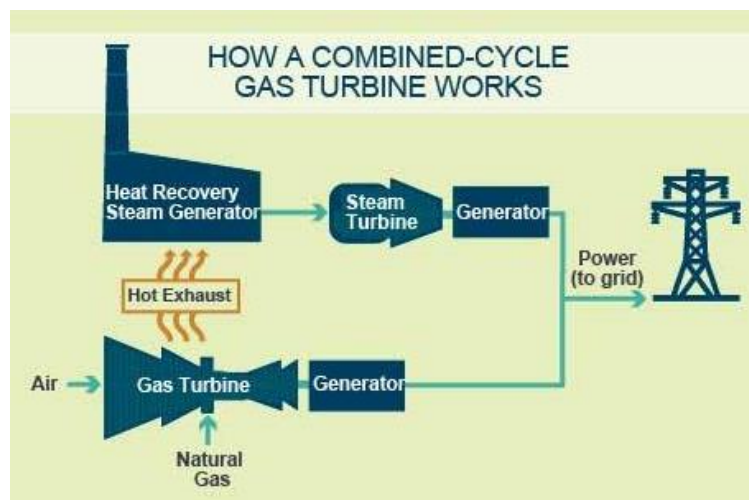
Natural gas power plants combust natural gas to generate electricity. There are two main types of natural gas power plants: simple cycle combustion turbine plants and combined cycle combustion turbine plants.

Simple cycle combustion turbine plants are like jet engines — they combust natural gas under pressure forcing very high-temperature, high-pressure gas into a turbine, which spins to generate electricity; waste heat is expelled.⁴ They operate with thermal efficiencies (the percent of fuel converted to electricity compared to what is released as heat waste) between 15 and 42 percent.⁵

Combined cycle combustion turbine plants use a simple cycle combustion turbine for the first electricity generation cycle, but then capture the waste heat to drive a steam turbine to generate electricity in a second cycle.⁷ Combined cycles operate with thermal efficiencies of 38 to 60 percent.⁸ While simple cycles are less efficient, they are less expensive to build relative to other fossil generation resources and can be started and stopped quickly, making them more flexible.⁹ Simple cycle combustion turbine plants are often referred to as “peaker plants” because they are used to serve peak electricity demand needs.

Combined cycles are more efficient but also more capital intensive and take longer to start and stop, making them more likely to produce ongoing steady electricity that meets the baseload demand needs of the electricity system. Natural gas power plants may also use heat recovered from combustion for heating or industrial processes.

Figure 1: How a Combined-Cycle Gas Turbine Works⁶

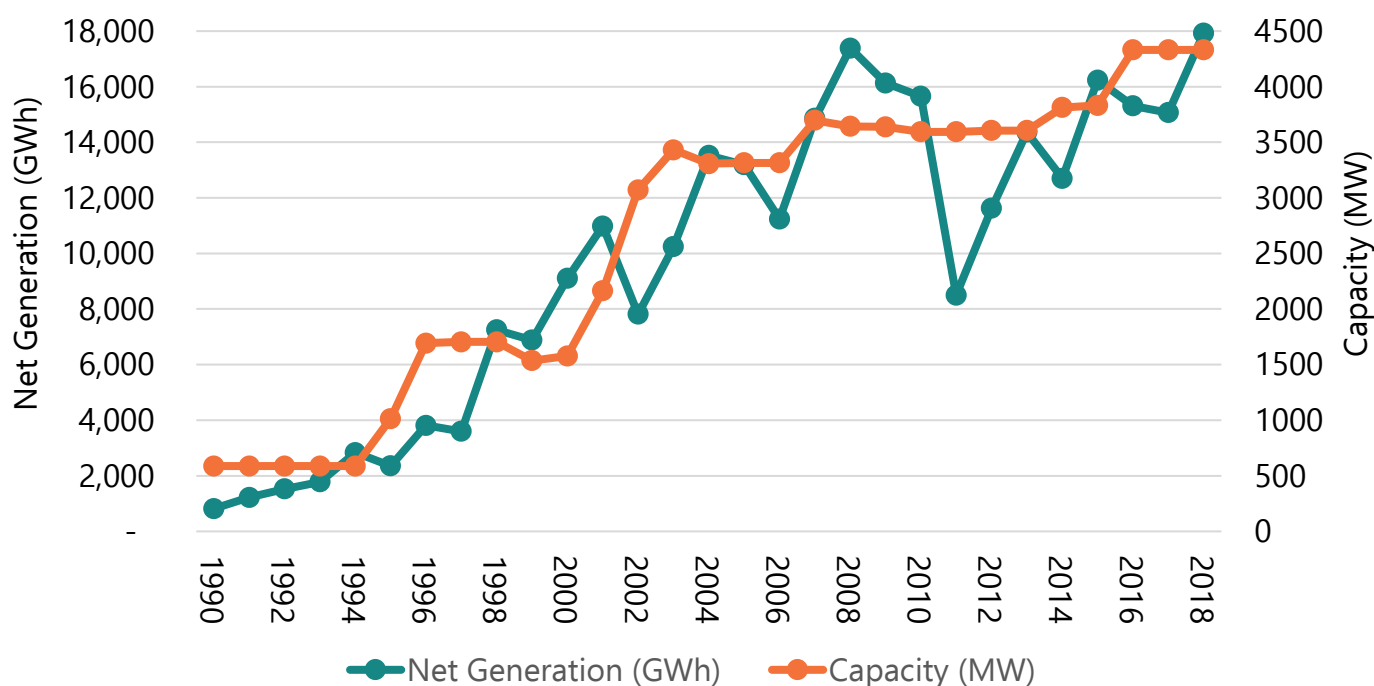


Oregon imports almost all the natural gas it uses. The Mist field in northwestern Oregon is the state's only natural gas field, and it produces a small amount of Oregon's usage (less than 500 million cubic feet of natural gas in 2018 or around two-tenths of 1 percent).¹⁰ The rest of Oregon's natural gas comes through inter-state pipelines primarily from western Canada through Washington and from Nevada and Idaho.¹¹ In 2018, Oregon used 256 billion cubic feet of natural gas; 48 percent went to electricity generation.¹²

Trends and Potential in Oregon

In 2018, natural gas-based electricity made up 28 percent of Oregon's electricity generation and 21 percent of Oregon's energy consumption.¹³ Generating capacity has grown substantially in the past two decades, with capacity almost tripling from 2000 to 2018.¹⁴ Net generation has grown proportional to capacity but fluctuates from year to year. This is typically due to variations in annual hydropower generation; when hydropower generation is high, natural gas generation is lower and when hydropower is low, natural gas generation is higher.¹⁵ This relationship highlights the flexible nature of natural gas electricity generation, which can serve as baseload for constant electricity supply, or as a flexible generator that can be turned on and off to meet fluctuating electricity consumption (load following) to balance the integration of variable renewable resources. Across the fleet of 18 generating facilities in Oregon, five facilities accounting for 954 MW capacity run as "peakers," operating less than 15 percent of the time on average in 2018. Nine facilities accounting for 3,149 MW ran as baseload, operating around 60 percent or more of the time on average in 2018. Three facilities generated electricity for industrial onsite consumption only and one facility did not generate electricity in 2018.¹⁶ Because of the flexible nature of natural gas, it is often the fuel that supplies the last unit of electricity in a given hour; the marginal, price-setting resource.^{i 17}

Figure 2: Oregon Natural Gas Net Generation and Capacity by Year



ⁱ The marginal resource can vary, and in some hours may be renewables like hydropower, wind, or solar.

Natural gas electricity generation is likely to continue to be an important part of the electricity resource mix, especially as less efficient and higher emission coal plants are retired in the region.¹⁸ Natural gas may also have an important role in facilitating higher levels of variable renewable resources on the grid as it can provide flexible, cost effective generation at times when renewable electricity cannot meet load. A recent study of low-carbon electricity scenarios suggested that natural gas generation may be key to meeting GHG emissions reductions goals “reliably and at least cost.”¹⁹

In the Western Electricity Coordinating Council region of the northwest U.S., between 2020 and 2027, there are 15 proposed natural gas projects totaling approximately 6.2 GW of capacity.²⁰ Eleven of these are planned in California and Arizona, with two in Utah, one in New Mexico, and one in Oregon – the 415 MW Perennial Wind Chaser Station, a “peaker” plant that received a State site certificate and has started construction in Umatilla County for completion by 2023. Approximately half of this future capacity is for “peaker” plants (including Perennial Wind), and the rest are combined cycle combustion turbine baseload plants.

Non-Energy Implications

Natural gas is a fossil fuel made up primarily of methane, and its combustion for electricity or other uses results in greenhouse gas emissions. Carbon dioxide is the main pollutant associated with burning natural gas to produce energy; natural gas emits, on average, approximately 50-60 percent of the emissions associated with coal combustion.²¹ Natural gas is methane, which is also a powerful GHG. Natural gas extraction, storage, and transportation can result in methane leaks (fugitive methane), which account for approximately 32 percent of U.S. methane emissions and about 4 percent of U.S. GHG emissions.²² Natural gas companies in Oregon have taken measures to reduce fugitive emissions of methane, such as lining pipes and implementing monitoring and controls that reduce these emissions.²³

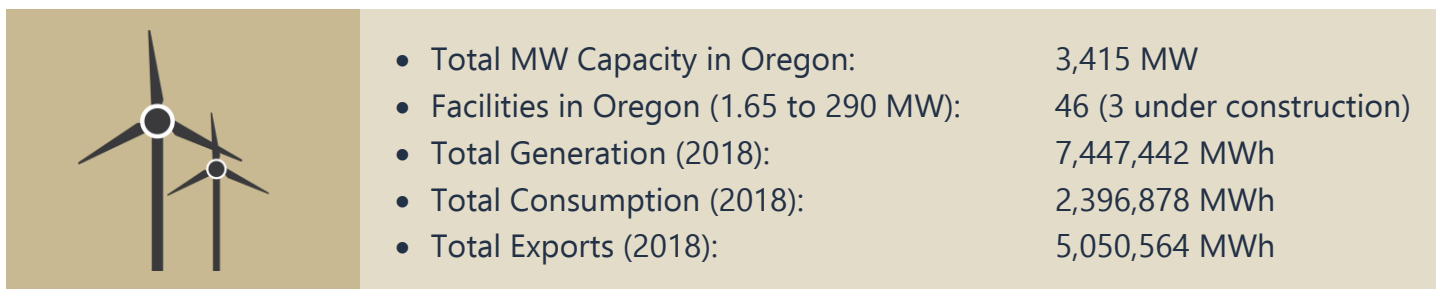
Extraction of natural gas, including hydraulic fracturing (fracking) to access natural gas in shale formations, has additional environmental and public health impacts.²⁴ Hydraulic fracturing in particular consumes substantial amounts of fresh water, and can lead to induced seismic activity, ground and surface water contamination, and can have negative effects on air quality and land use.²⁵ Hydraulic fracturing can also produce materials contaminated with technologically enhanced naturally occurring radioactive materials.²⁶ Transportation of natural gas mostly occurs through pipelines, which can have land use impacts including disturbing sensitive environments, affecting waterways, and causing habitat fragmentation.²⁷

Natural gas transportation, distribution, and electricity generation can have positive economic impacts in Oregon. Development of natural gas electricity generation projects and associated natural gas transportation pipelines can lead to increased employment and economic activity. In addition, as described above, natural gas generation can play an important role in supporting the integration of variable renewable resources and could play a near-term role in decarbonizing our economy.

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Resource Review: Wind Power



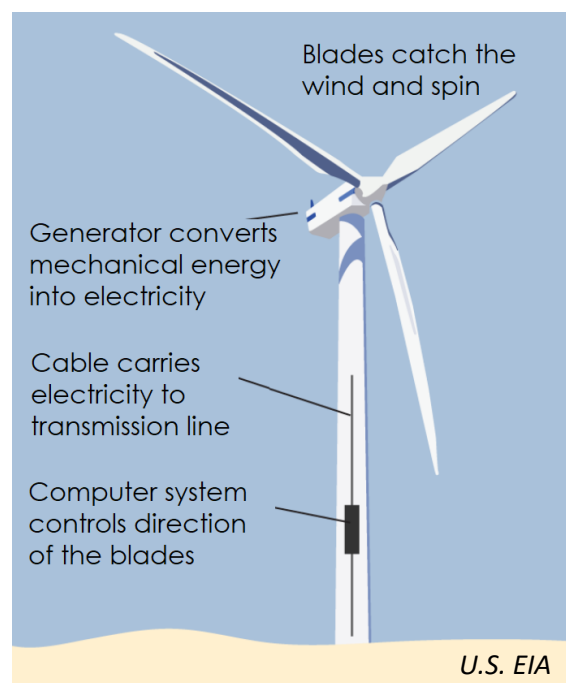
Wind turbine blades capture the wind's motion and transform that mechanical energy into electricity.¹ The average individual utility-scale wind turbine in Oregon has a capacity of 1.75 MW, with the largest at 3.6 MW.² While there are currently none in Oregon, offshore wind turbines use the same principle, but are sited off the coast where wind resources tend to be stronger and more constant.³ Most offshore wind farms are in shallow waters where turbines are directly fixed to the seabed (fixed-bottom turbines).⁴ Floating wind turbine farms that can take advantage of better wind resources in deeper waters are producing electricity in places like Portugal and Scotland.⁵

Trends and Potential in Oregon

Onshore wind is the second-largest zero carbon-emitting electricity resource in Oregon next to hydropower. Wind power makes up 11.6 percent of Oregon's electricity generation and 4.69 percent of Oregon's energy consumption.⁷ Oregon wind capacity has grown substantially since construction of the state's first wind facility in 2001. With 3,415 MW of wind generation, Oregon is ninth nationally in terms of overall wind capacity and third among the 14 U.S. states in the Western Electricity Coordinating Council,⁸ behind California and Colorado.⁹ Most wind generation projects are large, utility-scale projects ranging in size from 1.6 MW to 300 MW.¹⁰

As of October 1, 2020, there are 46 existing wind farms and four state jurisdictional facilities under construction in Oregon totaling an additional 894 MW, with an additional 550 MW of wind projects approved or in review.¹¹ Developers are also upgrading turbines at many older facilities, a process called repowering. Repowering involves full or partial upgrades that can either increase maximum generation capacity, increase generation efficiency allowing turbines to generate more electricity per hour at given wind speeds, or both.¹² Oregon has approved repowering of four facilities to date.¹³ The approved projects replace turbine components to increase turbine generation efficiency, but do not replace generators to increase maximum capacity.¹⁴

Figure 1: Horizontal-axis Wind Turbine⁶



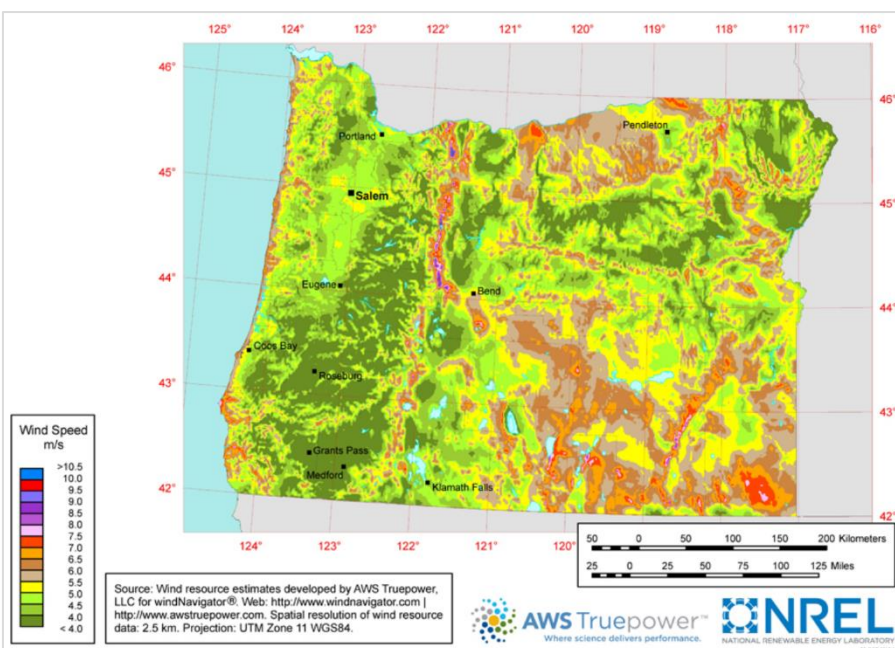
The majority (76 percent) of existing and planned wind utility-scale generation in Oregon lies on the Columbia River Plateau in Wasco, Sherman, Gilliam, Morrow, and Umatilla counties, with a few developments in Eastern Oregon. Development occurs in these regions due to the rich wind resources along the Gorge, as well as access

to existing transmission infrastructure and capacity. Wind generation also varies depending on when the wind is blowing. Seasonally in Oregon, wind generates at its highest capacity during the spring and early summer months, with lowest generation capacity in the fall and winter.¹⁵ During the day, wind generation in Oregon is at its highest in the evening.¹⁶

Onshore Wind Potential

Despite significant wind development in the Columbia River Plateau, there are still substantial untapped wind resources in Oregon. A 2012 National Renewable Energy Laboratory (NREL) study indicates Oregon has technical potential for 27 GW of onshore wind power.¹⁷ Much of this technical

Figure 3: Oregon Annual Average Wind Speed at 80 m



ⁱ The Oregon Renewable Energy Siting Assessment project, funded by the U.S. Department of Defense and led by the Oregon Department of Energy, is due for completion in 2021, will provide additional insight into Oregon wind energy potential.

<https://www.oregon.gov/energy/energy-oregon/Pages/ORESA.aspx>

time in the same geographic region can present challenges for grid integration and project economics; there is limited capacity on transmission lines and projects may not be able to sell the electricity they are producing or may get prices for electricity that are too low for a project to be economically viable.²⁰

Offshore Wind Potential

Offshore wind is a rapidly growing resource, globally. Technological innovation, falling costs, and growing support from the public and private sectors have driven growth of global installed offshore wind capacity from 3 GW in 2010 to 29 GW in 2019.²¹ While the United States has only one operational facility, the 30 MW Block Island Wind Farm in Rhode Island, NREL estimates the offshore wind project pipeline at 25.8 GW thanks to recent market activity and state procurement policies.²² Oregon has some of the richest offshore wind resources in the nation, particularly off the Southern Coast, with an estimated technical potential of 62 GW.²³ While offshore wind holds significant technical potential, there are challenges to overcome. In addition to federal and state regulatory requirements, environmental concerns, transmission constraints, and concerns about effects on important economic and cultural activities, much of Oregon's potential is in waters deeper than 60 meters (197 feet), requiring floating turbine technology that is costly (additional discussion of these issues is provided in the offshore wind Policy Brief).²⁴

Non-Energy Implications

Wind is a zero-carbon emitting resource with a low lifecycle carbon footprint. Minimal greenhouse gas emissions are associated with the product lifecycle, from raw materials extraction to decommissioning.^{25 26} Wind turbines can impact flora and fauna – in particular birds and bats can collide with wind turbine blades – however, newer designs have reduced collisions and fatalities.²⁷ Wind turbines can be more than 600 feet tall and can have a visual impact on the landscape. Wind turbines take up land, but Oregon has requirements to protect wildlife and agriculture, and developers often site projects in dryland agricultural areas that allow for farming to continue up to and around turbines.²⁸ In addition, transmission lines from facilities can similarly disturb sensitive environments, affect waterways, and cause habitat fragmentation.

Wind energy contributes significantly to the state and local economies. Wind projects generate property tax revenue for counties and additional revenue streams for landowners or farmers. Wind projects can take advantage of the Strategic Investment Program, which provides economic benefits to local communities. Wind energy projects also provide employment for over 1,000 Oregonians.²⁹ The average annual wage of a wind technician, one of the more common wind related jobs, is \$52,910.³⁰ Oregon has several notable workforce preparation programs related to wind energy, such as the Columbia Gorge Community College Electro-Mechanical Technology program, that successfully prepare people for many of these jobs.³¹

Energy Jobs: The average annual wage of a wind technician is \$52,910.

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Resource Review: Coal



- Total Capacity in Oregon: 0 MW*
- Facilities in Oregon: 0*
- Total Generation (2018): 1,476,244 MWh
- Total Consumption (2018): 12,681,244 MWh
- Total Imports (2018): 11,204,853 MWh

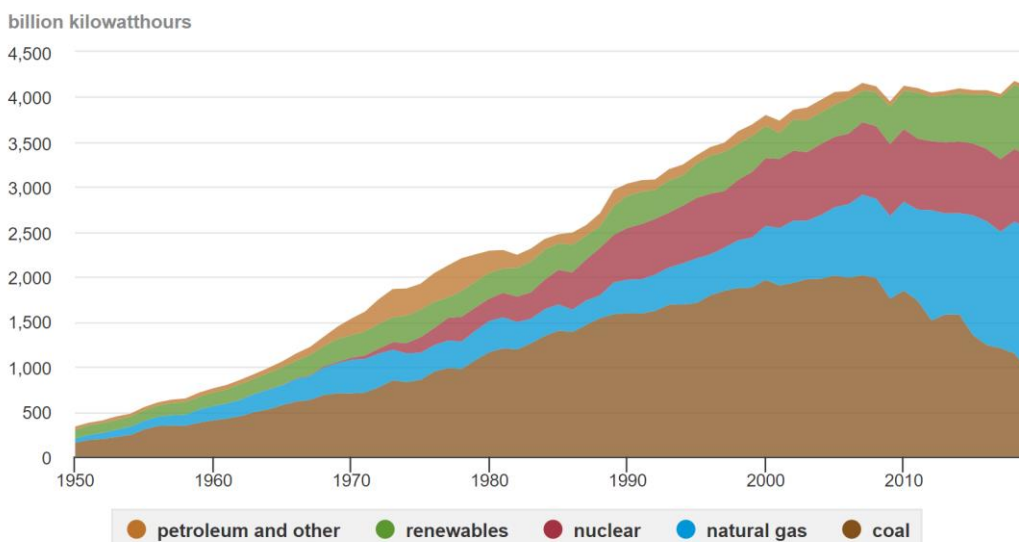
*The 575-megawatt Boardman Coal Plant, which was Oregon's only coal plant, closed in October 2020.

Coal is a fossil resource that has long been a primary fuel for electricity and industrial processes. In 2018, the electricity sector used 93 percent of coal consumed in the United States, and industrial processes used the remaining 7 percent.¹ While coal remains a major source of energy and electricity in the United States, coal use has fallen substantially in both the electricity and industrial sectors. In the electricity sector, coal has fallen from 48 percent of generation in 2008 to 27 percent of generation in 2018,² largely due to more available lower-cost natural gas and renewable electricity generation. In Oregon, coal is third behind hydropower and natural gas in electricity used, and fourth behind hydropower, natural gas, and wind in electricity generated.³

To produce electricity, coal power plants burn coal to create steam that drives electricity-generating turbines. Coal is also used in industrial processes, primarily as heating sources for non-metallic mineral production (cement, glass, and ceramics) and food processing.⁴ Coal can also be converted into gas or liquids for use as fuel, these fuels are known as synthetic fuels or "synfuels."⁵ The Great Plains Synfuels Plant in North Dakota is the only commercial-scale facility making synthetic gas from coal; there are no commercial facilities producing liquid synfuel.⁶ In the Western U.S., coal power plants range in size from 11 to 856 MW.

Coal mining occurs in 23 states, but five states account for over 70 percent of production: Wyoming, West Virginia, Pennsylvania, Illinois, and Kentucky.⁷ Wyoming accounts for 40 percent of national coal production and is where the majority of coal used for electricity consumption in Oregon is mined. In many instances the mined coal must be transported around the country to be used as fuel in coal

Figure 1: U.S. Electricity Generation by Major Energy Source, 1950-2019



Note: Electricity generation from utility-scale facilities.

Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 7.2a, March 2020 and *Electric Power Monthly*, February 2020, preliminary data for 2019



plants. Some plants, such as Montana’s Colstrip, are purposely located near their coal fuel resource to reduce the costs of fuel transportation.

Trends and Potential in Oregon

The Boardman Coal Plant in Oregon, which began operating in 1980, is the only coal-fired power plant to have operated in Oregon. The owner of the plant, Portland General Electric, closed the plant on October 15, 2020.⁸ The Boardman Coal Plant had capacity of 575ⁱ MW,⁹ and in 2018 accounted for 2.3 percent of Oregon’s electricity generation and 12 percent of the total coal-generated electricity used in Oregon.¹⁰ The remaining 88 percent of coal electricity Oregonians use is imported from other states, and imports will continue to serve Oregon’s electricity needs until 2030.ⁱⁱ Coal accounts for approximately 25 percent of Oregon’s electricity consumption.¹¹



PGE’s Boardman Coal Plant closed on October 15, 2020.

In 2016, the Oregon Legislature passed the “Clean Electricity and Coal Transition” bill (SB 1547), which prohibits utilities in Oregon from charging their customers for coal-generated electricity through rates by 2030.¹² This will lead to the removal of the majority of electricity generated using coal from Oregon’s electricity resource mix. However, some coal fuel may persist in the overall state electricity mix because SB 1547 did not exclude spot market purchases.ⁱⁱⁱ In 2018, regional market purchases of coal accounted for approximately 4 percent of total electricity consumed in Oregon.¹³ The electricity market nation-wide is also seeing a decline in coal generation as more coal plants retire due to concerns about climate impacts and difficulty competing against lower-cost natural gas and renewable electricity sources. Along with increasing retirements, currently there are no new coal plants planned for construction in the U.S. – the last planned facility, Plant Washington in Georgia, was cancelled in April 2020.¹⁴

Non-Energy Implications

Coal mining and consumption have well-documented, adverse effects on the environment and public health. While there is no coal mined in Oregon, underground and surface coal mining in other states can have serious effects on the surrounding environment.¹⁵ Combustion of coal results in emissions that can affect human and environmental health. Coal is the United States’ leading emitter of greenhouse gases from electricity generation, primarily carbon dioxide.¹⁶ Coal combustion also emits

ⁱ Reported capacity values for the Boardman plant vary depending on the source. USDOE’s Energy Information Administration lists 642 MW, the Northwest Power and Conservation Council lists 601 MW, Oregon’s Energy Facility Siting Council lists 550 MW, and PGE lists 575 MW.

ⁱⁱ With one exception that would enable rate-basing costs for up to five years after the plant has fully depreciated. This would apply exclusively to Colstrip plant in Montana

ⁱⁱⁱ Spot market purchases are the procurement of electricity very near to the time it is needed. This can be within 15 minutes of delivery of the electricity up to a day ahead.

particulate matter and pollutants like mercury, sulfur dioxide, and nitrogen oxides which can cause acid rain, leach into soil and water, and have serious health impacts.¹⁷ Coal power plants are disproportionately located near low-income communities and communities of color, so these impacts are felt most by vulnerable communities.¹⁸

Reduced use of coal and closure of coal plants will have economic costs and benefits. In some regions, coal retirements may affect electricity prices, but with competitive alternatives like natural gas and renewables, the magnitude and direction of the change is uncertain and coal plant closures may lead to reduced electricity prices and rates.¹⁹ Some local economies may see reduced employment and loss of tax revenues from plant closures. Utilities and local governments, as well as regulators and planners, are working to mitigate these impacts and identify new opportunities. For example, in the ten years prior to the October 2020 closure of the Boardman Generating Station, PGE worked with a wide range of stakeholders to plan for the closure and reduce the local economic impacts. The utility has worked with plant employees to assist with their transition to new positions within PGE or elsewhere. Boardman's closure has been factored into PGE's resource planning since 2010 so the company could take steps to ensure reliable electric service to customers after the plant's shutdown.²⁰

Oregon CUB: Reflecting on the Boardman Coal Plant Closure

The Oregon Citizens' Utility Board (CUB) was created in 1984 by ballot initiative to advocate on behalf of the residential customers of investor-owned utilities in Oregon. Like many other discussions that affect Oregon ratepayers, CUB was at the table in 2008 when Portland General Electric was considering the future of its only coal-generated power plant.



The Boardman Coal Plant was facing regional haze retrofit rules – rules designed to reduce haze to background levels in national parks and wilderness areas. Every five years, states have to show they are making reasonable progress toward reducing haze, and facilities like Boardman are required to consider the best available retrofit technology.

PGE considered several avenues, including a \$600 million retrofit to meet the haze rule requirements, which would have meant running the plant until at least 2040 to recover its capital costs. CUB shared its concerns that not only would a \$600 million retrofit be expensive for ratepayers, it would also mean the state's largest carbon emitter would continue operating for decades longer.

CUB Executive Director Bob Jenks was appointed to an advisory committee to look at the economic effects of the haze rule and how PGE could meet the requirements. An important factor in the haze rule is the life of the plant, and what would be the most cost-effective haze control options over its life. The advisory committee floated an interesting question: if PGE voluntarily closed the plant early, how would that change the dynamics of the haze rule and would it be cost-effective?

PGE modeled closing the plant in 2020, which showed that it was much lower-cost than completing a retrofit and running the plant to 2040. Ultimately, PGE agreed to close its plant early – it was the first time a utility agreed to voluntarily close a coal plant in the United States.

The Oregon Public Utility Commission, Department of Environmental Quality, and Environmental Quality Commission were all highly receptive to making it work and approved the closure to meet haze rule requirements and the least-cost risk to ratepayers. The plant closed in October 2020.

CUB's Bob Jenks reflected on the creativity and collaborative effort among PGE, State of Oregon agencies, and fellow advocacy groups to find the best solution moving forward. "A lot of people were out there pushing to make this change," said Jenks. "It really was a grassroots effort to find the best solution that works for everyone – the utility, its customers, and the environment."

Learn more about Oregon CUB: <https://oregoncub.org/>

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Resource Review: Solar Energy



Solar energy is radiant light and heat from the Sun. Solar technologies harness this energy for electricity generation, space and water heating, and other uses. Solar energy is a renewable resource as the energy comes from the sun, however, because sunlight varies depending on location, time of day, season, and weather conditions, it is also an “intermittent” resource. Solar output in the United States more than doubled between 2015 and 2018 from 39 GWh to 93 GWh, and represented 2.23 percent of U.S. electricity generation in 2018.¹

Solar photovoltaic (PV) cells are the most common technology for generating electricity from solar energy.² Solar PV cells absorb photons from sunlight and convert their energy into electric current. PV cells are connected together into panels for installation on rooftops or ground-mounted systems. The average solar panel has between a 200- and 400-watt capacity.³ Joining panels together creates solar arrays, which can be virtually any size, from less than one kilowatt to hundreds of megawatts or more. The largest solar PV array in the United States is the 579 MW Solar Star facility in Kern County, California.⁴ Solar electricity can also be produced by using mirrors to focus sunlight onto a container of fluid, which is then heated and converted to steam to run a generator turbine.⁵ These are known as Concentrating Solar Power systems, and are generally used for large utility scale projects. There are no Concentrating Solar Power systems in Oregon.ⁱⁱ

Solar PV can provide electricity at different scales for different uses due to its modular nature. Residential solar PV typically consists of independent small arrays installed on home rooftops. Residential solar is usually grid connected and installed “behind-the-meter,” meaning the array is on the customer’s side of the electricity meter; electricity from the system is used on site with excess electricity passing through the meter to the grid.⁶ Solar may also be used to power off-grid homes. The average residential solar array installed in Oregon in 2018 was 6.5 kW.⁷

Commercial solar PV is also typically “behind-the-meter” but consists of larger arrays to serve the electricity needs of businesses. The average commercial



Learn more about net metering in the Energy 101 section.

ⁱ Residential and commercial capacity is measured in megawatts of direct current (DC) and utility capacity is measured in megawatts of alternating current (AC).

ⁱⁱ For more information about solar technologies see the U.S. Department of Energy Solar Technology Office’s website: <https://www.energy.gov/eere/solar/articles/solar-energy-technology-basics>.

solar array installed in Oregon is 28 kW.⁸ Utility-scale solar refers to large solar arrays, usually 1 MW or larger, installed to produce electricity for the electricity grid. Utilities and energy service suppliers own or purchase wholesale electricity from these arrays for sale to retail customers. Some large corporations also own or have contracts to purchase electricity from these arrays to serve their own electricity needs. A relatively new model of solar deployment is community solar. Community solar involves utilities, developers, nonprofits or other entities building solar systems that community members have the option to buy or lease part of, and then receive credits on their electric bills for their portion of the energy generated. Community solar provides access to the benefits and costs of solar to people who face barriers to accessing solar in conventional ways, for example due to lack of roof space or funding for upfront capital costs.⁹

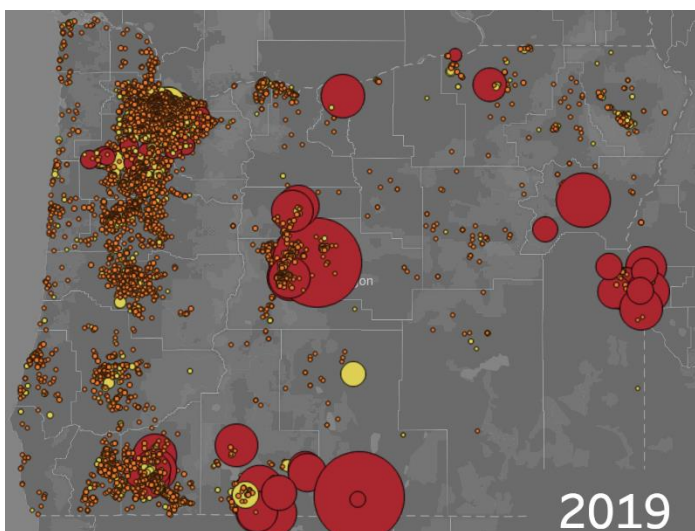
Trends and Potential in Oregon

In 2018, utility-scale, commercial, and residential solar generated approximately 776,000 MWh or 1.2 percent of all electricity generated in Oregon (18th among all states). Oregonians consumed approximately 680,500 MWh accounting for 1.3 percent of all electricity consumed in Oregon.ⁱⁱⁱ Oregon solar grew over five-fold between 2015 and 2019, with installed capacity growing from 91 MW to 592 MW, and generation increasing from 116,000 MWh to 776,000 MWh.¹⁰ During this period, residential and commercial solar grew at a consistent rate. However, most growth in solar capacity came from utility-scale solar; in 2018 utility-scale solar accounted for 79 percent of solar generation, with commercial solar accounting for 13 percent and residential solar accounting for 8 percent.

Solar energy is a viable resource throughout Oregon, generating electricity across the state. Residential and commercial solar is more common in regions with higher population density west of the Cascades. Utility-scale and large commercial solar is more common east of the Cascades and in Southern Oregon where solar resources are more abundant. The largest operating solar photovoltaic facility in Oregon is the 56 MW Gala facility in Crook County near Prineville, although several larger facilities have been approved or are under review. For example, the approved Bakeoven Solar Project in Wasco County near Maupin is expected to be 303 MW, and the proposed Obsidian Solar Center and the proposed Archway Solar Energy, both in Lake County, are proposed at 400 MW each.

A combination of policy and market factors is driving solar adoption. At the state level, Oregon has a long history of policy and program support for solar energy including net metering, utility ratepayer incentives, and tax credit and rebate programs to promote commercial and residential solar

Figure 1: Snapshot of ODOE's Oregon Solar Dashboard



www.tinyurl.com/OregonSolarDashboard

ⁱⁱⁱ Total 2018 Oregon electricity generation was approximately 64,300,000 MWh. Total 2018 Oregon electricity consumption was approximately 51,100,000 MWh

installation. The Oregon Renewable Portfolio Standard established a target of 50 percent renewables for the state's largest electric utilities by 2040. At the federal level, the investment tax credit (ITC) provided a 30 percent non-refundable tax credit for solar installations. The ITC dropped to 26 percent in 2020 and will phase out in 2022 unless renewed by Congress. Decreasing costs of solar have also driven solar adoption. Between 2010 and 2018, national residential solar installed system costs fell from an average of \$7.34 per Watt (DC) to \$2.70 per Watt (DC) and utility-scale solar installed system costs fell from an average of \$5.08 per Watt (DC) to \$1.10 per Watt (DC).¹¹ At times when it is available, energy produced by utility-scale solar is now cost competitive with fossil fuel generation in many cases.¹²

Oregon has significant solar generation potential, with a 2012 National Renewable Energy Laboratory (NREL) study estimating annual technical potential for solar in Oregon at 1,775 terawatt hours; Oregon's total 2018 electricity demand was around 51 terawatt hours.¹³ This potential, coupled with improvements in solar technology and falling costs, means Oregon is likely to see increased development of solar resources. Due to variability in climate and geography, solar potential differs by region in Oregon, with regions east of the Cascades having up to 40 percent greater solar resources than regions west of the Cascades.¹⁴ While there is substantial potential for solar, particularly in eastern and southeastern Oregon, there are constraints on this potential. Solar PV is an intermittent resource that generates only during daylight hours, presenting challenges to large-scale, cost-effective grid integration. Pairing solar with storage technologies can help overcome these challenges. Solar projects require large land areas, with NREL estimating solar needs between 3.2 and 6.1 acres per MW of capacity.¹⁵ Solar development opportunities also need to be weighed against other land-use needs and potential effects on sensitive environments and communities from the large land footprint. Similarly, the need for transmission infrastructure to link these remote areas to electricity load centers, such as the Willamette Valley, will also require oversight and regulatory approvals that can increase the time and cost for future development.

Non-Energy Implications

Solar energy is a renewable, zero-emission resource with a low carbon footprint. Minimal greenhouse gas emissions are associated with processes over the product lifecycle, from raw materials extraction to decommissioning. Solar energy is an important resource for transitioning to a clean electricity system. Utility-scale solar projects, however, do require large areas of land, which may affect wildlife habitat and have implications for other potential uses of the land. In addition, transmission lines from remote facilities can similarly disturb sensitive environments, affect waterways, and cause habitat



Learn more about solar and agriculture in the Policy Briefs section.

fragmentation. To address these issues, Oregon has implemented rules for siting solar projects, and several counties also have additional, specific rules regarding solar projects.

Solar PV can supplement grid electricity for residential and commercial customers, reducing their overall energy bills in some instances and increasing their access to clean electricity. Solar energy can have positive economic effects at the state and local level.

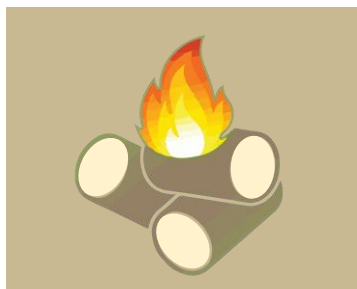
At a local level, solar projects can generate property tax revenue for counties, increase local economic activity, and contribute to local and state revenues. Solar projects can take advantage of the Strategic Investment Program, which provides economic benefits to local communities. Solar also has positive impacts on local employment, providing an estimated 5,700 jobs for Oregonians in 2019;¹⁶ the median wage of a solar installation technician, one of the more common solar related jobs, is \$44,890 per year.¹⁷

**Energy Jobs:
The median annual
wage of a solar
installation
technician is \$44,890.**

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Resource Review: Biomass

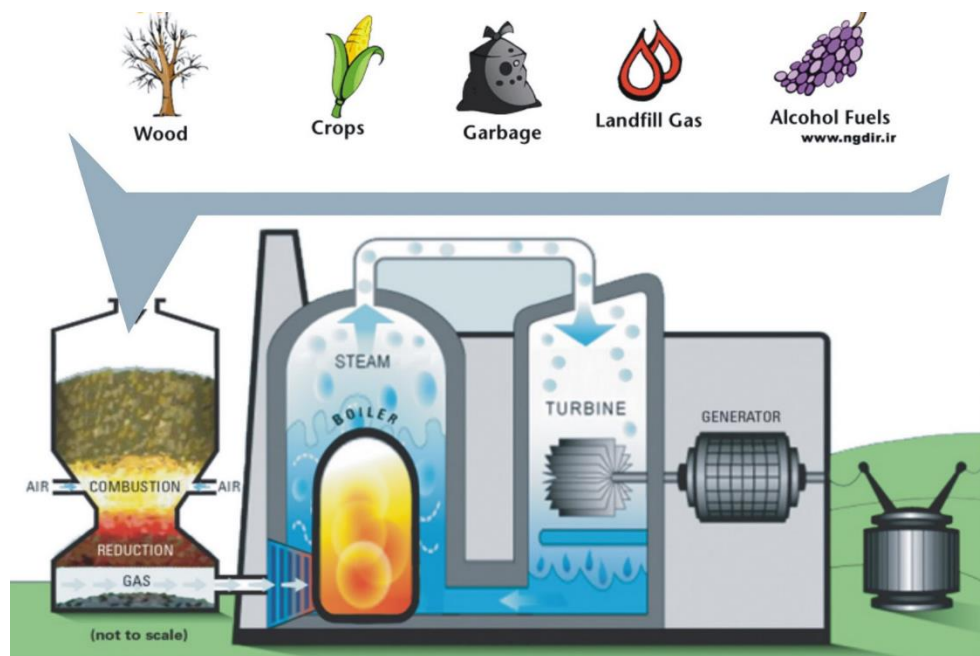


- Total Capacity in Oregon: 288 MW
- Facilities in Oregon (1.5 to 51.5 MW): 16
- Total Generation (2018): 738,296 MWh
- Total Consumption (2018): 700,841 MWh
- Total Exports (2018): 37,454 MWh

Biomass is a renewable energy resource derived from organic matter produced as a byproduct of human or natural processes (e.g., logging or food production) or that is specifically grown for fuel.¹ The focus of this review is biomass for electricity generation, however, there are many energy uses for biomass, including conversion to biofuels like ethanol for powering transportation and burning for district heating and industrial processes.¹ Some forms of biomass like agricultural waste, landfill waste, and wastewater can also create biogas.

Biomass can generate electricity in several ways. The most common systems use direct-fired combustion – burning wood material, agricultural or municipal waste, or other organic materials – to produce steam to spin a turbine. Direct-fired combustion of biomass is one of the oldest forms of energy generation known to humans.³ Other systems include co-fired systems where existing coal plants use biomass as a substitute fuel, and biomass gasifiers that heat biomass into a flammable gas prior to combustion.⁴ Biomass can also be converted to biogas or renewable natural gas that can be used for electricity generation or as a transportation fuel.⁵ In 2017, biomass constituted 9 percent of the total non-hydropower renewable electricity generation in the U.S. (about 1.6 percent of total generation).⁶

Figure 1: Types of Biomass²



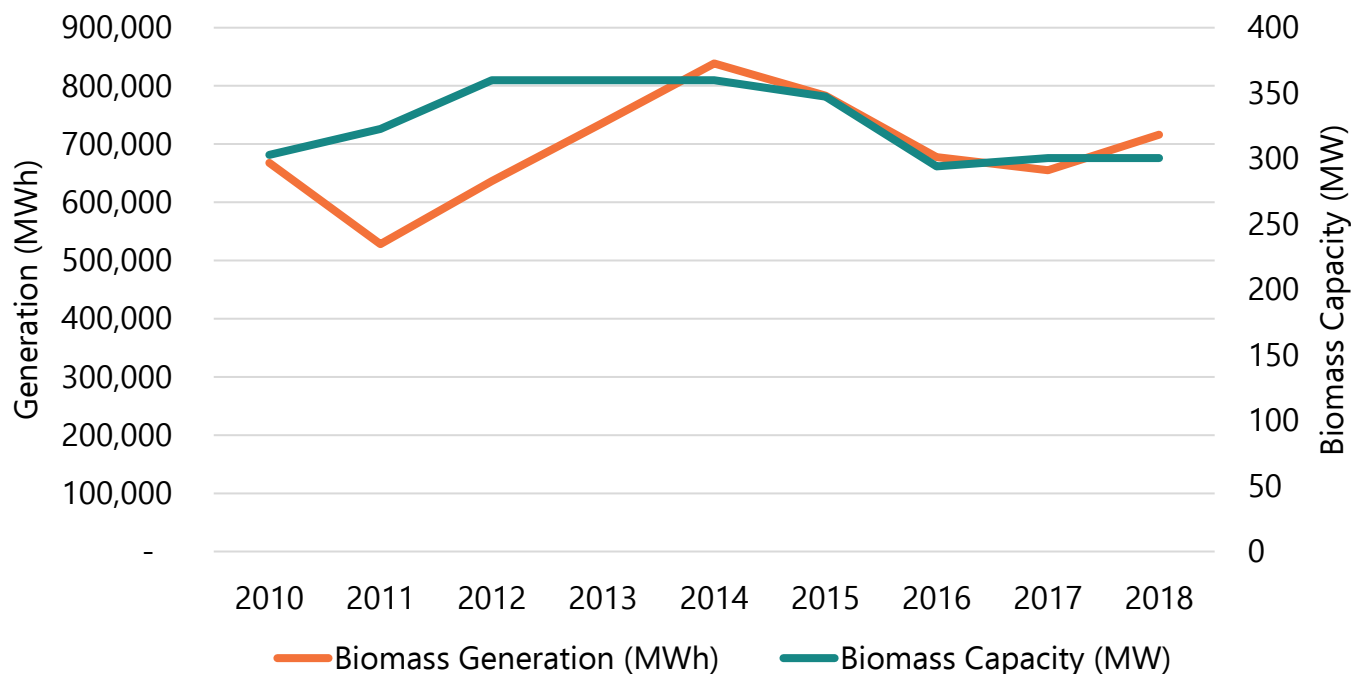
Trends and Potential in Oregon

Oregon ranks 19th among states in terms of biomass generating capacity.⁷ In 2018, facilities in Oregon generated 738,296 MWh of electricity from direct-fired combustion of biomass, equivalent to 1.15

¹ District heating systems use a central plant to channel hot water or steam via a network of underground pipes to many buildings in an area.

percent of Oregon's total electricity generation.⁸ Biomass electricity accounted for 0.54 percent (276,589 MWh) of Oregon's retail electricity consumption. A further 424,532 MWh of electricity generated from biomass is consumed onsite by industrial or commercial facilities. There have been no new biomass facilities constructed since 2011.⁹

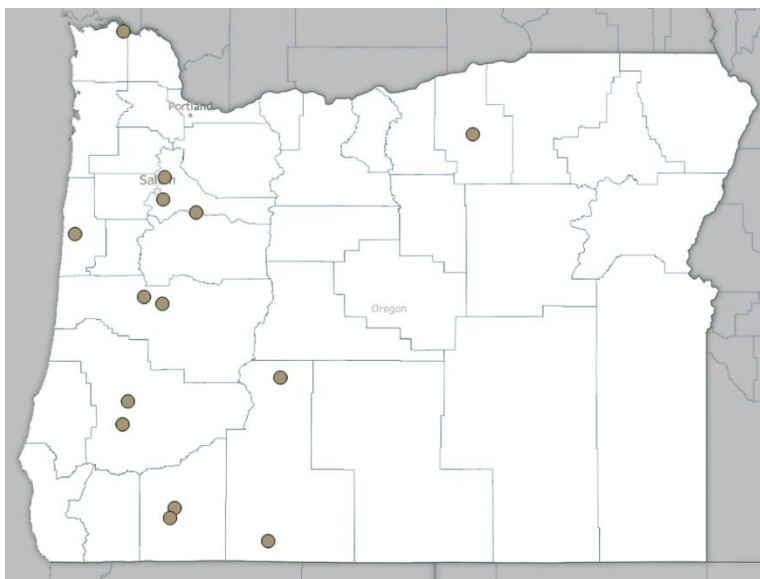
Figure 2: Oregon Biomass Generation and Capacity by Year



Sixteen facilities use direct-fired combustion of biomass to generate electricity in Oregon. Fifteen of these facilities, accounting for 92 percent of biomass electricity production, burn wood and wood byproducts, mostly from pulp and paper mills or lumber mills. Thirteen of the facilities are cogeneration facilities that also produce heat for onsite use. One biomass facility, the Covanta facility in Marion County, burns municipal solid waste.ⁱⁱ Transportation of biomass materials can be expensive, so facilities are typically located close to the source of materials. Facilities in Oregon are in eight counties that are primarily rural.

Availability of feedstock and facilities to combust resources, the economics of obtaining feedstock, and environmental impacts drive the potential for biomass generation. Oregon has substantial forestry and agricultural industries that produce potential feedstock for biomass facilities. In addition, material harvested as part of forest health activities and materials from municipal

Figure 2: Biomass Facility Locations in Oregon



ⁱⁱ The Covanta facility burns both organic municipal solid waste (classified as biomass), and inorganic waste. Generation from inorganic solid waste is not included in data reported.

waste are potential resources. In total these resources generate approximately 8.7 million dry-tons of feedstock, which is capable of generating 8.7 GWh in an average-efficiency generation technology.¹⁰ The potential of these resources is constrained by factors such as transportation costs, land-use restrictions, and concerns about greenhouse gas emissions.¹¹

Non-Energy Implications

Using biomass for electricity generation can reduce waste material and potentially reduce forest residue and decrease wildfire potential. Biomass direct-fire combustion can produce significant quantities of carbon dioxide and other emissions depending on the fuel and generation equipment used.¹² However, the biomass (plants and trees) that are the source of biomass may capture some portion of carbon dioxide emitted potentially reducing the net carbon emissions.¹³ A full understanding of the relative environmental effects and sustainability of biomass requires a comparison of systems to the effects of displaced or alternative sources of energy.¹⁴ Biomass generation can also provide local and state economic benefits in terms of employment and providing additional revenue streams for industrial and agricultural industries.¹⁵

Bear Mountain Forest Products Creates Oregon Biofuel

Bear Mountain Forest Products, a biofuel company created in Oregon in 1988, currently employs 60 Oregonians. Bear Mountain converts wood waste materials from the lumber industry into wood fuel pellets, compressed wood fire logs, fire starters for use in wood burning stoves, fireplaces, and campfire and BBQ pellets. Lumber waste materials that would typically go to the landfill are kiln dried and processed into wood fuel products that are shipped to retailers across the country. Raw wood materials used to make the products come from the residual waste or sawdust of Oregon sawmills. Bear Mountain's manufacturing process leads to virtually no waste of the excess residual wood the company receives from lumber mills. Raw materials not used to make product, which is about 20 percent of the materials they get, fuel the company's dryer system to remove moisture from the wood during the manufacturing process.

Bear Mountain has two plants in Oregon. A Cascade Locks plant produces predominantly wood fuel pellets for home heating and cooking pellets used for barbecuing. The dryer uses wood waste for most of its fuel and propane as a supplemental fuel source. A Brownsville, Oregon plant has two dryer systems, one that uses natural gas and one that uses wood waste to dry the wood in the production process. The Brownsville plant produces mostly wood fuel pellets to heat homes.

In 2019, Bear Mountain turned 130,000 tons of wood waste from mostly Oregon sawmills into 117,000 tons of retail wood products. The company estimates that 60 percent of that product – or about 70,000 tons – is used in Oregon for home heating. At an average of 1.5 tons per home, the company estimates that it serves heating to 46,800 Oregon homes.

Learn more about Bear Mountain Forest Products:

<https://lignetics.com/pages/bear-mountain-forest-products>



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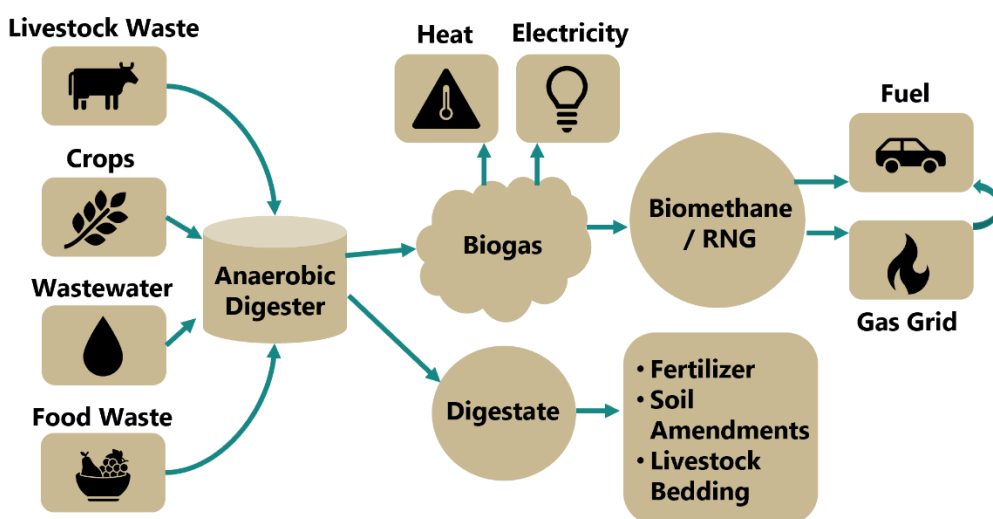
Resource Review: Biogas and Renewable Natural Gas



• Total MW Capacity in Oregon:	52.6 MW
• Facilities in Oregon (0.07 MW – 6.4 MW):	25
• Total Generation (2018):	299,000 MWh
• Total Consumption (2018):	55,589 MWh
• Total Exports (2018):	243,411 MWh

Biogas is a renewable energy source generated from decomposition of organic material. Facilities historically ignited or “flared” biogas to prevent release into the atmosphere, but when it is captured, facilities can use biogas to generate heat or electricity.¹ Refining biogas to a high concentration of methane creates a product interchangeable with conventional natural gas, termed renewable natural gas.

Figure 1: Anaerobic Digestion Pathways



Anaerobic digestion is the most common way to create biogas today.² When organic matter decomposes in an anaerobic environment (an environment without oxygen) it generates a gas that contains 40 to 75 percent methane.³ Common biogas feedstocks include waste streams like livestock manure, food waste, wastewater, organic material in landfills, and crop or

forestry residue.⁴ Biogas can also come from other organic materials, such as dedicated crops or algae, grown specifically for this purpose.⁵ These materials decompose in purpose-built anaerobic digesters or in existing facilities like landfills. Facilities can burn the resulting biogas in combustion engines that generate heat and/or electricity for use onsite or to sell onto the electricity grid. RNG is biogas that has been cleaned and conditioned to have a greater methane content – for example, NW Natural requires a methane content for pipeline gas of 97.3 percent. RNG can replace fossil natural gas to generate electricity or heat, or can be used as compressed natural gas for transportation fuel.⁶ RNG can also be injected into existing natural gas transmission and distribution pipelines.

Biogas can also be created via thermal gasification, which is an overarching term for several methods that use heat to partially combust biomass, separating out combustible gases from the solid material. While plants using gasification technology for generating synthetic gas and liquid fuels from coal and biomass are in commercial use, there are no commercial-scale plants that use thermal gasification to produce



See Energy 101 and Policy Brief sections for more about renewable natural gas.

biogas for electricity generation or renewable natural gas in the U.S., although there are in other countries.⁷

Trends and Potential in Oregon

Oregon ranks 19th among states in biogas generating capacity.⁸ In 2018, biogas-based electricity made up 0.46 percent of Oregon's electricity generation and 0.08 percent of Oregon's energy consumption, excluding electricity generated for use on site.⁹ The first biogas generation facility in Oregon came online in 1992 and biogas has seen steadily increasing adoption with the most recent facility, The Dalles Wastewater Treatment Facility, becoming operational in 2015.¹⁰

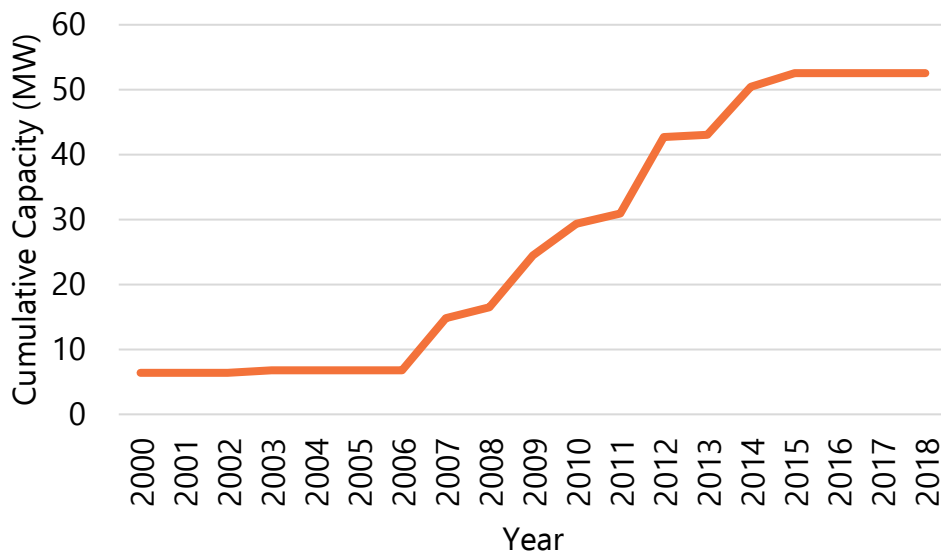
Forty-nine facilities produce or have produced biogas in Oregon, including 26 wastewater treatment plants (WWTPs), 13 landfills, nine agricultural waste facilities, and one food waste facility.¹¹ Among these, 25 facilities generate electricity for commercial sale – 10 WWTPs, eight landfills, six agricultural waste facilities, and one food waste facility. Fourteen facilities are cogeneration facilities that use produced heat for facility operations. Biogas production and generation facilities are typically located close to or at the site of the source materials to reduce the cost of transportation. Biogas facilities in Oregon are in 12 counties that are both rural and urban.¹²

There is one operational RNG facility in Oregon today, the Threemile Canyon facility in Boardman, which creates RNG from dairy cow manure.¹³ Four other facilities are scheduled to come online in 2020 or 2021: the Columbia Boulevard WWTP in Portland, the largest WWTP in the state;¹⁴ the Metropolitan Wastewater Management Commission WWTP in Eugene;¹⁵ the Shell Energies RNG project in Junction City;¹⁶ and the Port of Tillamook Bay digester project in Lincoln City.¹⁷

Opportunities

A 2018 Oregon Department of Energy study inventoried biogas and RNG potential across six organic material pathways – waste food, agricultural manure, landfills, WWTPs, forest residue, and agricultural residue.¹⁸ The study found the gross potential using anaerobic digestion technology alone is around 10 billion cubic feet of methane per year (approximately 4.6 percent of Oregon's annual natural gas use). Thermal gasification technology would

Figure 2: Biogas Cumulative Capacity (MW) in Oregon (2000-2018)



A 2018 ODOE study found that up to 20 percent of Oregon's natural gas needs could be met with renewable natural gas.

add an additional 40 billion cubic feet of methane potential per year, or 17.5 percent of Oregon's total yearly use of natural gas. Combined, these resources could generate energy equivalent to 49 trillion Btu, or up to 20 percent of Oregon's total natural gas needs. Despite this potential, there remain economic and technical barriers to biogas and RNG production and use. The costs relative to fossil natural gas are high, particularly with respect to the capital and operating costs of capturing and cleaning biogas.

To create a pathway to increasing production and use of RNG from biofuels, Oregon passed Senate Bill 98 in 2019, which allows natural gas utilities to invest in new RNG projects and procure RNG from existing projects. The bill also established voluntary targets of up to 30 percent RNG by 2050 for large natural gas utilities with over 200,000 customers (presently, only NW Natural exceeds the customer threshold).¹⁹

Non-Energy Implications

Biogas and RNG production and combustion do emit greenhouse gases. However, when replacing fossil natural gas or other fossil fuels, biogas and RNG can reduce overall greenhouse gas emissions and pollutants.²⁰ CO₂ emissions from biogas and RNG are biogenic, meaning they are part of the natural carbon cycle; a portion of these emissions would have occurred naturally, and depending on the fuel source and process may be considered carbon neutral.²¹ Biogas generation reduces methane emissions that would otherwise have been flared or emitted into the atmosphere. Collecting, cleaning, and using raw waste materials, such as manures that generate biogas for a productive energy use also reduces waste and can lead to reduced landfill needs and improved air and water quality. Biogas and RNG also improve domestic fuel diversity, have a positive effect on the economy, and strengthen resilience through construction and maintenance of infrastructure and increased supply of local fuel.²²

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Resource Review: Geothermal Energy

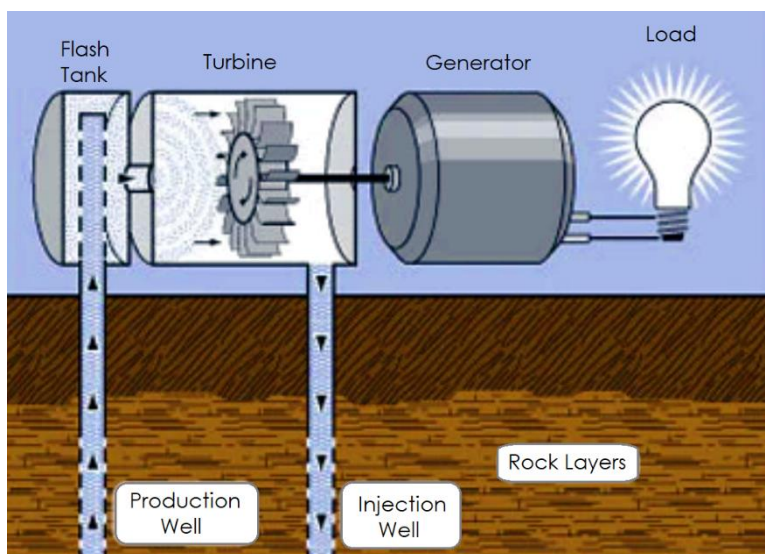


Geothermal energy is a renewable resource from heat generated continuously within the earth. Geothermal energy can fuel electricity generation, as well as provide heating and cooling for buildings or industrial processes at small or large scales. The United States leads the world in installed geothermal electricity capacity with over 3 GW of capacity.¹ In 2019, geothermal power fueled approximately 0.4 percent of total U.S. utility-scale electricity generation.²

Geothermal energy is naturally occurring heat created from processes within the earth and stored in magma, rock, and hydrothermal (hot water or steam) reservoirs. To be a productive resource, the geothermal energy must be hot enough, be accessible, and have fluid present (usually water) either naturally or introduced by humans to conduct the heat.³ Geothermal resources at different temperatures are useful for different applications. Direct use applications like heating buildings require water or steam temperatures between 120 and 390 degrees Fahrenheit.⁴ Lower-temperature water can also act as an exchange medium to operate heat pumps for building heating and cooling. Geothermal electricity generation requires high temperatures – between 300 and 700 degrees.⁵ Because these temperatures usually occur very far underground, there are limited accessible geothermal resources in the U.S. to produce electricity. However, in Oregon there are unique geological formations that bring geothermal heat sources like magma closer to the Earth's surface.⁶

Geothermal electricity power plants typically use hydrothermal resources to generate electricity. Power plant operators drill production wells to access hydrothermal reservoirs, and bring hot water or steam to the surface.⁷ There are three types of geothermal power plants in the U.S. Flash steam plants pipe hot water from deep wells to the surface and convert the water to steam to drive a generator turbine.⁸ Binary cycle power plants, which can use water at lower temperatures than flash steam plants, also pipe hot water from deep wells to the surface. This water is used to transfer the heat from the water to a different liquid with a lower boiling point, which in turn creates steam to drive generator turbines.⁹ A third type, dry steam, uses steam directly piped from below the surface to drive generator turbines.¹⁰ Cooled water from these power plants can be injected back into the earth to be reused.

Figure 1: Flash Steam Power Plant⁸



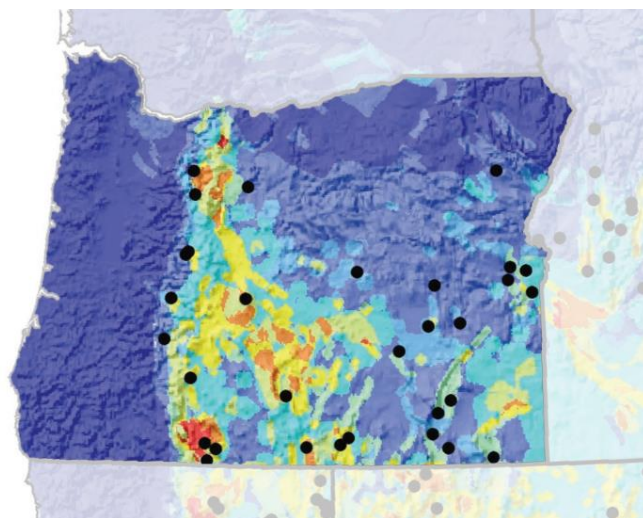
Because geothermal heat is a continuous resource, geothermal can provide consistent electricity generation, making it capable of operating as a dispatchable, firm resource.¹¹ Geothermal power plants are also relatively inexpensive on a per unit basis once constructed. However, geothermal energy is not in widespread use, primarily due to limitations in geographic availability of resources, challenges identifying productive resources, and high upfront costs of exploration and development.¹²

Trends and Potential in Oregon

Oregon has three geothermal power plants, but currently only two are actively generating energy. The first, completed in 2010, is the 1.75 MW Oregon Institute of Technology plant in Klamath Falls that generates electricity used on campus. The second, completed in 2012, is the Neal Hot Springs Geothermal Project near Vale, Oregon. This plant has a capacity of 22 MW and provides electricity to Idaho Power. A third plant, the 3.1 MW geothermal facility in Paisley, Oregon, became operational in 2015, but has not generated electricity since 2017 and it is unknown if it will restart operations. Geothermal electricity accounts for 0.3 percent of electricity generated in Oregon and 0.01 percent of electricity consumed in Oregon (not including onsite consumption). There are no proposed new geothermal plants in Oregon; however, exploration projects are underway at Newberry Crater in Deschutes County, and at Crump Geysers and Glass Butte in Lake County.

Accessible hydrothermal geothermal resources are concentrated in the western United States. In Oregon, a U.S. Geological Survey estimated 540 MW of potential capacity from identified conventional geothermal resources, and approximately 1,900 MW of potential from unidentified conventional resources.¹³ The report also identified over 43,000 MW of potential capacity in Oregon from enhanced geothermal systems (EGS). EGS is an emerging technology that extracts geothermal energy without requiring naturally occurring water, which expands access to geothermal resources. An EGS system injects high pressure water into high temperature, dry rock, which enhances natural fractures in the rock. The injected water collects heat from the rock and then returns to the surface through a production well.¹⁴ The Newberry Crater in Deschutes County has been a prominent site for research and demonstration of this technology.¹⁵

Figure 2: Potential Geothermal Resources¹³



Adapted from a USGS map showing geothermal resources in the U.S. Warmer colors equate higher favorability of geothermal potential. Black dots represent identified geothermal systems.

While there is substantial potential energy from geothermal resources, accessing and developing resources can be costly and challenging. Developing geothermal resources can be a lengthy and uncertain process requiring resource exploration; deep, high temperature drilling; and substantial construction infrastructure. These elements contribute to geothermal power projects generally having

high capital and financing costs, estimated at two to three times higher than natural gas, onshore wind, or utility-scale solar.^{16 17}

Non-Energy Implications

Once constructed, geothermal electricity generation has near-zero carbon emissions and very low emissions of other pollutants.¹⁸ In general, geothermal facilities also have a smaller land-use footprint than other renewable electricity generation resources like wind and solar.¹⁹ Water is required for geothermal energy production and water resources can be depleted,²⁰ but extracted water can be injected back into the earth, which helps renew the geothermal resource but adds to the operating costs. Geothermal has lower average water use than other thermal power sources.²¹ Drilling and groundwater extraction and injection can have environmental impacts including potential contamination of water sources, although there have been no reported cases of water contamination from geothermal sites in the United States.²² Fluids produced from geothermal wells can also contain a variety of substances,²³ including potentially harmful chemicals and technologically enhanced naturally occurring radioactive materials.²⁴

Geothermal projects can have positive economic benefits including increased employment and local tax revenues. For example, the Neal Hot Springs Geothermal Project employed approximately 150 people during construction and maintains approximately 12 full time positions.²⁵ Statewide in Oregon, geothermal is estimated to employ 27 people.²⁶

**Energy Jobs:
Geothermal energy
currently employs
about 27 people in
Oregon.**

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Technology Review: Utility-Scale Storage



• Peak Power Capacity in Oregon (2019):	5 MW
• Facilities in Oregon (2019):	1 (5 MW)
• Total Capacity of Storage Under Construction:	430 MW
• Maximum Stored Energy in Oregon (2019):	1.25 MWh
• Total Energy Discharged (2018):	545 MWh

Utility-scale storage (1 MW or greater) can provide additional capacity to the electric grid and affords electricity providers with many different opportunities to more flexibly manage their generation, transmission, and distribution systems.¹ Storage can also play a valuable role in decarbonizing the grid by optimizing the generation from resources that have varying levels of carbon emissions and providing fast-acting supplies of electricity to offset the use of natural gas peaker plants for the integration of renewable energy resources.²

Many different technologies can store and discharge electricity:

- mechanical storage makes use of gravity or kinetic force
- thermal storage makes use of heating or cooling materials
- chemical storage makes use of chemical and electrochemical reactions
- electro-magnetic storage makes use of electrical or magnetic fields³

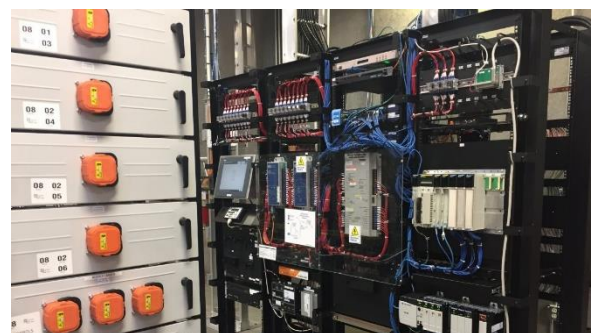
Some of these technologies are relatively new such as hydrogen storage, while others are mature like pumped-hydro storage and lead-acid batteries.⁴ Lithium-ion batteries have become a prominent form of utility-scale storage, accounting for 88 percent of new storage additions nationally since 2010,⁵ and 90 percent of all utility scale battery storage additions.⁶ This is partly due to advances and cost reductions related to the widespread usage of lithium-ion batteries in consumer goods and electric vehicles.⁷ Each technology offers different benefits based on its specific characteristics and intended uses.⁸ For example, a technology's maximum volume of discharge (MWh) at its maximum power rating (MW) can help determine if it is best suited to supply electricity to serve loads, or balance short term fluctuations in loads and generation on the electricity grid.⁹



See the Policy Brief section for more on energy storage and power-to-gas technologies.

Trends and Potential in Oregon

Oregon is currently ranked 24th among states in terms of energy storage capacity (MW),¹⁰ with one operational utility-scale storage facility, PGE's Salem Smart Power Center – a standalone lithium-ion battery and inverter system with 5 MW capacity and 1.25 MWh of stored energy.¹¹ Numerous projects, however, are in various stages of development. To comply with HB 2193 (2015), which required investor-owned utilities to deploy at least 5 MWh of energy storage by 2020, PGE and PacifiCorp are



PGE's Salem Smart Power Center

developing projects that will add at least 82 MWh (25 MW capacity) of utility-scale storage and 17 MWh (6 MW capacity) of residential and other customer-sited storage.^{i 12} In addition to adding volumes of storage far beyond the requirements of HB 2193, utilities and developers are actively planning to add even larger volumes of utility-scale storage to the grid. Most of the new storage projects currently under development will be integrated with existing or planned generation facilities, although in the future we may also see stand-alone storage sited on the distribution system. Table 1 presents a list of proposed utility-scale storage projects in Oregon requiring state approval through the Energy Facilities Siting Council or federal approval through FERC; there are many other smaller storage projects that would require only local or county approval. Table 1 provides insight into the level of activity in energy storage development; however, it is not certain that all projects will be built.

Table 1: Approved or Proposed Pipeline for Utility-Scale Energy Storage in Oregon

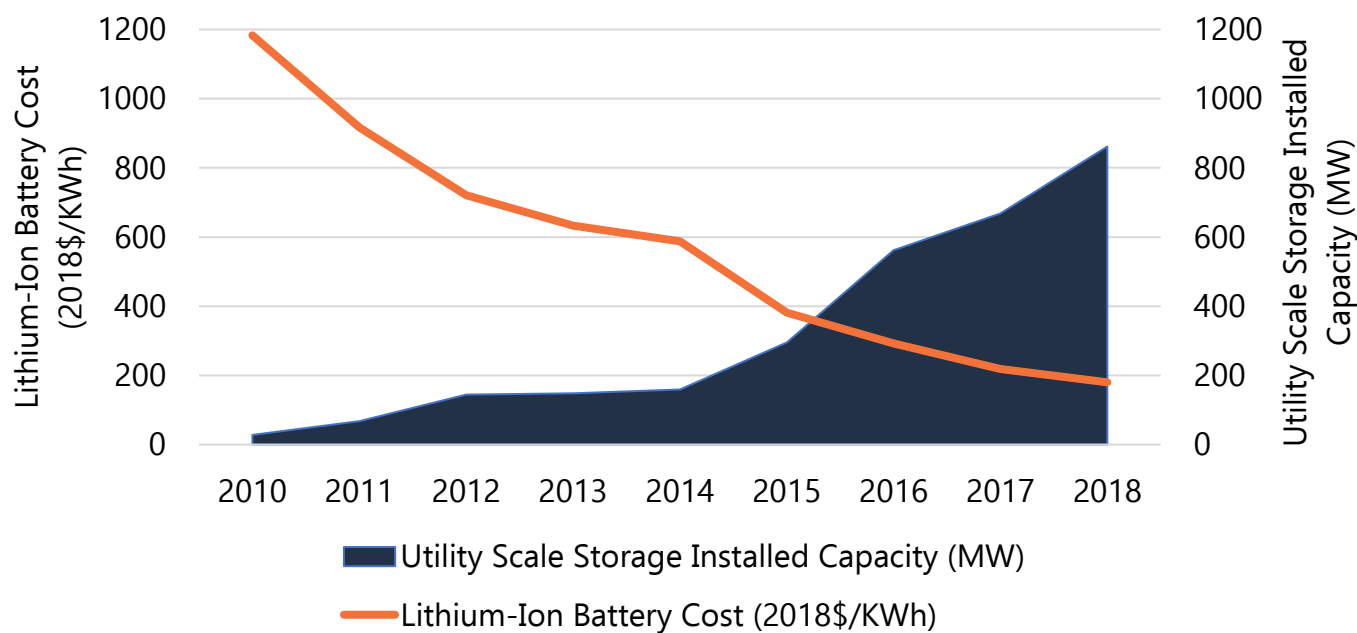
Project Name	Technology	Paired with Generation	Size (MW/MWh*)	Status	Projected Operation Date
Bakeoven	Battery	Solar	100MW	State Approved	2023
Wheatridge II	Battery	Wind & Solar	30MW	State Approved	2025
Montague	Battery	Wind & Solar	100MW	State Approved	2023
Port Westward	Battery	Natural Gas	6MW	State Approved	2021
Obsidian Solar	Battery	Solar	50MW / 250MWh	State Application	TBA
Madras Solar	Battery	Solar	240MWh	State Application	TBA
Archway Solar	Battery	Solar	TBD	State Application	TBA
Bonanza Energy	Battery	Solar	1,100MW	State Application	TBA
Swan Lake Pumped Hydro	Pumped-hydro	No	400MW	FERC Approved	2025
Owyhee Pumped Hydro	Pumped-Hydro	No	600MW	FERC Application	TBA

Sources: Oregon Energy Facility Siting Council¹³; Swan Lake Project website¹⁴

* Size is reported in MW and/or MWh depending on which was provided in the application to EFSC.

Utility-scale storage is undergoing rapid planning and development in Oregon. Until recently, most energy storage technologies were unproven or too expensive to deploy. Over the past decade, however, the costs of storage, particularly battery storage, have fallen substantially, making scalable grid-scale storage economically feasible.^{15, 16}

ⁱ Not all HB 2193 projects will be completed in 2020.

Figure 1: Storage Cumulative Installations and Costs per kWh (Sources: EIA, Bloomberg NEF)

Federal and state policy support is driving additional deployment of storage in Oregon. At the federal level, the solar and storage Investment Tax Credit (ITC) incentivizes storage that is charged with renewable energy.¹⁷ At the state level, the Strategic Investment Program provides property tax benefits to large scale energy developments, including storage. Smaller scale residential and commercial battery storage could also be aggregated by utilities or third-party aggregators as a grid-scale storage resource.

These incentives, combined with the dramatic reduction in costs for battery storage, have now led utilities to identify utility-scale storage as a cost-effective choice to meet their capacity needs. In 2016, neither PGE nor PacifiCorp identified utility-scale storage in their Integrated Resource Plan's preferred portfolios. Just three years later in 2019, both utilities included substantial energy storage assets in their plans. PacifiCorp's preferred plan includes nearly 600 MW of battery storage capacity by 2023, all co-located with new solar resources.¹⁸ PGE's preferred plan includes nearly 240 MW of battery storage capacity by 2024.¹⁹

Non-Energy Implications

Storing electricity can provide environmental and public health benefits. Electricity storage can help reduce reliance on generation resources with high emissions of carbon and other harmful pollutants by charging with lower emission resources that then replaces electricity from higher emission resources; the most common case of this will be to replace more emission-intensive generation during peak load hours.²⁰ Battery storage is also a dense electricity resource that can lower land use impacts compared to some other resources.²¹ Battery storage has environmental costs. Batteries use raw materials such as lithium and lead, which is often mined in regions with poor environmental and labor oversight.²² These materials also present environmental hazards if they are not disposed of or recycled properly.²³ Other storage technologies like pumped-hydro storage can have substantial land use impacts.

Electricity storage can also have economic benefits. Storage can be charged when electricity prices are low and discharged when electricity prices are higher. Using batteries can help existing generation facilities operate more optimally, delaying or avoiding the need to build more generation resources.²⁴ Storage can also help optimize the use of existing transmission lines by moving electricity from generators to loads during off-peak hours when transmission rates and costs of generation can be less expensive than during peak hours.²⁵ This can help smooth electricity prices by better matching supply and demand across all hours of the day, and can reduce the need for large scale investment in costly generation and transmission infrastructure, which could translate into lower overall costs.²⁶ The energy storage industry is a growing industry that could bring local economic benefits in the form of increased economic activity and employment. In 2020, there were an estimated 1,284 jobs in energy storage in Oregon.²⁷

**Energy Jobs: In 2020,
there are more than
1,200 energy storage
jobs in Oregon.**

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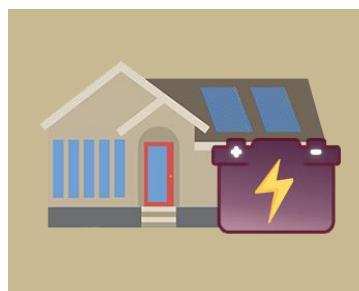
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Technology Review: Residential Energy Storage



- Peak Power Capacity in Oregon: 670 kWⁱ
- Facilities in Oregon: 291
- Maximum Stored Energy in Oregon: 1,440 kWhⁱ
- Range of Sizes: 2.4 to 46 kWh

Residential battery storage systemsⁱⁱ are large rechargeable batteries designed to store and deliver electricity to a home. The batteries may be charged by the grid or with an onsite generator, such as a rooftop solar system. Controls allow the batteries to provide power to the home during a power outage or to supplement electricity use in the home. In cases where customers agree to allow the utility access to the battery, they can also be used by the utility to support grid operations.

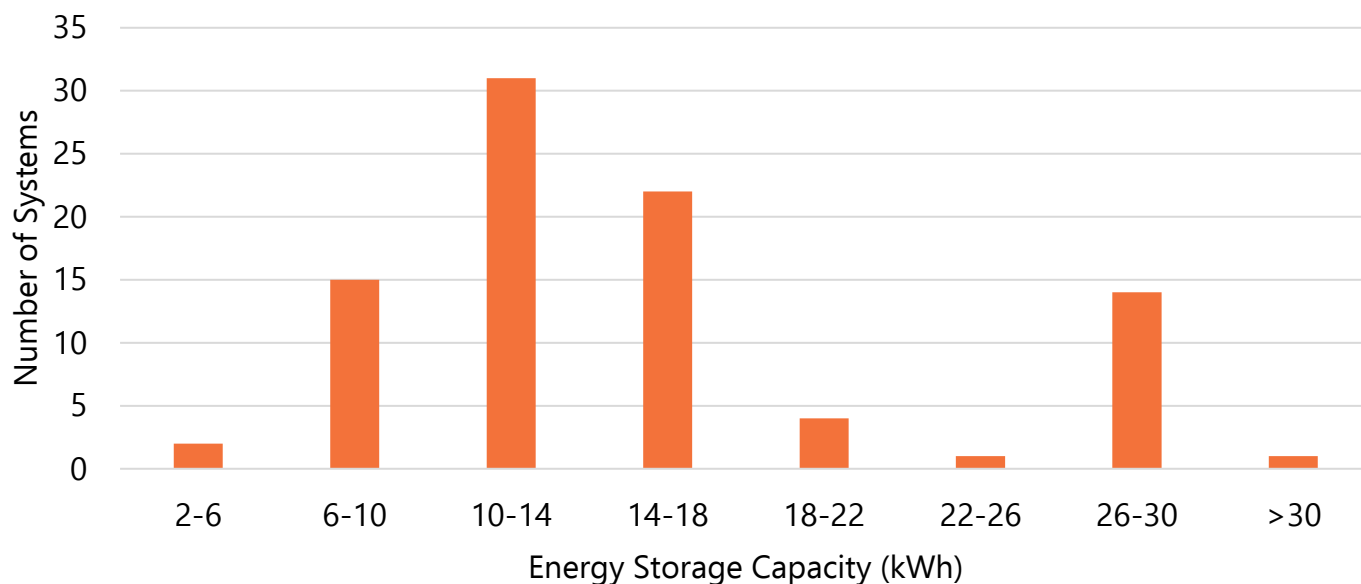
Residential batteries are described based on their power rating and their energy storage capacity. Power rating is measured in kilowatts and is the maximum electrical output that a battery can deliver at any given time. Storage capacity is measured in kilowatt-hours and represents the duration of time a battery can discharge electricity before needing to be recharged, depending on the load. Often, the storage capacity of a residential system is sized to supply power for critical loads such as lighting and refrigeration. For example, a battery with a storage capacity of 12 kilowatt-hours could support a load of 2 kilowatts for six hours.

Trends and Potential in Oregon

There are at least 289 residential batteries in Oregon installed in conjunction with residential solar systems.¹ Seventy-two of these projects are off-grid dwellings where onsite generation and battery storage provide 100 percent of the electricity for the home. The cost of residential battery storage varies by system size and complexity. The average cost of a residential battery system in 2020 was \$15,670. This does not include the cost of solar components if present. The storage capacity of residential batteries in Oregon ranges from 2.4 kWh to 46 kWh, with an average capacity of 11 kWh. Figure 1 demonstrates the range of residential battery sizes reported in Oregon between 2018 and September 2020.

ⁱ Estimated values for systems installed from 2018 – August 2020

ⁱⁱ The residential storage systems in this section are all installed in conjunction with residential rooftop solar projects. Additional residential energy storage systems may be installed as stand-alone systems but are not included in the data sets used in this report.

Figure 1: Range of Residential Battery Sizes in Oregon (2018-2020)

Residential battery systems provide multiple benefits for the owner and may also be used to provide services to local utilities and grid managers. Rocky Mountain Institute has identified 13 services batteries can provide to three distinct stakeholder groups: customers, utilities, and grid system operators. Services vary from grid stability support, meeting peak loads, more cost-effective management of transmission and distribution systems, and customer benefits including cost savings and backup power.²

Most residential battery systems are used to provide backup power to a home. For customers serviced by utilities that offer time-of-use rates – rates that vary depending on the time of day the electricity is consumed – battery systems can also be controlled in ways that help shift a home’s consumption of utility power to hours when electricity rates are cheaper, which can provide savings on utility bills. Savings are dependent upon how much the time-of-use rates vary and the round-trip efficiency of the battery storage system.

Residential battery systems can also be configured to communicate with a utility. Utilities can then operate the battery as a resource to benefit their entire system. For example, utilities can use residential batteries to help meet peak loads, maintain local grid stability, optimize the generation from low-cost resources when available, or make use of excess renewables that would have otherwise gone unused. To realize these utility benefits, residential battery systems must be operated by a utility or configured to automatically respond to market signals that indicate a need for services on the grid. The different benefits battery systems can provide are often in competition. For example, a battery system operated by a utility to provide services to the grid may result in less capacity available for the homeowner in the event of a power outage. Agreements between utilities and homeowners may limit utility use of the battery system to ensure there is always adequate capacity to provide backup power to the homeowner. Portland General Electric has launched a pilot program to test utility operation of residential energy storage systems.⁴

Some of the functions provided to utilities by battery storage systems are known as *ancillary services*, which are services necessary or incidental to the transmission and delivery of electricity from generating facilities to retail electricity consumers. These include scheduling, load shaping, reactive power, voltage control, and energy balancing services.³

Opportunities

Historically, deployment of residential battery systems has been limited by the up-front cost of the system; incentives are available that can help offset some of the up-front costs. In 2020, residential battery systems qualified for a federal tax credit equal to 26 percent of the project cost if they were installed in conjunction with a solar PV system and charged solely with solar energy. The federal tax credit will be reduced to 22 percent of system cost in 2021. As of September 2020, the Oregon Solar Plus Storage Rebate Program provided financial incentives for 11 residential battery systems paired with solar PV installations, with an additional 15 rebate reservations not yet completed.

As of September 2020, the Oregon Department of Energy's Oregon Solar + Storage Rebate Program has provided rebates for 11 residential battery systems paired with solar.

Because most residential batteries in Oregon are used as backup power, there are also limitations on cost savings opportunities. Having backup power improves the resilience of a household but does not provide financial benefits on a customer's electric bill. As utilities work to modernize their distribution system infrastructure, utilities may be able to track electricity provided from batteries that could support programs that can realize cost savings for customers and the utility.

Portland General Electric is operating a pilot program that provides incentives for 525 residential battery systems contributing up to 4 MW of aggregated electricity to PGE's grid. These distributed battery systems will be operated to provide grid services to PGE and will also be available for the participants as backup power in the event of a power outage. The batteries may be operated individually or aggregated by PGE to serve as a virtual power plant.⁴ The financial incentives are available to customers living within three neighborhoods participating in PGE's Smart Grid Test Bed, and will provide higher incentives to low- and moderate-income households to help ensure a more equitable distribution of benefits.⁵ The pilot represents the first program by an Oregon utility to operate residential battery systems to provide grid services.

Barriers

Equitable access to the benefits of residential storage battery systems is a significant barrier for many Oregonians. At over \$15,000, the typical up-front cost of an average storage battery system is out of reach for many Oregonians, particularly when most systems are currently only used for backup power. Enabling access to cost saving value streams could bridge the cost gap for some Oregonians, but for many, the existence of any up-front cost could prohibit access to residential batteries.

Non-Energy Implications

Residential battery systems can help support higher levels of renewable energy resources on the grid by providing services to grid operators and deferring investments in new fossil fuel generators.⁶ Distributed residential storage systems can also be aggregated and operated by utilities in a similar way to utility-scale battery storage systems. In aggregate, these could help utilities meet their peak utility loads and optimize their generation resources. Battery systems also have resilience benefits during power outages. These benefits can be enhanced when they are paired with rooftop solar systems that allow batteries to be recharged without utility power – benefits that would increase in the event of a prolonged power outage.



Utility-scale storage is discussed in a separate Technology Review.

Batteries have several negative environmental and social impacts. These impacts include unsustainable and/or un-ethical mining practices in some countries where raw materials are sourced,⁷ hazardous material handling, and difficulties in recycling. In 2019, Tesla announced it will be adding a lithium-ion battery recycling facility to the company's battery Gigafactory in Nevada.⁸

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Resource Review: Nuclear



- Oregon Total Capacity and Facilities: 0
- Oregon Consumption (2018): 1,390,000 MWh

The United States is the world's largest producer of nuclear power, which supplies around 20 percent of the nation's electricity.

Nuclear energy comes from splitting atoms in a reactor to heat water into steam, which turns a turbine to generate electricity. Most commercial nuclear plants in the United States generate a large amount of electricity – 1,000 megawatts or more – which is comparable to the output of the Bonneville Dam. Nuclear power plants are firm resources, meaning they are designed to produce steady output 24 hours per day, most times of the year. The capacity factor of a power plant is an annualized measurement of how often the plant is operating at full power or maximum output. Annual capacity factors of nuclear power plants vary according to their refueling cycles. In large part this is because nuclear power plants are designed to operate for long periods between refueling, typically 1.5 or 2 years.¹

Trends and Potential in Oregon

Only one nuclear plant – the Columbia Generating Station near Richland, WA – provides electricity to the Northwest grid and Oregon. It produces 3.8 percent of the electricity generated in Oregon and has a capacity factor of around 89 percent.²

Oregon's lone commercial nuclear power plant, Trojan, operated for 16 years and was shut down nearly 30 years ago. It was located along the Columbia River about 40 miles northwest of Portland. Trojan went on-line in May 1976. The plant was licensed to run for 30 years and generated 1,100 megawatts at full capacity. After a lengthy series of mechanical problems, Portland General Electric shut the plant down for economic reasons in November 1992 and permanently closed the plant in January 1993.³

Oregon law prohibits new nuclear power plants unless two conditions are met. The first is a finding from Oregon's Energy Facility Siting Council that the federal government has licensed a repository for the permanent disposal of commercial spent nuclear fuel (which has yet to occur). Then, if that condition is met, the second condition is that any proposal for a new nuclear power plant would go to a vote of Oregon residents. This law stems from an initiative passed by Oregon voters in 1980.⁴

Nuclear power plants cost far more to build than natural gas, wind, and solar facilities and have a history of cost overruns.⁵ They also take much longer to permit and build. The nuclear industry is hopeful that a new technology – small modular reactors – can be quicker to develop and more price competitive. See the small modular reactors Technology Review for more information.

Currently, 95 nuclear reactors in 29 states generate nearly 20 percent of the electricity generated in the United States – that percentage has not changed since the 1990s.⁶ Two new reactors are currently

under construction in the United States at the Vogtle Plant Site in Georgia (at a combined estimated cost of \$27.5 billion).⁷

However, America’s nuclear “fleet” is shrinking. The number of operating plants is expected to decline during the next several years as more plants are shut down, primarily because of their age, and that maintenance costs cannot compete with the price of natural gas-fired plants.⁸ Since electricity was first generated from a nuclear reactor in 1951, about 36 nuclear plants,⁹ including Trojan in Oregon, have been shut down or decommissioned,¹⁰ and others are likely to close over the next few years. However, some closures have been deferred in part as concerns about climate change have grown and the nuclear industry has made an argument to save greenhouse gas emissions-free energy generation.¹¹

America’s nuclear plants average 39 years of age, ranging between 4 and 51 years old. Most plants’ operating licenses from the U.S. Nuclear Regulatory Commission will expire in the 2030s or 2040s, and six have operating licenses allowing them to operate into the 2050s.¹² Assuming the reactors will operate to the end of their license without extensions, the average lifespan of the existing inventory is 57 operating years.

Figure 1: Number of New Reactors in the United States by Decade¹⁰

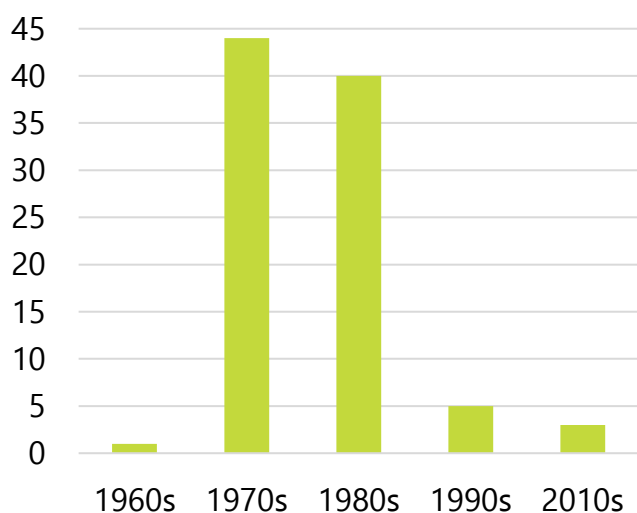
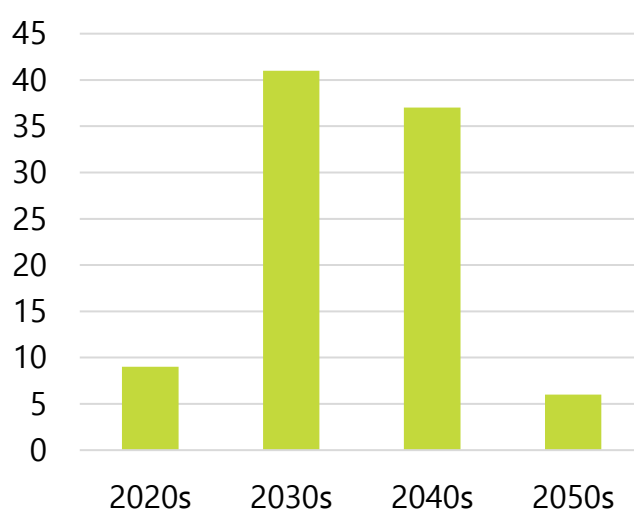


Figure 2: Number of Expiring Reactor Licenses in the United States by Decade¹²



Non-Energy Implications

Nuclear-based electricity production does not create carbon dioxide or other greenhouse gas (GHG) emissions.¹³ The United Nations Intergovernmental Panel on Climate Change (IPCC) has said nuclear energy could play an important role in mitigating the effects of climate change if concerns regarding nuclear power, such as safety, economic efficiency, and waste management are effectively addressed. However, there are environmental impacts and GHG emissions from plant construction, plant operations, fuel procurement, and the thermal load of the cooling water being discharged into water bodies during operation.¹⁴

Nuclear power generation also creates a radioactive waste stream that persists for hundreds of thousands of years. There is no known technology that can shorten the amount of time the waste remains a risk to human health and the environment.¹⁵ As a result, the plan for this waste is to store it

in a central repository which will keep it far out of reach of humans and isolated from the environment. About 80,000 metric tons of spent nuclear fuel is currently stored onsite at reactor sites throughout the United States.¹⁶ The federal government has been struggling for decades to site, construct, and operate a deep geologic permanent disposal facility for this fuel. The USDOE no longer predicts when such a facility may be available and ready to accept the radioactive waste.

Nuclear power also poses a risk of catastrophic accidents that doesn't exist with other forms of energy generation. The 1979 accident at Three Mile Island in Pennsylvania crippled the reactor and cost nearly one billion dollars in cleanup,¹⁷ while the accidents at Chernobyl and Fukushima have had far-reaching consequences in terms of health impacts and environmental damage and have cost hundreds of billions of dollars each in cleanup.^{18 19} These accidents have reinforced a generational concern over safety by the public.²⁰

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Technology Review: Small Modular Nuclear Reactors



- Total Capacity and Facilities in Oregon: 0
- Range of Potential Sizes: 60 – 250 MW per module

Oregon-based NuScale developed the first modular reactor to receive design approval by the U.S. Nuclear Regulatory Commission.

Small modular reactors (also referred to as SMRs), as the name implies, produce smaller amounts of electricity than typical nuclear reactors. Nuclear reactors use the heat generated from nuclear fission to generate steam. The steam is then used to spin turbines, generating electricity. SMRs generate 300 megawatts (MW) or less of electricity per module¹ compared to traditional nuclear reactors of 1,000 MW or more per module (i.e., Columbia Generating Station in Washington state has a nameplate capacity of 1,207 MW). They are scalable to fit diverse energy needs, are factory-fabricated (both to save cost and time), and are equipped with passive/inherent safety systems.

Oregon-based NuScale Power is the first modular nuclear reactor to receive design approval from the U.S. Nuclear Regulatory Commission.² The SMR being designed by Oregon-based NuScale is expected to be able to safely shut down and self-cool indefinitely with no operator action, no AC or DC power, and no additional water.³ SMR technology can be operated as a firm (or consistent) resource, but theoretically may also have some limited capability to vary its output based on changes in demand.⁴

While there are small, traditional nuclear reactors operating in the world, there are no new-generation SMRs yet in operation. The International Atomic Energy Agency reports that of the 50 or more designs being pursued, there are “four SMRs in advanced stages of construction in Argentina, China and Russia, and several existing and newcomer nuclear energy countries are conducting SMR research and development.”⁵



Learn more about nuclear energy in the nuclear Technology Review.

Trends and Potential in Oregon

While Oregon law prohibits site certification of an SMR in the state,⁶ Oregon is home to one of the world’s leading SMR companies, NuScale. NuScale is based in Portland but traces its origins to Oregon State University. The company’s goal is to develop a fully factory-fabricated module capable of generating 60 MW of electricity using a “safer, smaller, scalable” version of pressurized water reactor technology.⁷

On August 28, 2020, NuScale received a Final Safety Evaluation Report from the U.S. Nuclear Regulatory Commission. The Standard Design Approval from the NRC is anticipated to follow shortly. Both of these items signify NRC approval of the NuScale design. Final design certification is scheduled for August 2021.⁸

In June 2013, NuScale Power launched the Western Initiative for Nuclear (Program WIN), a broad, multi-western state collaboration to study the demonstration and deployment of a series of NuScale

SMR power plants in six western states. The first project to come out of Program WIN is a 12-module, 720 megawatt NuScale power plant that will be sited at the Idaho National Laboratory for the Utah Associated Municipal Power Systems' (UAMPS) Carbon Free Power Project. The first module is anticipated to be operational by mid-2029, with the remaining 11 modules to come online for full plant operation by 2030.⁹ The plant will be operated by Energy Northwest.¹⁰

Opportunities

SMRs have been supported by the U.S. Department of Energy through research, development, and deployment support. The reactors are envisioned to vary in size from a few megawatts (called microreactors) up to hundreds of megawatts, and have the potential to be used in a variety of applications for power generation. They may also be able to provide resilient and reliable off-grid power directly to remote locations, including military installations and other national security infrastructure.¹¹

In addition to NuScale, 50 or more other entities, including Holtec International and TerraPower, are moving forward with their own designs.¹² The layouts, fuel sources, stage of development, and safety features vary widely.¹³ The most advanced SMR project may be in China, where Chinergy has begun construction of twin 250 MW high temperature gas cooled reactors.¹⁴

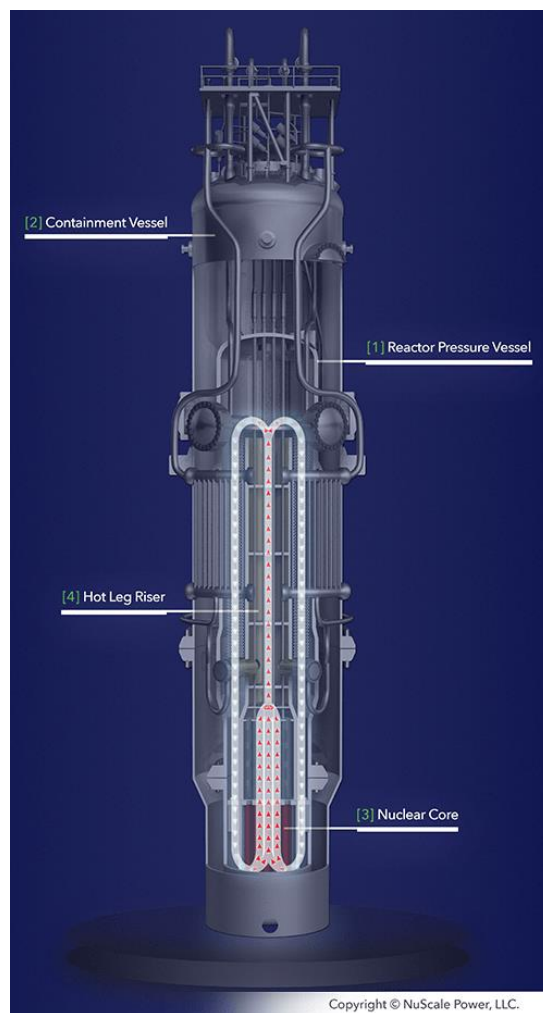
Electrical utilities, industry groups, and government agencies throughout the world are investigating alternative uses for SMRs beyond electricity generation such as:

- Producing steam supply for industrial applications and district heating systems – as one example, China is developing small district heating reactors of 100-200 MW capacity, as the market for heating in northern China is now served almost exclusively by coal.¹⁵
- Making products such as hydrogen fuel and desalinated drinking water.¹⁶

Potential advantages of SMRs remain to be seen. However, the following are some differences between SMRs and typical large-scale nuclear reactors.

- The SMR designs may eliminate many of the technical safety issues inherent with large reactors.¹⁷ Modular offsite construction allows more opportunities for inspections to catch construction defects before the reactor goes online. Since there is less centrally located fuel, there is less likelihood of a catastrophic release to the environment.

Figure 1: Design Illustration of NuScale Power Modular Reactor



- SMRs may also have a role in community resilience. SMRs can start up from a completely de-energized condition without receiving energy from the grid; meaning SMRs can operate connected to the grid or independently during disasters.
- SMRs can be built underground, making them less vulnerable to extreme weather events, earthquakes, or intentional destructive acts.
- SMRs can store a decade’s worth of fuel on site without the need for an external fuel supply; and a plant can stagger the refueling of its modules, allowing them to stay online and provide constant power to the grid without any disruptions.¹⁸

Barriers

Modular components, factory fabrication, and a much shorter construction duration should help control costs.¹⁹ Whether that will make SMRs cost competitive is likely too early to answer at this point, as the final cost of construction is yet to be determined.

In Oregon, there are statutory barriers to siting unique to nuclear power. An SMR operator would have to show that there is a federal repository for the spent nuclear fuel and get approval through a statewide vote.²⁰

Oregon has statutory barriers to siting nuclear power plants in the state. One barrier: Oregon voters would have to approve any nuclear facility.

Non-Energy Implications

The main advantage SMRs have over fossil fuel electric generation is that, like regular nuclear reactors, they do not directly produce greenhouse gases during their operation – they are carbon free (excluding fuel mining and processing, construction, and ancillary carbon emissions associated with operation and maintenance).²¹ The United Nations Intergovernmental Panel on Climate Change has said nuclear energy could play an important role in mitigating the effects of climate change if concerns regarding nuclear power, such as safety, economic efficiency, and waste management are effectively addressed.

The use of SMRs will not alleviate the need for a solution to the nuclear waste issue. Instead, it will add to the inventory of spent nuclear fuel waiting for a disposal site.

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Technology Review: Demand Response

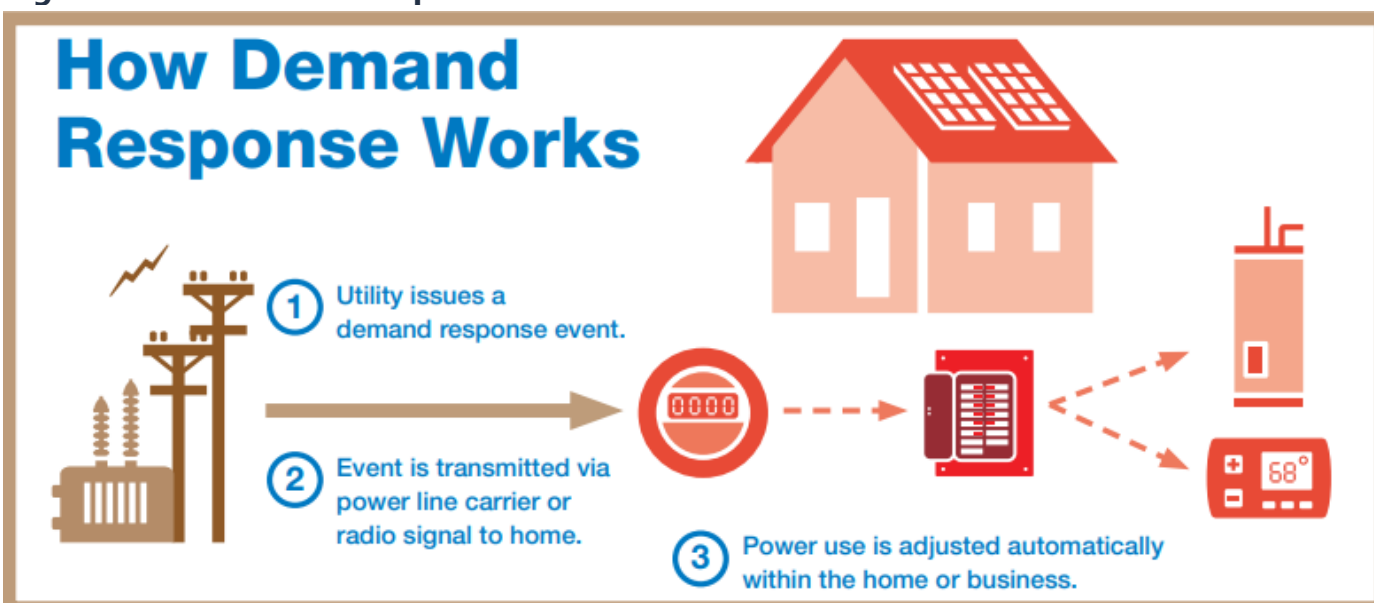


- The Northwest Power and Conservation Council’s Seventh Power Plan identified demand response as the least-cost solution for providing new peaking capacity.^{1 2}
- Portland General Electric’s Smart Grid Test Bed is a nationally-recognized project looking to deploy demand response at-scale across three selected geographic areas.^{3 4 5 6}

One strategy used by utilities to better align demand for electricity with the availability of supply is demand response, often referred to as DR, which refers to a deliberate change in a customer’s normal electricity usage pattern in response to a change in price, contract, or request from a utility or grid operator. The electric system, as explored in greater detail elsewhere in this report, is unique in its relative lack of storage capabilities. As a result, electric infrastructure is necessarily designed and built to be capable of simultaneously generating and delivering to customers the electricity needed to meet peak demands. This infrastructure is only used to its full capacity for relatively few hours of the year (i.e., those when demand for electricity is exceptionally high relative to average use) and these hours contribute disproportionately to total system costs. It is within this context that demand response has traditionally been used by utilities and grid operators as an alternative to building additional capacity (either generation or transmission) to deliver more electricity to customers.⁷

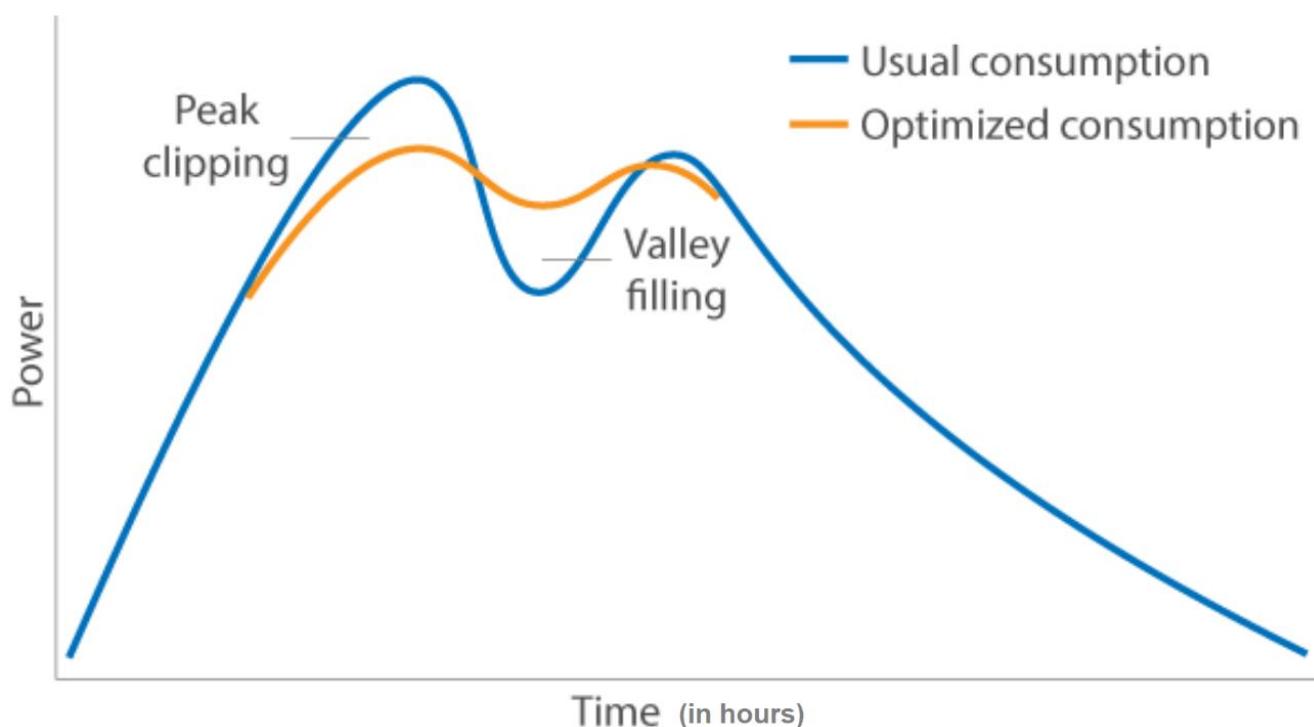
Utilities and grid operators sometimes find it more cost-effective to encourage or incentivize customers to adjust their demand rather than building new infrastructure to serve incremental peak demand. The result is typically a temporary, intentional change in electric consumption by an end-use customer in response to a request from a utility or grid operator, and the customer is then paid for this change.⁸ Figure 1 from the Bonneville Power Administration illustrates how demand response technologies within the home can interact with the grid. Note that while the graphic indicates power is *automatically* adjusted, this is the exception not the rule and customer intervention is often still required:⁹

Figure 1: How Demand Response Works⁹



While demand response programs have typically encouraged or incentivized customers to *reduce* demand during system peak in the past, utilities and grid operators are seeing more opportunities to incentivize customers to instead *shift* their demand, which may increase demand during certain times. This is also referred to as demand response, and might occur for a variety of reasons, including: to avoid curtailing otherwise excess renewable generation, to adjust net load to alleviate operational ramping constraints, or to provide grid balancing services.^{10 11} Figure 2 from the Northwest Power and Conservation Council illustrates a demand curve (blue) and how demand response could hypothetically optimize the curve (orange) by flattening it to reduce the peak and minimizing the severity of the ramps in power output (up or down) required to meet changes in consumption:¹²

Figure 2: How Demand Response Can Help Meet Changes in Consumption



There are generally two broad categories of demand response resources: **(1) controllable DR resources:** resources that are controllable by the utility and can deliver a firm or dispatchable resource, and **(2) price-based DR resources:** resources that are considered non-firm because they are based upon mechanisms to induce customer changes in demand which may or may not materialize and are not directly controllable by the utility. While the Council did not include consideration of non-firm, price-based demand response resources in its Seventh Power Plan,¹³ several Oregon utilities are actively exploring the potential for these resources and the Council has included them in its analysis that will inform the 2021 Power Plan.

In a Demand Response Potential Study published in 2019, BPA identified the following non-exhaustive, representative list of different types of demand response products by sector. It is reproduced in Table 1 to illustrate the wide range of products and technologies that can be deployed across sectors as demand response resources.¹⁴

Table 1: Types of Demand Response Products for Different Sectors

Sector	Types of Demand Response Products
Residential	Direct Load Controls: Water heating; space heating; central air conditioning; smart thermostats ⁱ Tariff-Based: Critical Peak Pricing Event Notifications: Behavioral demand response
Commercial	Direct Load Controls: Small and medium commercial spaces Automated: Lighting controls Other: Thermal storage; contractual demand curtailment
Industrial	Tariff-Based: Real-time pricing Other: Contractual demand curtailment
Commercial and Industrial	Tariff-Based: Interruptible tariff
Agricultural	Direct Load Controls: Irrigation
Utility System	Other: Demand voltage regulation / reduction

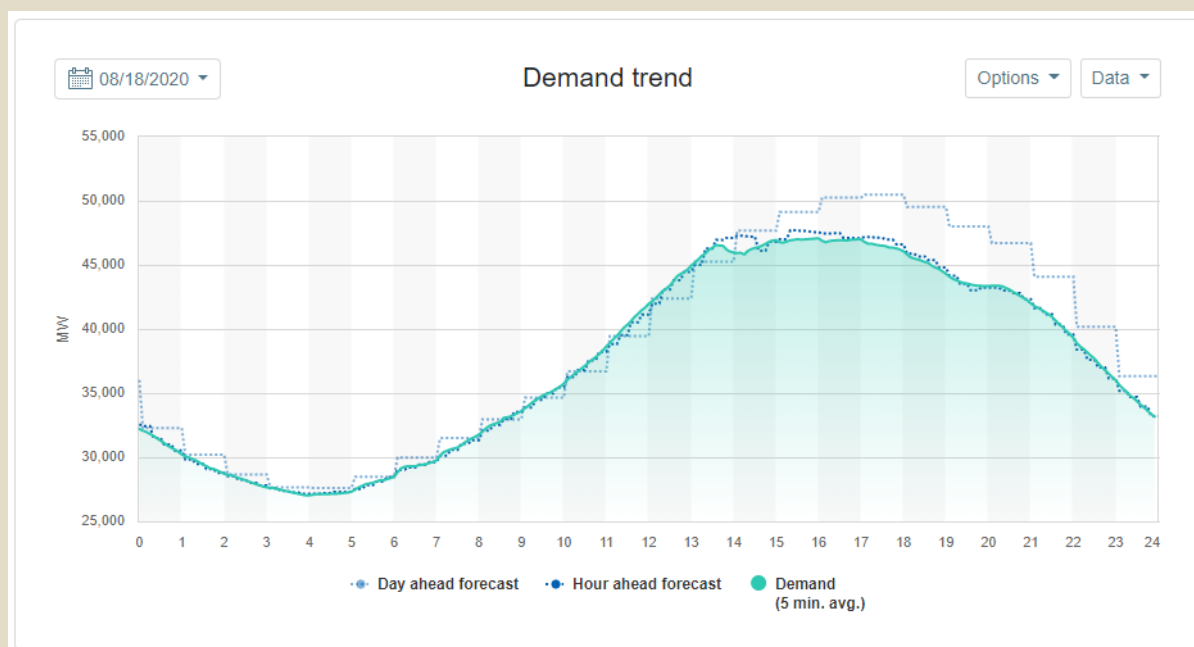
Demand Response in Action: CAISO Example

In August 2020, an extreme heat event affected much of the western United States and sent electric demand skyrocketing, particularly within the California Independent System Operator balancing area. For reasons not yet fully understood and still being investigated,ⁱⁱ CAISO was forced to institute rolling blackouts for several days to maintain grid stability.^{15 16 17} In the days that followed, CAISO relied on demand response resources to help reduce the system's peak demand and avoid continued blackouts.^{18 19}

The CAISO demand curve below for August 18, 2020 reflects this success in averting additional blackouts.²⁰ The day-ahead demand forecast for that day expected demand to crest above 50,000 MW between the hours of 4 p.m. and 6 p.m. Note that CAISO's all-time peak demand (set in July 2006) was 50,270 MW.²¹ As shown below, however, actual demand began to diverge significantly from the day-ahead forecast beginning around 2 p.m. and continuing through the remainder of the day. The actual peak demand for the day ended up occurring at 4 p.m. at 47,067 MW, or approximately 3,000 MW (or 6 percent) less than what had been forecasted.

ⁱ In the years ahead, it is likely that EV charging will present another opportunity for residential direct load control. For more information, see the electric vehicles Technology Review for more.

ⁱⁱ Note, however, that state agencies in California published *Preliminary Root Cause Analysis: Mid-August 2020 Heat Storm* in October 2020: <http://www.caiso.com/Documents/Preliminary-Root-Cause-Analysis-Rotating-Outages-August-2020.pdf>



So, what happened? How was CAISO able to reduce its expected peak demand by 6 percent in 24 hours and avoid the need for continued blackouts? Customer participation in demand response efforts played a large role. CAISO issued FlexAlerts,²² which call upon customers to voluntarily reduce demand during critical hours, while utility-administered demand response programs were available that could compensate customers for reducing demand.



A full accounting of exactly what type of demand response resources contributed to achieve this level of reduction is not yet available, but early indications suggest a robust customer response. Southern California Edison used its demand response programs to reduce peak demand by more than 800 MW, including the use of direct load control air conditioners and smart thermostats for more than 250,000 residential customers. Pacific Gas & Electric, meanwhile, achieved significant reductions by triggering interruptible service agreements in place with certain large commercial and industrial customers.^{23 24}

On that night of August 18, Steve Berberich, President and CEO of the CAISO, offered the following comments:²⁵ "Californians made tonight a success. Everyone pulled together and responded to our warning with action to avoid any interruption in electricity supplies."

"It is time to take demand response as seriously as we take the hardware solutions to grid reliability." ²⁶

~ Professor Severin Borenstein, Member, CAISO Board of Governors

Trends and Potential in Oregon

The Federal Columbia River Power System (FCRPS) has provided the foundation of the power system in Oregon and the region for over 80 years. The robustness of this system allows the northwest power sector to benefit from flexible, low-cost, zero-emissions hydropower and to largely avoid the types of capacity constraints that have led other regions of the country to develop significant demand response resources over the past decades. The Council has now identified a potential capacity deficit in the northwest within the next decade driven primarily by continued load growth, increasing constraints on the FCRPS, and coal plant retirements.

Learn more about resource adequacy in the Energy 101 section.

Despite this future capacity deficit, and the Council's finding in the Seventh Power Plan that demand response resources are the least-cost solutionⁱⁱⁱ for providing new peaking capacity,²⁷ the northwest "has yet to make substantial progress" on the development of new demand response resources according to the Council's Mid-Term Assessment of the Seventh Power Plan published in early 2019.²⁸ Council staff have recently finalized demand response supply curves for inclusion in the forthcoming 2021 Power Plan and find a significant amount of achievable potential across the northwest (over the 2022-2041 time horizon considered by that plan) that could meaningfully contribute to meeting the region's peak capacity needs in the years ahead.

Table 2: Achievable Demand Response Potential in the Northwest by Season

Season	Total Achievable Potential (MW) from 2022-2041 ²⁹	Achievable DR Potential as an Approximate Percentage of Regional Seasonal Peak Demand (2041) ³⁰	Top 3 Products by Achievable Potential (% of Regional Peak) ³¹	Levelized Fixed-Cost of DR Potential (Weighted Average) ³²
Winter	2,761	9%	<ul style="list-style-type: none"> Residential Electric Water Heating (3%) Residential Heating (2%) Demand Voltage Reduction (2%) 	\$39.52/kW-year ^{iv}
Summer	3,730	12%	<ul style="list-style-type: none"> Residential Electric Water Heating (3%) Agricultural Irrigation (3%) Demand Voltage Reduction (2%) 	\$31.17/kW-year

ⁱⁱⁱ The Power Council has identified the fixed-cost of DR potential in the range of \$30 to \$40/kW-year. By comparison, in Appendix H: Generating Resources of the Seventh Power Plan (see, pp. H11-H12), the Power Council estimated that a new combined-cycle combustion turbine (CCCT) with an in-operation date of 2020 would cost between \$180 and \$205/kW-year.

^{iv} \$/kW-year is a metric commonly used to estimate the annualized fixed cost of planning, building, and maintaining a capacity resource. This cost is fixed irrespective of whether the capacity resource is used to generate electricity. This is in contrast to \$/kWh which is a metric commonly used to measure the variable levelized cost of actually generating electricity, which requires inclusion of an analysis of all fixed (e.g., capital costs) and variable costs (e.g., fuel costs).

Electric utilities in Oregon have identified significant demand response potential in their respective service territories,^{33 34} and recent planning efforts indicate that more resources are likely to be developed in the years ahead.^{35 36} For example, in the Action Plan for its 2019 Integrated Resource Plan, Portland General Electric forecasts a cumulative addition of 190 MW (summer) and 129 MW (winter) of demand response capacity in its business as usual case for 2023.³⁷ If developed, these resources could contribute 5.4 percent and 3.7 percent, respectively, toward PGE's summer and winter peak load as forecasted for 2023.³⁸ To put these Oregon-specific numbers in broader context, according to the Federal Energy Regulatory Commission, the percentage of demand response resources in national organized wholesale markets in 2018 was 29,674 MW, or 6.0 percent of total system peak.³⁹

Opportunities

As recognized by the Council's Seventh Power Plan, there remain significant opportunities for demand response to contribute to meeting the needs of the electric sector in the northwest and in Oregon. Some key benefits include:

- **Low-Cost Capacity Resource:** As identified by the Seventh Plan, demand response resources can be a low-cost capacity resource (\$/kW-year), which is likely to have additional value for the region in the years ahead given forecasts of a capacity deficit within the next decade.
- **Non-Wires Solution:** As with many other distributed resources, demand response resources can help utilities manage peak power flows and potentially eliminate or defer the need to build large centralized resources, such as new sources of generation or transmission and distribution upgrades.^{40 41}
- **Efficient Utilization of Existing Resources:** Demand response resources can improve the efficiency of the overall electric system by better aligning customer consumption with the actual costs of operating the system, often resulting in cost savings both for utilities and customers.^{42 43}
- **Renewables Integration:** The quick-responding demand flexibility that demand response resources provide can also help the grid by ramping loads up or down to integrate the variable output of wind and solar projects.^{44 45}

Barriers

While the potential and value of demand response has been identified in Oregon and across the region, there remain challenges to the deployment of demand response resources, including:

- **Valuation Framework:** There is no clear mechanism (e.g., standard contract, tariff, or market) for valuing and pricing the benefits that demand response—or other distributed resources—can deliver to the grid.^{46 47 48}
- **Distributed Data Systems:** Depending on the type of resources deployed, utilities and customers may need to invest in new technologies to enable two-way communications between the grid and end-use customers.^{49 50} To the extent that these enabling technologies

are required, it is likely that access to these demand response resources will be distributed inequitably due to the up-front capital costs required and the disparate ability of individual customers to afford those investments.

- **Perceptions of Uncertainty:** From the utility perspective, the diversity of demand response resources (e.g., direct controls, voluntary customer actions, automated responses, etc.) can create concerns around a potential lack of clarity in communicating offerings to customers, and can create uncertainty about how firm the resources are going to be for meeting the utility's needs.^{51 52}
- **Customer Concerns:** From the customer perspective, concerns about adverse effects on business operations (for commercial and industrial customers) or comfort for residential customers (e.g., direct control of a thermostat) are potential barriers, as are concerns over privacy and information security.⁵³

Non-Energy Implications

The deployment of demand response resources has potential implications beyond the energy sector. As with many distributed resources, demand response offers potential solutions to meeting the grid's needs without the development, and associated environmental impacts, of building new sources of generation or transmission and distribution upgrades. More unique to demand response are the potential privacy implications for customers and cybersecurity risks that stem from deploying two-way communication systems between the grid and customers.

Demand Response and Natural Gas

Demand response is not just used by electric utilities. Natural gas utilities also use demand response to ensure that there is sufficient fuel available to meet critical needs, such as heating during cold weather events. Natural gas is the largest source of direct fuel for heating in Oregon, and natural gas fuels power plants that provide electricity also used for heating. Natural gas consumption tends to peak during the coldest times of the year when natural gas is used to heat buildings and to generate electricity. Adding infrastructure to meet these types of infrequent peak demands are expensive investments for utilities and their customers.

Natural gas utility demand response programs use service agreements in which large industrial and commercial customers voluntarily allow their natural gas service to be occasionally interrupted, either partially or fully. This interruption could be for a few hours or days during extreme weather events or supply disruptions. Businesses that participate in demand response programs benefit from discounted rates for participating in the program. Customers can benefit from the cost savings the utility realizes by delaying or eliminating infrastructure upgrades due to a lower peak load. For example, NW Natural has enough participants in its demand response programs to interrupt approximately 9 percent of the gas it would otherwise have to deliver on extremely cold days, which reduces their need for infrastructure investments and any corresponding costs to their customers.⁵⁴



With the advent of automated metering infrastructure and smart devices, natural gas utility demand response programs may be able to cost-effectively include residential and small commercial customers in demand response programs. Turning down a thermostat in a home by very small amounts across thousands of customers could be sufficient to reduce loads during peak hours while still maintaining sufficient energy supply. Local data collection coupled with smart devices could also allow natural gas utilities to monitor for localized issues on their distribution systems and address these with incremental load reductions. For example, equipment that can detect low pressure on a specific feeder line could help address the issue with location-specific demand response programs to reduce load in the area.

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Technology Review: Advanced Meter Infrastructure or “Smart” Meters



For much of the history of the utility industry, *mechanical meters* were used to measure energy consumption for billing purposes, with utilities dispatching personnel to manually read individual meters. There has been a significant increase (nationally and in Oregon) in the utilization of *automated meter reading* (also referred to as AMR) and more recently *digital smart meters* (also referred to as Advanced Metering Infrastructure, or AMI).

Automated meters use radio frequency waves to transmit data directly to a utility, eliminating the expense of meter-reading personnel. Automated meters may transmit data via secure networks, power line communications, or in some cases, short range transmissions may be read by a passing vehicle sent by the utility. Automated meter technologies are most commonly used by electric utilities, though they may also be used for gas and water meters. For example, Cascade Natural Gas uses AMR devices to enable drive-by reading of meters, which eliminates the need for utility personnel to enter customer properties.¹ AMI smart meter technologies can measure and transmit customer consumption and production data in sub-hourly time intervals. They also allow for two-way communications, which provides customers with more detailed information about their own consumption and also enables the utilities to control smart appliances such as water heaters, thermostats, and electric vehicle charging stations. In addition, smart meters allow utilities to more rapidly pinpoint outages, and thereby reduce response time and power outage durations.

Two-way communication allows customers to opt in to utility programs that can lower their bills by optimizing smart appliances and devices. This can be accomplished by controlling when appliances and devices are used. For example, not allowing them to operate during high rate peak periods and shifting this load to lower priced off-peak hours. This can also allow utilities to better manage their system peak loads by effectively managing individual customer loads.

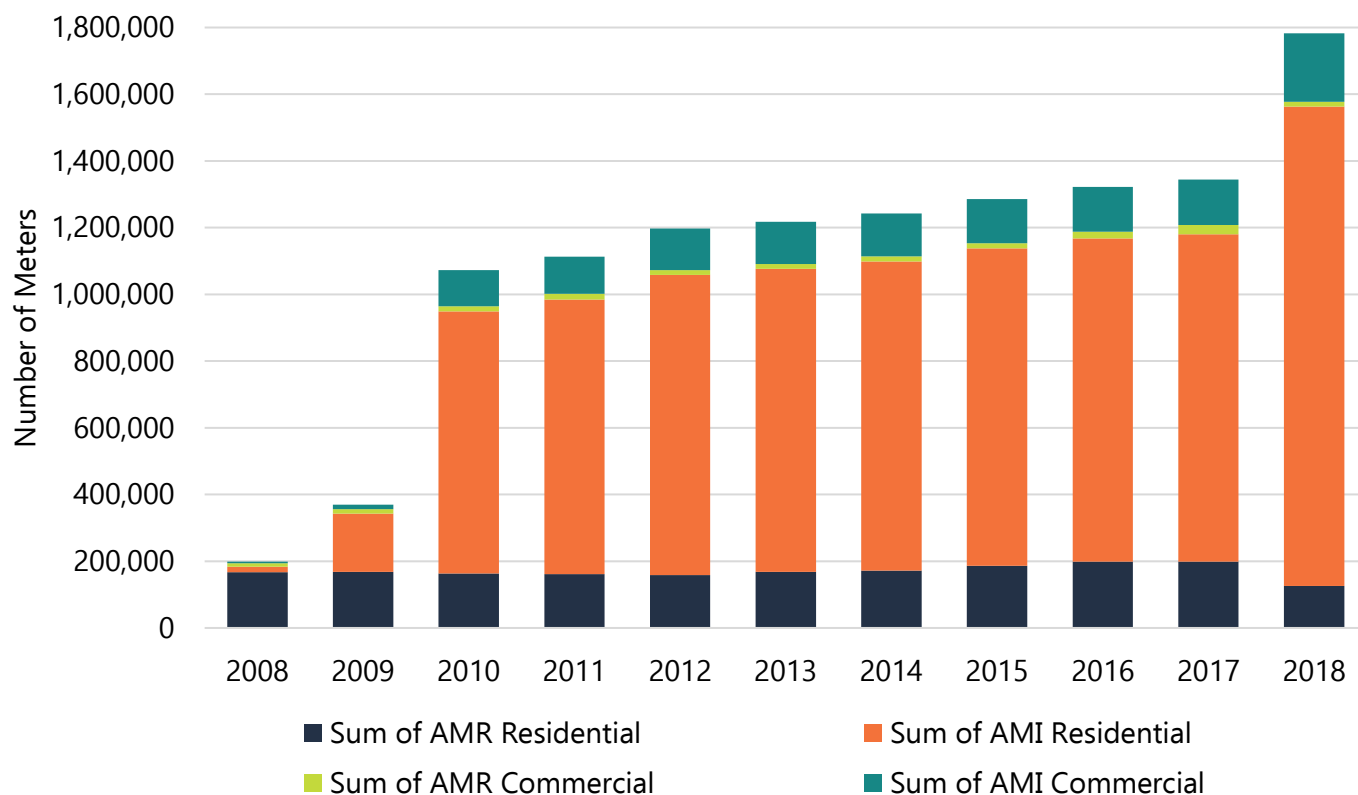
For example, at peak system energy consumption on a very hot day, a utility could temporarily stop charging an electric vehicle to ensure there is sufficient energy to meet system cooling needs, and then allowing charging in the off-peak hours (i.e., overnight).²



Learn more in the Demand Response technology review.

Trends and Potential in Oregon

By the end of 2018, electric utilities had deployed smart meters to approximately 128 million customers across the United States, with the majority of those installations for residential customers. In Oregon over the same period, utilities have deployed nearly 1.8 million AMR and AMI meters, with more than 48 percent penetration among commercial and industrial customers, and 87 percent penetration among residential customers.³ Figure 1 demonstrates the number of AMR and AMI meters installed in Oregon between 2008 and 2018. The reduction of residential AMR meters in 2018 is more than offset by the number of residential AMI meters, indicating a replacement of the older AMR technologies with new AMI smart meters.

Figure 1: Residential AMR and AMI Meters in Oregon by Year

Oregon's 87 percent residential penetration by 2018 of AMR and AMI technologies is on par with neighboring states with Washington at 72 percent, and California at 90 percent. Penetration of smart meters among Oregon's commercial customers (48 percent), however, is lower than neighboring states, with Washington and California at 67 percent and 90 percent respectively. The high penetration of smart meters for commercial and industrial customers in California is likely due to the requirement on utilities to institute *time-of-use rates* which enables customers and the utilities to lower their costs. Table 1 summarizes the penetration of AMR and AMI technologies by sector in Oregon, Washington and California.


 *Learn more about AMI in the Policy Briefs section.*

Table 1: Penetration of AMR/AMI Meters (2018)

State	Residential	Commercial & Industrial
Oregon	87%	48%
Washington	72%	67%
California	90%	90%

Source: U.S. Energy Information Administration

Opportunities

AMI is a prerequisite for *Smart Grid*, which enables more effective use of existing electricity generation, transmission, and distribution assets. Such optimization can reduce costs for utilities, which ultimately result in stable or lower costs and better reliability for utility customers. Detailed energy consumption data that AMI provides is necessary for many smart grid technologies and programs. For example, smart meters provide the data needed for utility demand response programs that offer customers financial benefits to limit their consumption during times of heavy electricity demand. In Oregon, Portland General Electric and Pacific Power offer time-of-use rates as well as direct load control, which provide financial savings to customers willing to adjust when they use electricity.⁴ Smart appliances can communicate with the utility, which in turn can send signals to those appliances to reduce or stop consuming energy during peak load time periods. In the future, smart appliances may use real-time market pricing information to determine when it is most cost-effective to operate. AMI can also help utilities better manage the distributed renewable electricity generation on their systems, such as rooftop solar. Smart meters provide data to help utilities do daily load following and allow them to better plan for the future needs of the distribution system. This improved data and planning are necessary to integrate higher levels of intermittent renewable energy onto the grid.



Learn more about distributed system planning in the Policy Briefs section.

Barriers

While smart meters can bring financial benefits to utilities and customers, there are significant upfront costs associated with replacing thousands of existing meters, in addition to other barriers to deployment and full utilization. One deployment barrier has been public perception of health risks associated with radio frequency radiation and data privacy issues associated with detailed electricity consumption records. Another barrier to full utilization of AMI technologies is a lack of installed smart appliances. Smart appliances may be configured to support grid operation in conjunction with smart meters; however, development of new products, product standards, and consumer adoption will be necessary to realize these benefits.

Non-Energy Implications

Smart meters play a critical role in improved operations, reliability, and planning of the electricity distribution systems. Better data collection and planning enables more efficient grid operations, which results in reduced GHG emissions.⁵ These reductions are made possible through more effective use of existing fossil fuel resources, as well as integration of more renewable energy resources. GHG emissions can also be reduced by eliminating millions of miles of driving by utility personnel to read meters. The use of smart meters enables Portland General Electric to annually avoid 1.2 million miles of driving, which reduces CO₂ emissions by 1.5 million pounds or nearly 700 metric tons.⁶

Eliminating millions of miles traveled by utility meter readers cuts transportation-related greenhouse gas emissions.

Widespread adoption of smart meters results in millions of existing mechanical meters being removed from service. Proper disposal of the old meters involves recycling as much of the materials as possible. Electric meters are composed of steel, glass, plastic, and non-ferrous metals, all of which can be recycled.

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Technology Review: Combined Heat and Power



- Installed Capacity in Oregon: ~1,700 MW
- Sites in Oregon: 30+
- Sites range in size from a few hundred kilowatts to several hundred megawatts, and are located at a variety of industrial facilities like pulp and paper mills, lumber mills, wastewater treatment plants, and universities.^{1 2 3}

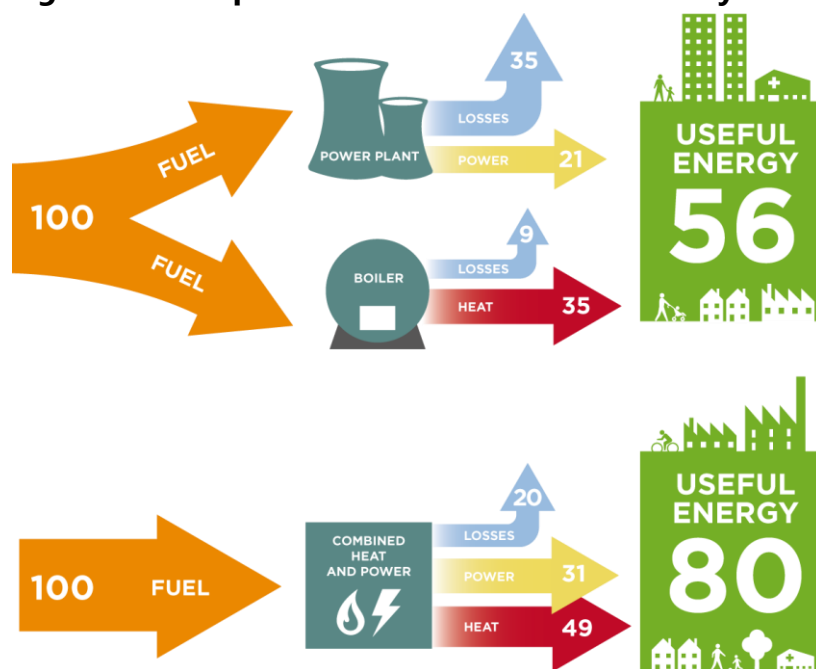
Combined heat and power, also referred to as CHP or cogeneration, is a process where multiple forms of useful energy are generated from the same fuel source. Typically, CHP involves concurrent production of electricity and thermal energy, and the combined system results in an overall efficiency that is higher than if each were generated separately, as depicted in the theoretical illustration in Figure 1.

CHP systems can come in various forms and sizes. Some systems involve a first stage of fuel use for electricity generation with subsequent heat recovery to provide useful thermal energy. This configuration is known as a “topping cycle” CHP. In contrast, “bottoming cycle” CHP uses fuel to first provide thermal energy and the rejected heat is then used to generate electricity. CHP systems can employ gas turbines or reciprocating engines to power a generator, and heat exchangers and heat recovery equipment to provide useful thermal energy commonly in the form of steam or hot water. The combined process takes advantage of energy that is typically “wasted” to achieve improved overall

efficiencies. CHP systems can range in size from 30 kW microturbines to large steam or gas turbines that power generators with capacity in the hundreds of megawatts.^{5 6} Costs for CHP are variable and depend on system types and application, but they are generally on the order of \$1,000/kW to \$3,000/kW of installed generation capacity.^{7 8}

CHP is not universally applicable, however. It is typically installed in locations with sufficient continuous demand for both electricity and thermal energy. These tend to be large, energy intensive industrial processes such as those in the metal, petroleum, paper, lumber, and chemical industries. However, CHP can also be applied to some commercial spaces such as hospitals. CHP systems are sometimes co-located with one or more end-users for the electricity and thermal outputs to maximize demand, continual operation, and efficiency. Excess electricity production can often be exported to the grid, but thermal energy presents a challenge to transport long distances. For this reason, CHP

Figure 1: Example Combined Heat and Power System⁴

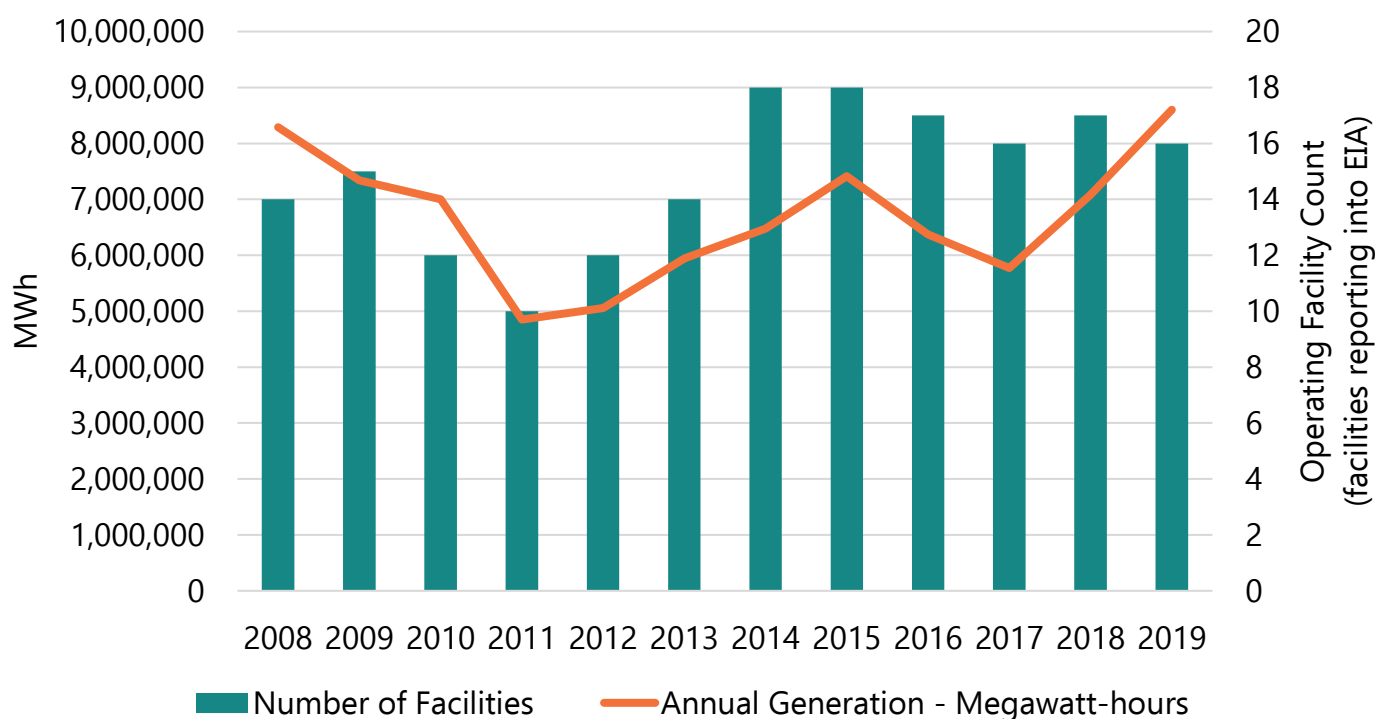


systems are commonly located very close to the point of thermal consumption, and systems must be sized appropriately to balance a site's thermal and electricity needs.

Trends and Potential in Oregon

Figure 2 illustrates the number of operational CHP facilities in Oregon reporting into the United States Energy Information Administration (EIA) by year and the associated electricity generation from these facilities (note: EIA data generally only includes facilities with greater than 1 MW capacity, as such there are a number of smaller facilities that are not included in the EIA database)⁹.

Figure 2: Combined Heat and Power Facilities in Oregon by Year



CHP installation and operation are dependent on an appropriate site that can utilize the electricity and thermal output. Studies have shown that Oregon has technically and economically feasible CHP potential remaining across the industrial and commercial sectors.^{10 11}

There are also examples where CHP systems can take advantage of biomass as a fuel, and in Oregon can potentially generate thermal renewable energy certificates (T-RECs) to contribute to the Oregon renewable portfolio standard, or RPS.ⁱ Traditional renewable energy certificates, or RECs, are created when electricity is produced using renewable fuels. T-RECs represent the thermal equivalent of a traditional REC. Both RECs and T-RECs represent a defined generation amount – 1 megawatt-hour and 3,412,000 Btu for RECs and T-RECs, respectively. In CHP systems that produce both electricity and thermal energy using RPS-eligible biomass as the feedstock, facility owners can earn credits for both the electricity and thermal outputs. These RECs and T-RECs can contribute to renewable facility operations and also provide the potential for monetization in a REC market to provide an incentive for renewable CHP operation. To date, Oregon has two CHP facilities – Seneca Sustainable Energy and the Gresham Wastewater Treatment Plant – that are certified as T-REC generators due to their renewably-sourced electricity and thermal energy generation.

ⁱ See ODOE's 2018 Biennial Energy Report for more information on the Renewable Portfolio Standard and T-RECs.

Non-Energy Implications

CHP systems can also have non-energy implications. Improved energy efficiency and on-site electricity generation can lead to operational utility cost savings for owners. Some incentives may be available for CHP installation and operation to offset capital costs. Grid-interconnection, equipment maintenance, and operational expenses can present additional issues for CHPs owners to address. Onsite production of electricity and thermal energy can potentially offer the resilience benefits of local, distributed generation, but this can depend on the availability of fuel in an emergency situation. There are also environmental considerations for CHP. While cogeneration can represent an overall energy efficiency gain, in many cases it incorporates fossil fuel combustion that still contributes to GHG emissions and should be balanced against emissions intensity of a local grid when performing a GHG emissions accounting analysis. Also, as discussed above, where CHP systems use renewable fuel sources, RECs and T-RECs can serve as an additional benefit for system owners.

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Technology Review: Electric Vehicle Chargers



Electric vehicle (EV) chargers are used to fuel electric vehicles. Over 80 percent of passenger EV charging occurs at home¹ by either plugging directly into a standard 110V socket (called Level 1 charging) or via a faster charging cable on a 220V plug (known as Level 2 charging). Many businesses and fleets also have Level 1 and 2 charging set up for their fleet vehicles, employees, or customers. There are also public chargers available throughout the state. Public charging can be Level 1, 2 or an even faster form of charging called DC fast charging (also referred to as DCFC or Level 3 charging), which are often located near common travel routes in the state, such as interstates and highways to the coast and central Oregon.

Overall charging times will vary depending on how much the battery has been depleted, the battery capacity, what type of charger is being used, and how much charge the driver needs to arrive at their destination. Most EVs come with a cord that will allow a vehicle owner to plug into a standard garage wall outlet. Depending on the distance traveled, it will take anywhere from a few minutes to over 10 hours to completely recharge the EV at two to five miles of range added per hour of charging. A driver can charge faster by installing a Level 2 charger, which uses 220V AC power, and supports 10 to 20 miles for every hour of charging.²

Unlike home or hotel charging, which generally occurs overnight, chargers used for travel beyond the battery range of the vehicle must be able to recharge in a relatively short amount of time so the traveler can get back on the road quickly. To accommodate this, DCFC stations are capable of charging at significantly higher rates than Level 1 and 2 chargers. Depending on how much the battery needs to be charged, using a DCFC rated up to 50 kW (the most common form of DC fast charger in Oregon), will add more than 80 miles of range in 30 minutes.³ Electrify America's recently-completed Los Angeles to Washington DC charging corridor has fast chargers approximately every 70 miles along the route, an example of the sort of infrastructure needed to enable longer road trips in EVs.⁴

There are two types of charging for electric medium-duty and heavy-duty vehicles: depot and on-route opportunity. Both technologies come with tradeoffs related to scheduling, maintenance, operations, and costs.⁵ Depot-based charging involves charging vehicles at the garage or "depot" where the vehicle usually parks when not in service.



An all-electric TriMet bus recharges at the Sunset Transit Station in Hillsboro.

Photo courtesy of TriMet



Learn more about medium- and heavy-duty vehicles and alternative fuels in the Policy Briefs section.

Vehicles using this method will require larger batteries to hold enough energy to complete their duty and return to the depot charger, and they typically require between one and four hours to charge depending on use, battery capacity, and charger type. Most of the current EV models for medium- and heavy-duty vehicles are used to travel from a central hub each day and return to that hub where they can be charged during off hours.

On-route opportunity-charging vehicles can charge during their scheduled service using chargers at layover terminals along their routes.⁶ Vehicles using opportunity charging usually have batteries that hold a smaller amount of energy, but only require several minutes to fully charge, and can therefore continuously operate for longer periods of time. Depending on how quickly the user needs to refuel, some lighter-weight vehicles, like local delivery trucks and school buses, can also use standard 220 V charging outlets.

Charging done in the home or for fleet vehicles is generally paid for via the home or business owner's electricity bill. Public charging usually requires the user to pay for usage, although some chargers are free to the public. Users will pay for the charging either by credit card, smart phone application, payment over the phone, or through membership with a particular EV charging equipment owner.

Rates for electric fuel are set by the providers. The charging companies have different business models, so the amount it costs to charge at public stations ranges from free to \$24 per session. Some pricing also includes the value of parking. Unlike the utility that supplies electricity to homes and business, which is overseen by regulatory bodies such as the Oregon Public Utility Commission or utility governing boards, non-utility companies operating chargers for EVs are not regulated by state or federal entities for the electricity that they provide.

Table 1: Charging Companies in Oregon

Nine charging companies operate in Oregon using a pay-to-charge model.⁷

Company	No. Charging Points
Blink	80
ChargePoint	62
Electrify America	16
EV Connect	7
Greenlots	8
OpConnect	6
Semaconnect	32
Tesla	56
Volta	26

Trends and Potential in Oregon

As of the end of 2018, Oregon ranked fourth in EV adoption per capita.⁸ As of July 1, 2020 there are 31,977 registered electric vehicles in the state, and year-over-year adoption growth has been about 36 percent since 2015.⁹ The number of charging station sites increased in Oregon by 63 percent between June 2015 and June 2020, and the number of connectors at each site has also increased, especially in the last two years.¹⁰

As of September 9, 2020, Oregon has 1,796 public charge points at 656 locations or stations. A station charger can have several charge points, just as a gas station has several pumps. Of these charging locations, 1,361 are Level 2 and 384 are DCFC.¹¹ This means there are approximately 23 zero-emission

vehicles for every Level 2 charging point and 83 for every DCFC, most of which are located in the Willamette Valley.

Because much of the public EV charging is clustered around major travel corridors and population centers, many rural parts of Oregon lack access to public charging. There have been investments in frequent travel destinations, such as coastal cities along US 101. For example, ODOE and the Oregon Department of Transportation secured funding to develop the first major long-distance DCFC corridor in the United States: the West Coast Electric Highway. The West Coast Electric Highway is an extensive network of electric vehicle DCFC and Level 2 charging stations along the West Coast, from British Columbia to the California-Mexico border.¹²

Investments from many of the state's utilities are helping to increase EV charging across Oregon, including in rural parts of the state.^{13 14 15} Many utilities use funds from the Department of Environmental Quality's Clean Fuels Program to procure and install chargers. Enrolled utilities receive credits for residential chargers that power EVs in their territory; the credits can be monetized for use by the utility.¹⁶ In addition, many private companies are making investments in Oregon, including Electrify America and ChargePoint.¹⁷ Some companies in Oregon help private business and housing owners install on-site EV charging and, if needed, establish a pay-to-use platform.¹⁸

Data is not readily available to determine the amount of private charging infrastructure; however, because most charging is done at home, it can be inferred that the majority of Oregon EV owners have access to charging at home. The lack of access to home charging can be a barrier for potential EV owners, as described below.

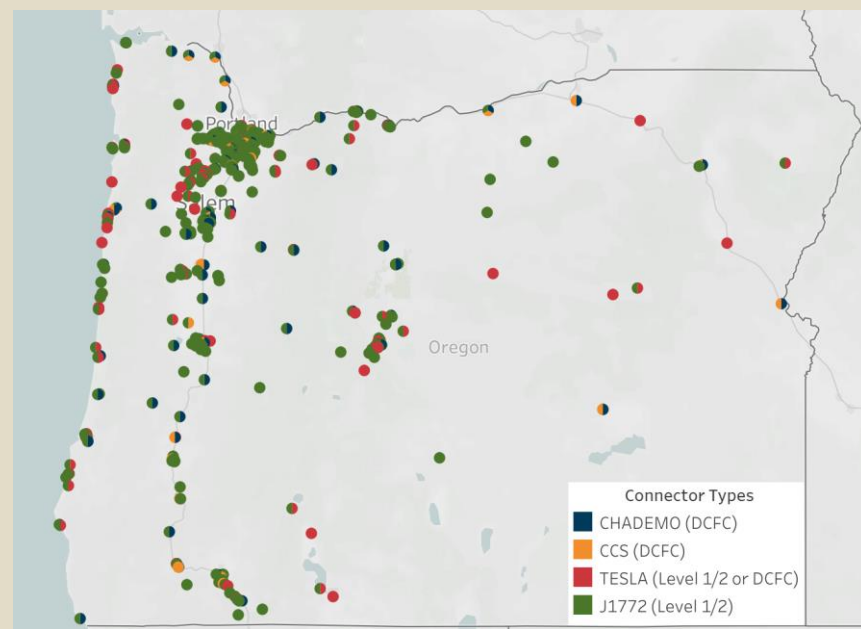
Opportunities

Investments in charging infrastructure by EV charging companies and utilities are a significant driver for increased adoption of EVs in the state. For example, Electrify America will establish Zero Emission

The Oregon Department of Energy's **Electric Vehicle Dashboard** provides an interactive map showing detailed information for Level 2 and DCFC stations in Oregon, including payment information.

tinyurl.com/ODOEEVDashboard

There are also several smart phone apps that can help drivers locate stations.



Vehicle (ZEV)ⁱ Investment Plans for two additional 30-month cycles. The State of Oregon submitted a proposal in August 2020 for investments in a third cycle.

Transportation Electrification Infrastructure Needs Analysis (TEINA)

The Oregon Department of Transportation, in collaboration with the Oregon Department of Energy, is undertaking a Transportation Electrification Infrastructure Needs Analysis (TEINA) study, as directed by Governor Brown's Executive Order 20-04, Directing State Agencies to Take Actions to Reduce and Regulate Greenhouse Gas Emissions. The TEINA study will assess transportation electrification charging infrastructure needs and gaps throughout Oregon, recognizing that convenient, accessible charging infrastructure is a critical driver accelerating Zero Emission Vehicle adoption and lowering greenhouse gas emissions. The study will highlight charging infrastructure needs for light-duty ZEVs in support of statewide adoption targets in SB 1044 (2019) and provide an overview of the charging infrastructure needs for other vehicle classes and use types, ranging from medium- and heavy-duty trucks and buses to e-bikes and e-scooters. The TEINA study will also suggest policy options and identify ways to expand charging infrastructure in Oregon to accelerate statewide transportation electrification. The outcome of this work will position Oregon to develop an overall ZEV charging infrastructure strategy that can help the state meet its transportation electrification goals.



Information Provided by the Oregon Department of Transportation

Barriers

The biggest barriers to increased EV infrastructure are costs to site and install a charger. In cases where chargers can simply be plugged into existing 110V outlets, there is no cost for the charging infrastructure. For businesses, and particularly those where medium- and heavy-duty vehicles are being charged, there is frequently a need to install a charger and upgrade the electrical service to the facility.

For public infrastructure, investments are generally made by EV service equipment suppliers or utilities. EV charging companies make investments in infrastructure in order to recoup their costs and potentially profit through the sale of the electric fuel. The profitability of these chargers depends, in part, on the amount of use and price to users. Not only is the number of users purchasing electricity critical to charging companies, but DC fast chargers are also subject to demand chargesⁱⁱ which can increase operational costs. Utilities also make investments in charging infrastructure and often recoup their costs through electric rates.

ⁱ In Oregon, for the most part, ZEVs are all-electric or plug-in hybrid models. Hydrogen fuel cell vehicles are also considered ZEVs, but Oregon doesn't yet have hydrogen fueling infrastructure for that type of vehicle.

ⁱⁱ Because electricity is made just in time for use, many utilities have commercial and industrial rates that include a demand charge. This is a fee on the customer's bill for the highest amount of electricity use over the course of the billing cycle.

Another challenge in siting charging infrastructure is finding an appropriate site. A location will need sufficient electricity supply to power the charger, access to food and restrooms for drivers to use while waiting for a charge, and often cellular or internet access. Chargers also need to be located where drivers are traveling. The confluence of these needs can make finding appropriate sites and contracting with landowners a time-consuming and expensive process. Some charging companies have mitigated this by developing contracts with large retailers that would enable development of charging at any of the retailer's locations.



This bank of Tesla chargers was being installed at a northeast Salem shopping center in September 2020.

Non-Energy Implications

There aren't many studies or data readily available regarding environmental impacts of charging infrastructure. The equipment itself contains a housing, some conductors (usually copper or aluminum) and circuit boards, chips, controllers, and switches, like many other meters or appliances. Bringing the electric infrastructure to the site is often the biggest environmental impact, including cutting of concrete or parking surfaces, excavating, or installing conduit. Any negative environmental impacts of EV charging should be considered alongside the significant environmental benefits of the transportation electrification it supports.

EV charging technology is still relatively new, and upgradeability is an important consideration. In some cases, technological changes have made early chargers obsolete before they are worn out. With planning, the major infrastructure can be built to handle charging that is not yet available. Standards are being improved to allow equipment interoperability so that it may be reprogrammed with software improvements and minimal hardware changes.

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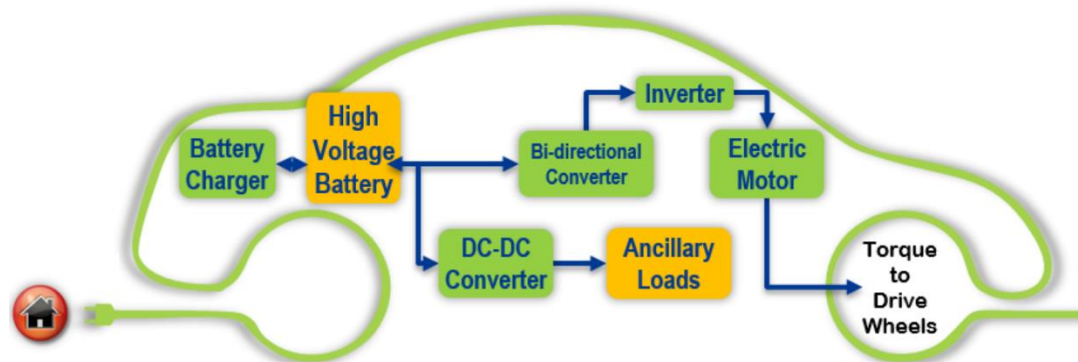
Technology Review: Electric Vehicles



- Number of electric vehicles registered in Oregon: 31,977¹
- Number of battery electric vehicles in Oregon: 20,251²
- Number of plug-in hybrid EVs in Oregon: 11,726³
- Number of public EV chargers in Oregon: 1,796⁴

Electric vehicles use batteries, either fully or in part, to supply electric fuel to the vehicle. Batteries power one or more electric motors, which provide the force that propels the car. Battery electric vehicles (BEVs) exclusively use batteries to provide electricity as a fuel source. Plug-in hybrid electric vehicles (PHEVs) use a battery to power the vehicle for some distance before switching to either a standard gasoline-powered car or use a petroleum-fueled generator to power the battery. Unlike standard hybrid vehicles, both BEVs and PHEVs need to be plugged in to recharge the batteries.⁵ A third form of electric vehicle – fuel cell electric vehicles – is discussed in the next Technology Review.

Figure 1: Electric Vehicle Drive System⁶



EVs are more energy efficient than their internal combustion engine counterparts. Standard gasoline vehicles lose over 60 percent of the fuel's energy, mostly due to heat loss during combustion and the

friction of moving parts. Electric vehicles lose only about 20 percent of the energy from their electric components.⁷ BEVs do not have combustion engines, so there is no need for oil changes, air filters, or belt replacements.⁸ EVs also use regenerative braking, a technology that converts the kinetic motion of the vehicle into electricity, which can be used by the vehicle or stored in the battery. Because the regenerative braking system reduces this kinetic motion, the vehicles brake pads experience less friction and therefore less wear and tear. Owners do not have to replace brake pads as often, also reducing overall maintenance costs for EVs.⁹ Fueling costs are about 25 percent of a typical average gasoline-powered vehicle.¹⁰

Trends and Potential in Oregon

Electric vehicle adoption has been steadily growing in Oregon. In 2015 there were just over 3,000 registered passenger EVs —by August 2020 there were more than 30,000.¹¹ BEVs show the highest rate of growth in Oregon, accounting for over 60 percent of total registered vehicles.¹² PHEV growth has held steady since 2018. The most popular light-duty models of vehicles in the U.S. are SUVs and pickup trucks.¹³

The most popular EV models in Oregon are the Tesla Model 3, Nissan LEAF, and Chevrolet Volt.¹⁶

Several manufacturers have released SUV EV models in the last several years, and many of those have indicated they will be releasing pickup truck models in the next few years.¹⁴ The USDOE projects that BEVs will grow by 6 percent per year and PHEVs by 3.1 percent through 2050.¹⁵

Barriers to EV Adoption in Oregon

The upfront cost to purchase an EV remains higher than most gasoline-powered vehicles. For example, the electric format of a Hyundai Kona was nearly \$17,000 more than its gasoline-powered counterpart.¹⁷ Total available incentives in Oregon for this vehicle range from \$10,000 to upwards of \$12,500, which offsets a significant portion of the total difference in cost.¹⁸ However, these incentives include a \$7,500 federal tax credit, which is dependent on the purchaser's tax liability. Lower-income Oregonians with less tax liability may not be able to take advantage of this incentive. Oregonians also buy more used vehicles than the national average. While Oregon has a robust used EV market with EV registrations accounting for nearly 20 percent of all EVs, the availability of used models, particularly the ones in highest demand (SUVs and pickup trucks), will take some time to filter into the used vehicle market.

In addition to the higher up-front cost of EVs, the availability of the necessary fueling infrastructure can be a barrier to EV adoption. According to surveys conducted by Deloitte in 2018 and 2020, the



Learn more about EV models, charging, and incentives:

GoElectric.oregon.gov

Platt Auto Group Meeting Oregon's Used EV Needs

In August 2020, the Oregon Department of Energy announced that Platt Auto Group was awarded a 2019 EV Leadership Award from Governor Kate Brown for helping to accelerate electric vehicle adoption in Oregon. Platt has been serving Oregon's electric vehicle community since 2013, when the auto dealer made the switch to focus exclusively on selling pre-owned EVs and educating customers about the benefits of going electric. Platt's business model of selling pre-owned stock helps expand access to more Oregonians, including lower-income families.



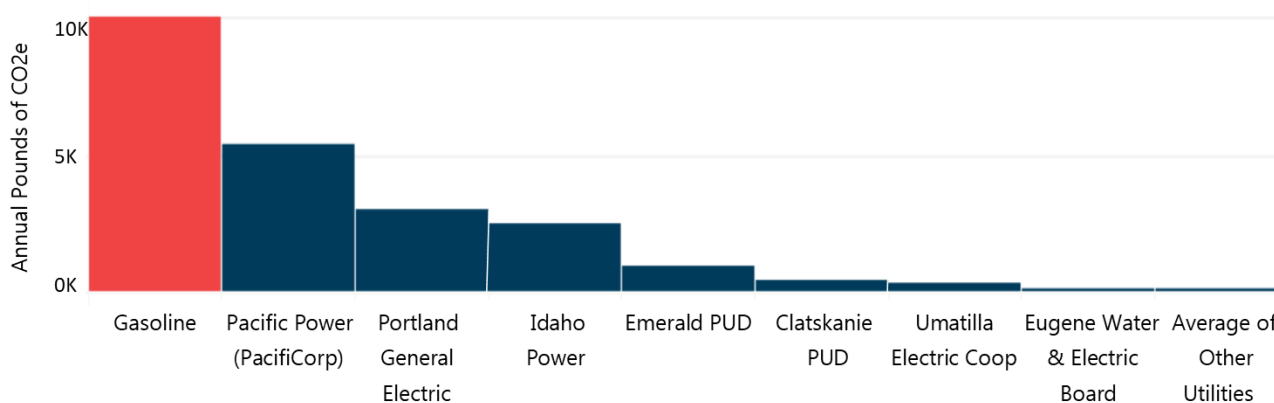
www.plattauto.com/

lack of vehicle electricity fueling infrastructure overtook the high up-front cost as the number one concern consumers had about purchasing an EV.¹⁹ Although investments in EV charging in Oregon have been steadily growing, the majority of charging infrastructure to date has been located in the Willamette Valley.²⁰ Lack of charging infrastructure in rural parts of the state may limit EV adoption in these areas. In addition, over 80 percent of EV charging is done at home.²¹ Oregonians living in multi-unit dwellings and in homes that lack driveways or other ways to access charging will require additional charging infrastructure to meet their daily charging needs.

Non-Energy Implications

EVs can reduce the environmental impacts of driving. EV adoption in the U.S. could reduce GHG emissions by 30 to 45 percent, depending on the mix of BEVs and PHEVs.²² BEVs have no tailpipe emissions of greenhouse gases or air pollutants, and PHEVs emissions will depend on how often the vehicle uses gasoline for power. Emissions associated with electric fuel come from the source of electricity itself. In Oregon, no matter where an EV is charged, the overall greenhouse gas emissions will be lower than using gasoline. In many parts of Oregon where hydropower and nuclear are the predominant electricity generators, the GHG reduction potential is over 95 percent.²³ As Oregon utilities continue to add more low- and zero-carbon resources to generate electricity, the associated carbon emissions from powering an EV will continue to go down.

Figure 2: Annual EV Emissions by Oregon Utility vs. Gasoline Vehicle²³



Emissions data is accurate as of 2018. Emissions from many utilities continue to decrease. ODOE will update this information annually. Bar chart emissions estimates are based on a 2020 gas-powered Hyundai Kona vs. a 2020 Hyundai Kona EV traveling 11,556 miles per year. All utilities in the "Average of Other Utilities" grouping have annual emissions less than 125 lbs CO₂e.

In addition to GHG reductions, driving EVs reduces other air pollutants that are harmful to human health, such as nitrogen oxide and particulates.²⁴

Most EV battery components can be recycled, but the separation of the different component materials is an expensive process. Most EVs are relatively new to the market and few vehicle batteries have reached the end of their useful lifetime, which limits the development of a battery-recycling market.²⁵ However, EV batteries are expected to last between 10-20 years as a power source for the EV, and after that, the batteries can be repurposed for other uses. Once they can no longer reliably power an EV, these batteries can be effectively used to do other tasks such as storing electricity to help manage the grid, or they can be used in homes and business as an electricity resource for backup power and be charged by the grid or on-site solar panels. When batteries are no longer viable energy storage devices, about half of their materials can be recycled, but the remaining 50 percent may still enter local waste streams.²⁶ In 2019, the USDOE Office of Energy Efficiency & Renewable Energy announced the Phase 1 Winners of a Battery Recycling prize, which encourages technologies that profitably capture 90 percent of all lithium-based battery technologies in the U.S.²⁷

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Technology Review: Fuel Cell Electric Vehicle (Hydrogen Cars)



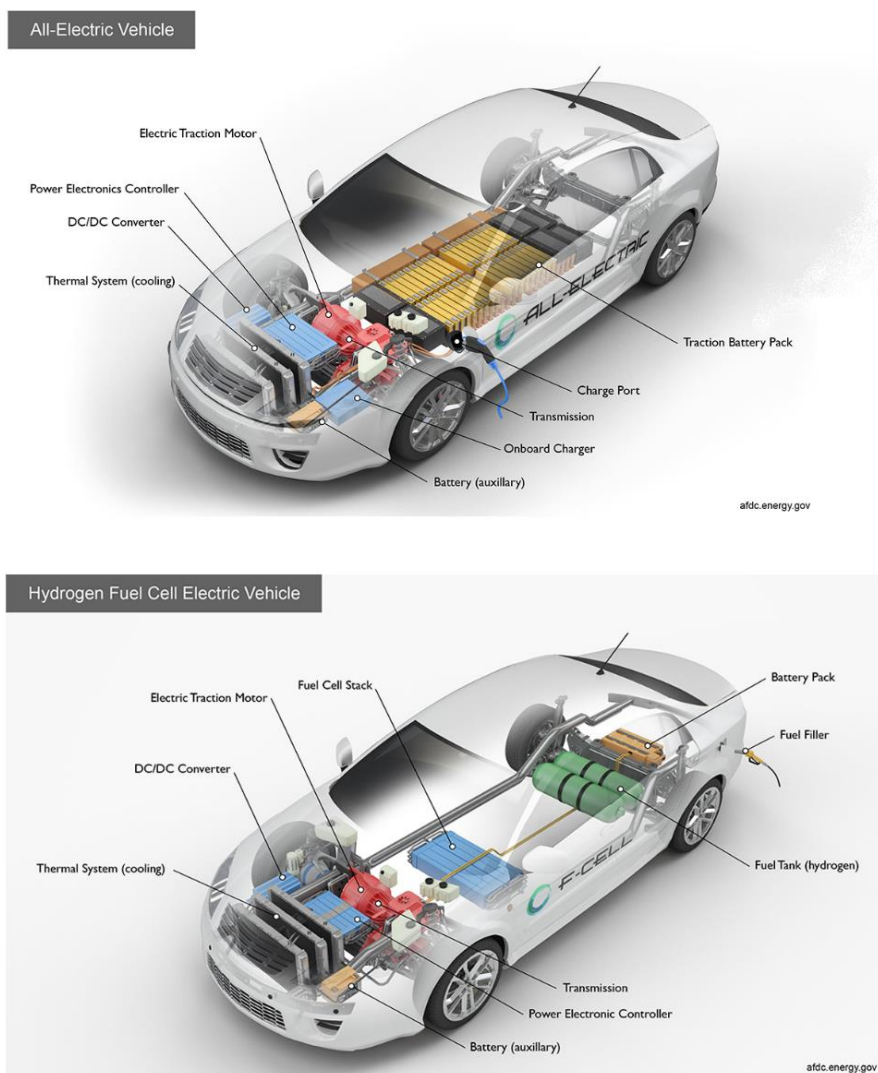
- Fuel cell vehicles registered in Oregon: 1
- Fueling facilities in Oregon: 0
- Fun fact: FCEVs emit only water from their tailpipes

Fuel cell electric vehicles (FCEV) or hydrogen vehicles, are similar to battery electric vehicles (BEV) because they are powered by an electric motor-based drivetrain. However, instead of a large pack of batteries as the source of the electric energy, FCEVs store energy as hydrogen in a fuel tank. Fuel cells use oxygen to split electrons from the hydrogen molecules to create the electric fuel that powers the vehicle, thus the name – Fuel Cell Electric Vehicles.

FCEVs have many of the same attributes as BEVs, including high torque (power directly to turn the wheels), quiet operation, and reduced emissions compared to conventional combustion engines. Unlike BEVs, FCEVs refuel at hydrogen fueling stations instead of plugging into a wall outlet or charger. FCEVs can refuel faster than most BEV recharging – about five minutes or less.¹ Where hydrogen fueling stations exist, FCEVs allow fast, centralized refueling like that of current gasoline-powered vehicles.

Like BEVs, FCEVs do not combust any fossil fuels and are therefore classified with BEVs as Zero Emission Vehicles. In fact, the chemical process of the fuel cell produces only heat and water.³ Regarding safety of hydrogen as a fuel, some of hydrogen's properties make it safer to handle and use than fuels commonly in use today (non-toxic and dissipates quickly).⁴

Figure 1: All-Electric vs. Hydrogen Fuel Cell Vehicle²



Trends and Potential in Oregon

Although three models of FCEV vehicles are available for purchase in the U.S., most of these are sold in southern California where the most robust hydrogen fueling infrastructure exists.⁵ Because there are not yet any hydrogen fueling stations in Oregon, the near-zero adoption rate of these vehicles is likely to continue in the near term. There may be greater near-term potential for FCEVs in the medium- and heavy-duty vehicle sectors. FCEVs offer the advantages of rapid refueling and lower overall vehicle weight compared to BEVs, which preserves the amount of payload a vehicle can carry. Due to these advantages and cost efficiencies in new fueling infrastructure for large fuel users, medium- and heavy-duty fleets may be some of the first vehicles in Oregon to adopt this technology.

FCEVs may also play a vital role in powering the freight sector. For example, the ultimate long-haul truck could have an electric drivetrain with both batteries and a fuel cell operating in tandem.⁶ This could enable the truck to have the range and fueling advantages of a FCEV but add the benefits of regenerative braking capacity and some efficiency by optimizing the two systems for complex conditions such as steep grades.

FCEVs may offer the potential to help Oregon utilize more renewable electricity generation resources that may otherwise be spilled (hydro) or curtailed (such as wind). Hydrogen gas can be created by large-scale electrolyzers, which use electricity to split water into hydrogen and oxygen. The hydrogen can then be stored as a fuel for various uses, including powering FCEVs.



Learn more about alternative fuels, power-to-gas, and other transportation information in [Energy by the Numbers](#), [Energy 101](#), [Policy Briefs](#), and [other Technology Reviews](#).

Barriers

The largest challenges to FCEV adoption are access to both vehicles and fueling stations. There are currently only three passenger FCEV models, all mid-size sedans: Toyota Mirai, Hyundai NEXO, and Honda Clarity. These vehicles have been adopted mostly in Asia and southern California, where fueling infrastructure exists. Oregon has no authorized auto dealers for these cars, and there is no public or private hydrogen fueling infrastructure. In contrast, there are more than 1,600 public electric vehicle charging stations in Oregon and dozens of models of vehicles for sale.

Cost is another area where FCEVs may need to improve before they are widely accepted in the marketplace. The 2020 Toyota Mirai has a price of

\$56,209, more than twice the \$26,155 price of a 2020 Toyota Camry Hybrid, which has similar attributes as mentioned above in Benefits of FCEVs.⁷ In addition to capital cost, FCEV operating costs are expected to be notably higher than BEV and standard gasoline models for the foreseeable future. California reports the price of hydrogen has remained fairly stable at \$16.50 per kg, which including the efficiency of hydrogen fuel cells is equivalent on a price per energy basis to \$6.60 per gallon of gasoline.⁸



FCEV Model: Toyota Mirai

Photo courtesy: Dein Nordrhein-Westfalen

Non-Energy Implications

Currently, about 95 percent of hydrogen in the United States is made from “cracking natural gas,” often as a byproduct of petroleum and fertilizer production. Therefore, while FCEVs have zero tailpipe emissions, the emissions associated with the extraction and production of the hydrogen fuel are approximately 230-260 grams/mile (as compared to 310-410 for small gasoline vehicles).⁹ As discussed above, hydrogen can also be created using electricity, including surplus renewably-generated electricity. Similar to electric vehicles charged with renewable electricity, when hydrogen is produced from a renewable resource such as hydro, solar, or wind, FCEVs can approach zero emissions.

FCEVs are roughly two to two-and-a-half times more efficient than gasoline powered cars, meaning given the same amount of energy, the FCEV would travel at least twice as far. So even when the hydrogen does not come from renewable sources, fuel cell cars can still cut emissions by over 30 percent.¹⁰ Depending on how it is made, hydrogen could also reduce lifecycle GHG emissions from the transportation sector when compared to gasoline vehicles, meaning FCEVs could help Oregon achieve its GHG emissions reduction goals.

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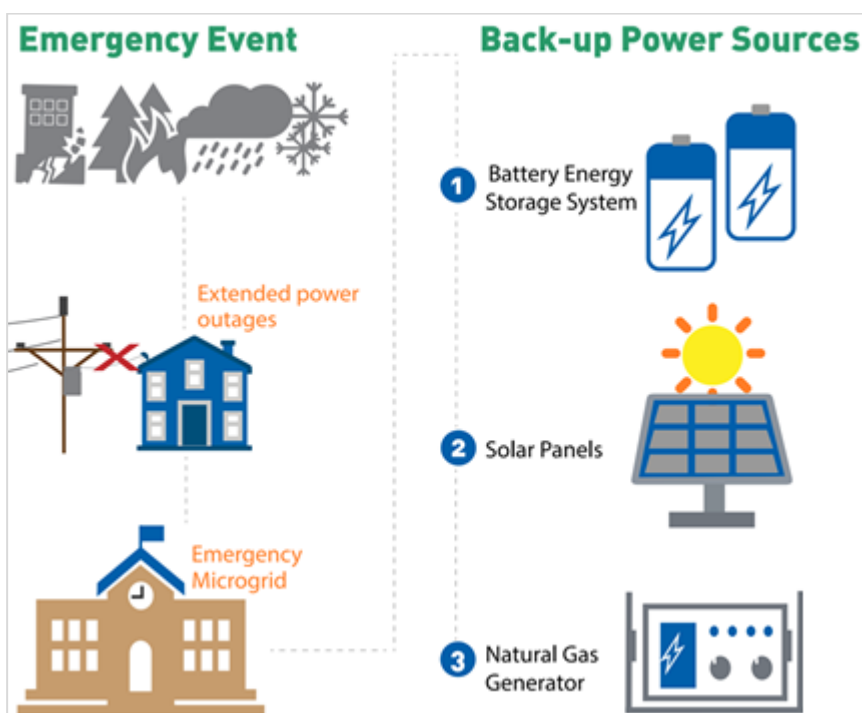
ⁱ “Cracking natural gas” is a chemical process using heat, pressure, and catalysts to break (or crack) long chain hydrocarbons into smaller chain hydrocarbons (often yielding excess hydrogen gas).

Technology Review: Resilient Microgrids

A microgrid is a group of interconnected end-use loads (ranging in size from a single home or building to an entire campus or even a city) and distributed energy resources (DERs) that act as a single controllable entity with respect to the larger electric grid. The key distinguishing characteristic of a microgrid is its ability to connect and disconnect from that larger grid so that it can operate either as a grid-connected resource or in island-mode to deliver power only to local loads.¹

A wide range of energy technologies can be used to power a microgrid, and additional benefits can often be achieved by combining complementary technologies (e.g., pairing solar with an existing generator to prolong a limited supply of stored on-site fuel). The most common systems incorporate diesel or propane generators, though increasingly solar and battery storage systems are used.² Installation costs for these systems can vary widely depending on overall size, technologies used, the efficiency of the building(s) involved, and whether the system is designed to power all regular loads or only the most critical loads when operating in island-mode.³ Figure 1 is adapted from a process flow diagram of a microgrid deployed by the Eugene Water and Electric Board to provide back-up power and to power a groundwater well during an emergency event.

Figure 1: Microgrid Process Flow (adapted from EWEB)⁴



Trends and Potential in Oregon

Microgrids in Oregon are employed in a wide range of situations today and most often rely on diesel or propane generators to provide emergency back-up power in case of a grid outage. These types of systems are especially common with certain types of commercial and industrial customers.

Meanwhile, rapid declines in the cost for solar and battery storage systems have led to an emerging interest in the deployment of microgrid systems based on these technologies, particularly at facilities that provide critical lifeline services to communities. Notable recent deployments in the state include EWEB's project at Howard Elementary School in Eugene⁵ and PGE's project at the Beaverton Public Safety Center.^{6 7} These types of microgrid projects can provide carbon-free power to support the continued delivery of critical lifeline services while avoiding the need to rely on imported liquid fuels or emit carbon.



Learn more about energy storage in fellow Technology Reviews.

Opportunities

Historically, many back-up generators have been installed by commercial and industrial customers that are uniquely sensitive to *any* potential disruption of power supply from the grid. Hospitals are one of the more common examples, where a routine two-hour grid outage caused by a severe storm could have significant adverse consequences for high-risk patients or sensitive medical equipment. Meanwhile, many advanced industrial processes (e.g., semiconductor manufacturing) are also susceptible to substantial adverse consequences resulting from even a minor grid outage. The following have been identified as the primary key benefits that microgrids can deliver:

- **Increased Power Reliability:** The traditional use for microgrids, usually utilizing diesel or propane generators, has been to provide increased power reliability for certain customers.⁸
- **Community Resilience:** Solar plus storage microgrid systems can provide significant community resilience benefits by supplying ongoing local power to critical community lifeline services during long-duration grid outages caused by high-impact, low-frequency events such as major seismic events, catastrophic wildfires, or cyberattacks.ⁱ
- **Local Clean Energy:** Solar-based microgrid systems can also help commercial and industrial customers⁹ or communities to meet policy objectives around local renewable energy targets, carbon reductions, or green jobs.

Technology Barriers

While propane and diesel generator-based microgrids have been in use for many decades, and solar based systems have emerged in recent years, there remain significant barriers to the deployment of microgrid systems to achieve the benefits identified above. The following are the primary barriers to the deployment of microgrid systems:

- **Grid Reliability:** Most utility customers already enjoy an incredibly high level of power reliability from standard utility service (typically reliable power is provided 99.99 percent of the time) at a comparatively low cost, and therefore the added reliability provided by microgrids may not be necessary or warrant the added cost in many cases.¹⁰
- **Cost:** Depending on the size of the microgrid system needed, up-front capital costs can still present a major barrier to deployment even as solar and storage costs decline. The National Renewable Energy Laboratory estimates the range of costs to be \$2 to \$4 million per megawatt of installed capacity for a typical industrial or community microgrid system. Actual costs vary widely depending on the size of a project (from several kW to tens of MW) and the type(s) of technology included (diesel generators, solar, battery storage, etc.).¹¹
- **Valuation Framework:** There is a lack of a standardized valuation framework (e.g., through market mechanisms or a standard tariff or contract) to value the benefits that microgrids can provide to maintain grid stability, shift electricity usage, and deliver community resilience.^{12 13}

ⁱ For a more in-depth exploration of community energy resilience and the contribution that microgrids can provide, see the [Oregon Guidebook for Local Energy Resilience](#).

Valuation of these benefits could help to offset costs.

Non-Energy Implications

Microgrids can have significant non-energy implications for Oregonians. For example, these systems can deliver community resilience benefits, as discussed above, to support system redundancy and the continued delivery of critical public services following a major event like an earthquake. These systems can also have environmental implications, including avoiding land use impacts by locating renewables on or in existing structures instead of on undisturbed land, or avoiding constituent air pollutants by displacing fossil generation.

Microgrids can support continued delivery of critical public services following a major event like an earthquake.

The deployment of microgrid projects can require significant up-front capital investments for generators, solar panels, battery systems, and microgrid controllers. As with many other technology-driven advancements in the energy sector, these up-front costs can result in inequitable access to the benefits provided by these systems.

Military Contributions to Energy Resilience

The Department of Defense must ensure energy resilience that supports mission assurance on our military installations. On March 16, 2016, DOD issued an energy resilience policy to address the risk of energy disruptions on military installations, and to require remedial actions to remove unacceptable energy resilience risks.¹⁴ The policy requires installation commanders and mission operators to plan and have the capability to ensure available, reliable, and quality power to continuously accomplish DOD missions from military installations and facilities.

The Oregon Military Department (OMD) is developing a statewide energy resiliency plan as directed by Department of Defense Instruction 4170.11, Installation Energy Management. OMD established mission-based priorities for energy and water sustainability and resilience at the outset of the program, and desired a streamlined and cost-effective approach to sustainability and resilience. OMD will closely coordinate its sustainability and resilience initiatives, streamlining multiple program requirements to gain efficiency. The department will systematically improve sustainability and resilience at its facilities and installations located throughout the state. The plan focuses on elements in five performance areas: energy, water, solid waste, hazardous waste, and other sustainability practices.

An energy resiliency plan has been written for Camp Rilea Training Site and the Clatsop County Emergency Operations Center.



Emergency Operations Center, Building 7022

This Energy Resiliency Plan addresses emergency planning requirements specific to Camp Rilea energy system(s).¹⁵ This plan addresses the electrical system, water system, wastewater system, and natural gas system. This plan satisfies the requirement to develop and maintain a preparedness plan contained in DoD Policy 92-1, "Department of Defense Energy Security Policy."¹⁶ The Camp Rilea ERP has been completed and fulfills nearly all the requirements of the IEWP guidance which was released during the course of the project. Furthermore, in 2012, Camp Rilea became the first military installation to achieve Net Zero water. Today, Camp Rilea continues to implement strategies to achieve Net Zero energy and Net Zero waste.

OMD is now better equipped to achieve its goals by integrating, for example, sustainability and infrastructure resiliency goals and standardizing emergency energy and water equipment and systems for OMD armories. The various measures being implemented will result in significant cost and energy savings.

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Resource Review: Marine Hydrokinetic Energy



Total MW Capacity in Oregon:
Facilities in Oregon:

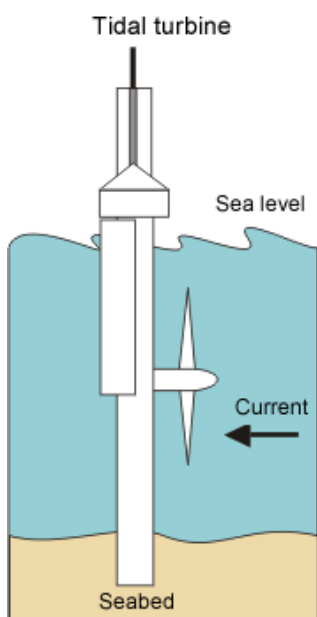
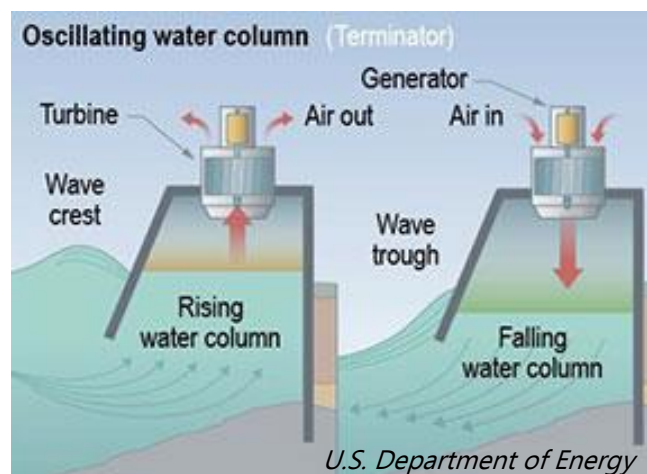
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2 test sites

Marine energy is an emerging technology resource. There is one grid-connected facility in the United States.

Marine hydrokinetic energy technologies capture energy from the movement of water in ocean waves, tides, and currents, or the heat energy in ocean waters, and then convert this energy into electricity.

Wave energy technologies extract energy from surface waves or from pressure fluctuations below the surface. An example of a wave energy technology is the oscillating water column, which uses the rise and fall of waves to push air through a turbine (pictured at right). Other wave technologies include overtopping devices, attenuators, and wave surge converters.¹

Wave energy technologies are still in early development. The largest operational grid connected facility in the world is the 3 MW Sotenäs plant in Sweden²; there are no large-scale grid connected wave energy facilities in the United States. The PacWave South facility near Newport, Oregon, with a potential capacity of 20 MW, will be the largest grid connected wave energy testing facility in the world and first of its kind in the United States when it becomes operational in 2022.³



U.S. Energy Information Administration

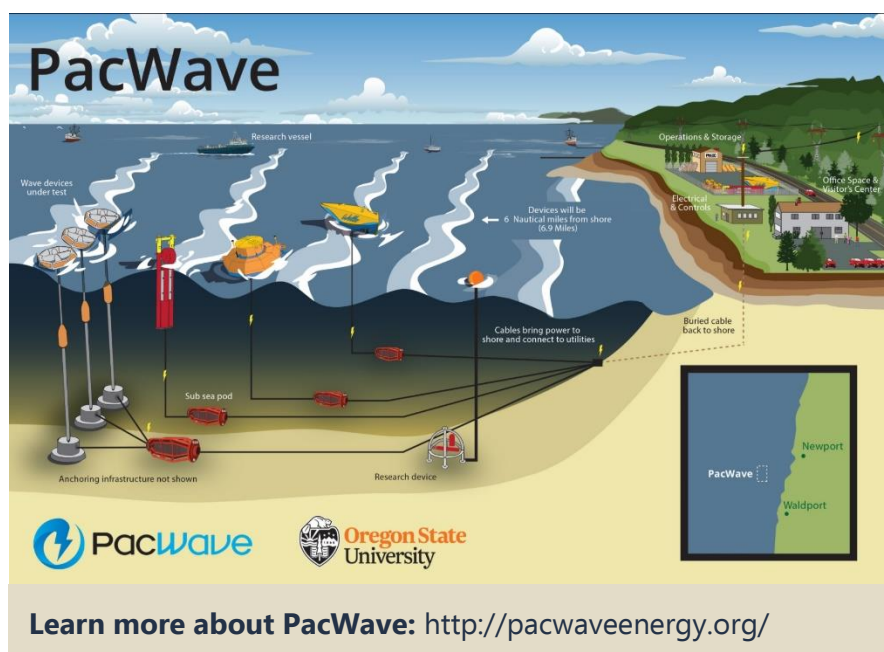
Tide and current energy technologies capture kinetic energy from the ebb and flow of tides or the flow of ocean currents and convert this energy into electricity. An example of a tidal or current technology is the axial flow turbine (pictured at left), which operates in a similar way to a wind turbine but uses water current rather than air current to spin a turbine. Other marine technologies include dams, tidal barrages, attenuators, and ocean thermal converters. Some tidal generation technologies have existed at a large scale for some time; tidal barrages (high-capacity dam-like structures that allow water into a reservoir at high tide then release water at low tide) have been in large scale use since the 1960s.⁴ The largest operational tidal facility in the world is the Sihwa Lake Tidal Power Station, a 254 MW tidal barrage facility in South Korea.⁵ The United States has no operational, grid-connected tidal energy facilities.

Trends and Potential in Oregon

While marine hydrokinetic energy is still an emerging technology sector, as costs decrease and demand for zero carbon-emitting resources continues to grow, marine hydrokinetic energy could become a prominent resource due to its unique characteristics. Like other renewables, marine hydrokinetic energy is variable in nature. However, due to the physics of the ocean, it is highly predictable and consistent in its variability. The predictable, consistent nature of marine hydrokinetic energy could make it a reliable complementary resource to other renewable technologies with less predictable and more variable generation. The combination of a diverse array of renewables including marine hydrokinetic energy could be a possible replacement for baseload generation.⁶ In addition, marine hydrokinetic energy sources have potential to supply local energy resilience and electric grid reliability benefits.

Opportunities

In the United States, the West Coast (and Oregon in particular) has some of the best marine energy resources.⁷ A 2011 study from Electric Power Research Institute estimated the potential of wave energy in the U.S. at 143 terawatt hours,⁸ and a recent National Renewable Energy Laboratory study identified Oregon as the highest-ranking region for long-term wave energy development in the United States.⁹ The Oregon coast also has available onshore transmission capacity, owned by the Bonneville Power Administration, that can transport electricity to serve load.¹⁰ A recent study estimated 2 GW of additional generation could be accommodated across the coast.¹¹



In addition to available resources, Oregon is a global leader in research and development of marine hydrokinetic energy technologies. Oregon State University leads these efforts as a member of the Pacific Marine Energy Center, a consortium of regional universities. OSU maintains two USDOE-funded test sites near Newport, Oregon.¹² The first, PacWave North, is an autonomous test site for small-scale, prototype technologies. The second site, PacWave South, due to become operational in 2022, will have capacity for grid connected testing

for projects totaling up to 20 MW in generation. A team of Oregon State University engineering graduates won the 2016 Wave Energy Prize from the USDOE for innovations in wave energy design that would improve the wave device's efficiency, which ultimately can lead to cost reductions for this type of technology.¹³ Finally, Portland-based Vigor Industrial constructed a 1.5 MW wave buoy electricity generator, which is currently deployed off the Hawaiian island of Oahu for testing.¹⁴

Barriers

While there is substantial potential for marine hydrokinetic energy in Oregon, these technologies face technical, economic, and policy challenges to commercial deployment at a large scale. Marine hydrokinetic energy technologies face significant engineering challenges associated with generating power from fluctuating, low-velocity waves and currents in a turbulent and corrosive ocean environment.¹⁵ They also face very high costs compared to other renewable and incumbent energy technologies. Research and development costs, as well as high capital and operating costs, drive up the overall expense of marine hydrokinetic energy.¹⁶ These costs may fall as the technologies mature. Another challenge for marine hydrokinetic energy lies in identifying and permitting facility sites, which requires technical knowledge and approvals across multiple state and federal agencies (additional details are provided in the Offshore Wind 101 in this report).¹⁷ The USDOE, in partnership with organizations like PMEC, are working to overcome these and other barriers through advancing research and development of marine hydrokinetic technologies and reducing barriers to technology deployment.¹⁸

Non-Energy Implications

Marine energy projects are zero-carbon emitting resources with a low lifecycle carbon footprint, comparable with other renewable resources.¹⁹ However, the deployment of marine hydrokinetic devices will inevitably involve contact with the physical marine landscape, flora, fauna, and existing marine activities like commercial fishing and tourism. Research to evaluate the effects of these interactions is ongoing and an important element to the technology's development and adoption.²⁰

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Technology Review: Carbon Capture and Storage

Carbon capture and storage is an emerging technology, capable of preventing a large amount of the carbon dioxide generated by a fossil fuel power plant from being released into the atmosphere. Carbon capture and storage (CCS)—also known as carbon capture and sequestration—is the process of:



1. Capturing or separating carbon dioxide from energy-related and industrial emission sources;
2. Transporting the removed CO₂; and
3. Storing the removed CO₂ in geological formations for long-term isolation from the atmosphere.¹

CCS is most suitable for large stationary emission sources of CO₂, including: coal and natural gas power plants, ethanol plants, cement plants, refineries, and iron and steel plants.² The CO₂ that is captured can be stored in deep onshore or offshore geological formations (e.g., saline aquifers). Using the same technologies developed by the oil and gas industry, storage of CO₂ has been proven to be technologically feasible.¹ When applying CCS to coal-fired power plants, CO₂ can be removed before or after combustion; for natural gas power plants, CO₂ is removed post-combustion.

Trends and Potential in Oregon

There are currently no large-scale projects (capturing more than one metric ton of carbon dioxide per year) in Oregon. There are currently six operating and five planned projects in the United States. Worldwide, there are another 13 operating projects and two planned projects.²

Energy experts and the Intergovernmental Panel on Climate Change (the leading body of climate scientists) have found that adding CCS to fossil fuel power plants is an important tool to help decarbonize and meet our greenhouse gas emission reduction goals, particularly to achieve net-zero emissions. While natural gas power plants can emit 50 percent less carbon dioxide than coal-fired power plants, they still release relatively high amounts of greenhouse gases, on average 0.92 pounds per kWh of electricity, compared to 2.21 pounds per kWh on average for coal plant.³ Adding CCS to natural gas plants can reduce GHG emissions by up to 95 percent.⁴ For example, the 40 MW Bellingham natural gas combined cycle power plant in Massachusetts demonstrated the technical viability of CCS. From 1991 to 2005, the facility captured 85 to 95 percent of the CO₂ that it would have otherwise released to the atmosphere.⁴ While Oregon's only coal plant closed in 2020 and therefore is not a candidate for CCS, the technology could be applied to Oregon's natural gas plants. Because Oregon utilities will still be able to source electricity from coal plants outside of Oregon until 2030,ⁱ CCS could be applied to those plants to reduce their GHG emissions and help Oregon meet its reduction goals.⁵

Adding carbon capture and storage to natural gas plants can reduce emissions by up to 95 percent.

ⁱ With one exception that would enable rate-basing costs for up to five years after the plant has fully depreciated. This would apply exclusively to the Colstrip plant in Montana.

Opportunities

CCS technology is currently commercially available for coal-fired power plants and natural gas combined cycle power plants, and engineers expect the market to expand within the next few years.^{4, 6} Significant technological advances, such as new CO₂ capture technologies, are expected to drive down current CCS costs for natural gas plants.^{7 8} The USE IT Act, passed by the U.S. Senate, would provide financial support and speed up federal approval for future CCS projects.⁹ Since 2018, the federal government has provided national tax credits through the Internal Revenue Code Section 45Q, and several states provide credits (e.g., California, Texas, Louisiana, Montana, and North Dakota).^{10 11}



Several natural gas CCS projects are being developed in the west, many of which are supported by external funding, such as from the U.S. Department of Energy. These include the Mustang Station of Golden Spread Electric Cooperative in Denver, Colorado and the California Resources Corporation's Elk Hills Power Plant in Kern County, California.¹² Companies are also identifying ways to "upcycle" captured CO₂ by turning it into carbon composites that can be used to make products—from wind turbine blades to bicycles—or by mixing it with industrial waste (such as coal ash) to make concrete.⁹

Barriers

The main barriers to CCS include: (1) the high capital and the operation and maintenance costs of CCS projects; and (2) the lack of a price on carbon to provide additional market value of CCS activities. Incentives, carbon prices, and/or a carbon cap-and-trade program would support wider deployment of CCS, which would help create economic efficiencies and potentially significant cost decreases. Without an incentive or carbon price signal there is not an economic reason to install CCS, which can currently add 25 to 90 percent to the capital cost of a project.² As of 2017, the estimated cost of CCS ranges from \$48 to \$104 per metric ton of CO₂.² In California, this is less than the cost of avoided CO₂ emissions under the state's carbon cap-and-trade market, which ranged from \$58 to \$121 per metric ton. Adding CCS has been estimated to add 2 to 5 cents per kWh to the cost of electricity.

Non-Energy Implications

The major societal and environmental benefit of CCS is the reduction of atmospheric levels of CO₂, while continuing to use fossil fuels to supply energy. Deployment of CCS supports a clean energy transition and can provide new job opportunities.⁴ The main risk posed by CCS is potential leakage of CO₂ during CO₂ capture and storage. Ensuring that CO₂ is being captured and stored properly is necessary to achieve the CO₂ sequestration benefits offered by CCS.

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Technology Review: Power-to-Gas



- Established technology in Europe; emerging in the U.S.
- NW Natural and Eugene Water & Electric Board and Bonneville Environmental Foundation are evaluating an 8.5 MW project opportunity in Oregon.
- Douglas County PUD in Washington is planning a 5 MW facility^{1 2}

Power-to-gas (PtG) describes the process of using electricity to split water into hydrogen and oxygen to produce hydrogen gas (H₂) that can be used as a combustion fuel like natural gas or in a number of industrial processes. The hydrogen can also be mixed with carbon dioxide via a process called methanation to produce synthetic natural gas that can serve as a direct replacement for fossil-based natural gas. Hydrogen is currently used in a number of industrial processes – it is a fundamental input for manufacturing ammonia, which is then used for fertilizer production; it is used to process crude oil into refined fuels, like gasoline and diesel; and it is also used as a “reductor agent” in the metallurgic industry.³

Most of the hydrogen produced in the world today is derived from steam reformation of fossil-based natural gas. Not only is PtG is an emerging alternative to the reformation of natural gas to produce hydrogen, but numerous potential end uses for hydrogen are emerging in the power and transportation sectors.

Power-to-gas works by using a decades-old technology called an electrolyzer, which uses electricity to split water into its hydrogen and oxygen components. The two most common types of electrolyzers are alkaline electrolyzers, which have been in use since the 1920s, and polymer electrolyte membrane (PEM) electrolyzers, introduced in the 1960s.⁴ PEM electrolyzers offer benefits over alkaline units such as operating range and size, but they have a higher capital cost and a shorter lifetime.⁵

Natural gas reformation produces carbon dioxide as a byproduct, the primary greenhouse gas (GHG) causing climate change, and the hydrogen produced from this process is sometimes referred to as “grey” hydrogen. Electrolysis results only in hydrogen, oxygen, and heat, although the type of electricity used

to power the electrolyzer may have other associated emissions (e.g., if natural gas or coal power is used). When the electrolysis is powered by renewable electricity, however, the resultant hydrogen is also considered renewable, in most cases greenhouse gas emissions-free, and is often referred to as

Figure 1: Alkaline Electrolyzer Illustration⁴

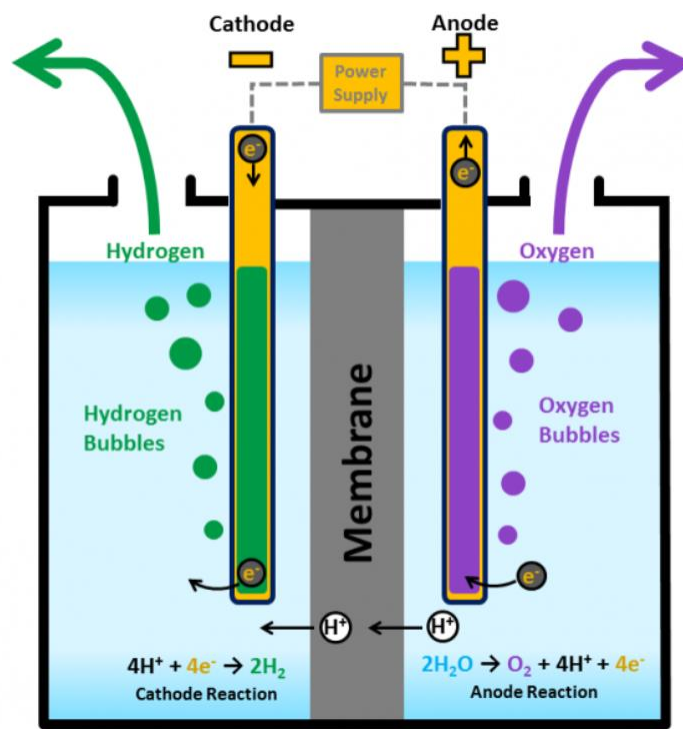
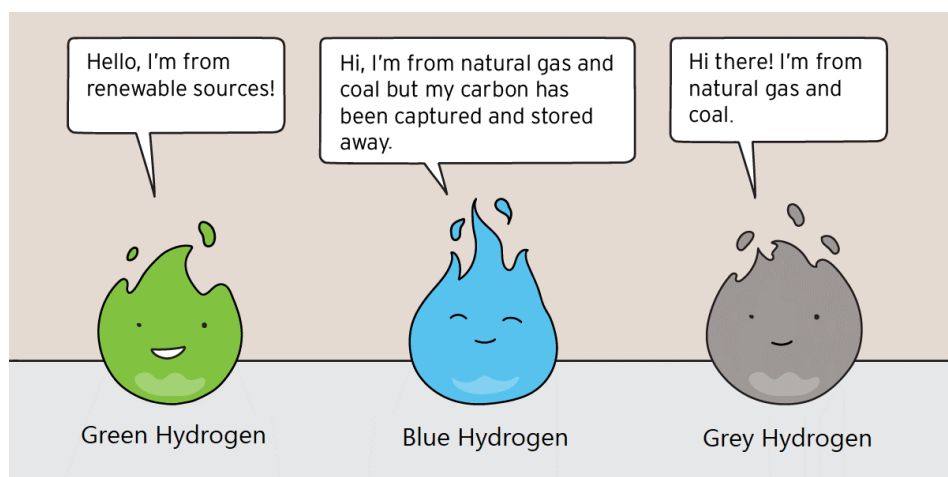


Figure 2: Green, Blue, and Grey Hydrogen Explained⁹

“green” hydrogen. “Blue” hydrogen is produced using methane reformation followed by carbon capture and sequestration⁶ (see the Carbon Capture and Sequestration Technology Review), which reduces the overall GHG emissions.^{7 8} Once created, hydrogen can be stored as a compressed gas or used to charge fuel cells, either of which can be used to generate

electricity at a later time, injected into the natural gas system for direct fuel use, or even as a fuel for a wide variety of vehicles.

Trends and Potential in Oregon

PtG electrolyzers can be built wherever there is electricity available to power the equipment and an adequate source of water. One of the biggest barriers to wider deployment of PtG in Oregon and in the U.S. is the cost. Hydrogen produced using PtG electrolyzer technology is much more expensive than hydrogen produced via natural gas reformation, and the two biggest costs are the electrolyzer and the electricity used to power the process. For this reason, PtG is most cost effective when the price of the electricity used to power the process is very low. For example, in California, where solar generation increasingly exceeds demand in the middle of the day during the mild weather of the spring months, electricity providers sometimes sell this power at zero, or even negative, cost. In some cases, they are even required to curtail, or turn off, solar output when there is surplus power relative to demand. The Pacific Northwest currently has more limited circumstances when this type of low-cost, or zero-cost, surplus electricity is available, mostly during the spring season when wind and some thermal generation may be curtailed.¹⁰

While still expensive, the costs of electrolyzers are falling – costs for alkaline electrolyzers made in North America and Europe dropped more than 40 percent between 2014 and 2019.¹¹ Still, to compete with the costs of producing hydrogen from the reformation of natural gas, the manufacture of electrolyzers would need to continue to scale up and costs would need to decline further. The U.S. Department of Energy indicates that to become cost competitive, the cost of producing green (or blue) hydrogen must be lowered by a factor of four.¹²

Another costly consideration is storage and transportation of hydrogen. While experts expect that hydrogen could displace between 5 and 15 percent of natural gas in a natural gas pipeline,¹³ volumes greater than that would require new, separate pipelines and other infrastructure. For hydrogen not bound for a pipeline, it must be stored and transported, both of which can add considerable cost. Hydrogen stored as a gas is typically compressed and then placed in high-pressure tanks, whereas hydrogen stored as a liquid requires cryogenic temperatures. The current cost of liquified hydrogen storage can exceed the cost of producing the hydrogen¹⁴ and the U.S. Department of Energy's

Hydrogen and Fuel Cell Technologies Office is focused on addressing the challenges associated with cost effective high-density storage of hydrogen.¹⁵

There are no PtG projects currently operational in Oregon, though there is interest from utilities such as NW Natural and Eugene Water and Electric Board, which have teamed up with Bonneville Environmental Foundation to develop a PtG pilot project in Oregon. The project is still in the conceptual phase, but current plans are for an approximately 8.5 MW electrolyzer located in Eugene, sited near industrial facilities capturing CO₂, which would be used to methanate the hydrogen before injecting it into the natural gas pipeline.¹⁶ Other electric utilities have also shown interest in PtG and hydrogen; for example Portland General Electric's 2018 deep decarbonization study included a scenario with over 2,000 MW of hydrogen electrolysis by 2050 as a way to consume excess renewable electricity to produce decarbonized pipeline gas, which would play a role in decarbonizing the transportation and direct fuel use sectors.¹⁷

Methanation is a process where hydrogen and carbon dioxide – potentially CO₂ that was captured from other power generation or industrial processes – are combined to create methane, which is freely interchangeable with natural gas as a fuel.¹⁹

A key benefit of PtG is that it can play a role in the decarbonization of the direct fuel use and transportation fuel sectors. Hydrogen can be used in some applications as a direct substitute for natural gas, such as injecting into a natural gas pipeline (up to 15 percent of the volume of gas in the pipeline).¹⁸ It can also be used to create synthetic natural gas through "methanation," a process where hydrogen and carbon dioxide – potentially CO₂ that was captured from other power generation or industrial processes – are combined to create methane, which is freely interchangeable with natural gas as a fuel.¹⁹ By displacing natural gas, hydrogen can help to reduce GHG emissions from sectors that are difficult to decarbonize, such as transportation, stationary fuel use, and heavy industry.



For more on reducing emissions from other sectors, energy storage, and power-to-gas technology, see the Technology Reviews and Policy Brief sections of this report.

PtG is also a potential end use for excess renewable electricity generation that would otherwise be curtailed or shut off. While Oregon currently has limited amounts of curtailed renewable energy, there is potential for increasing amounts in the future. In PGE's 2018 deep decarbonization study,²⁰ the utility indicated that planning and policy choices made on how to decarbonize all energy sectors may lead to increased amounts of excess renewables generation, which

could be used by PtG or other end uses, such as storage applications or demand response resources. PtG applications could soak up that excess electricity, thereby providing a storage benefit to renewable electricity providers or as a resource for direct use or transportation fuels. For example, Douglas County Public Utility District in Washington state has partnered with Cummins to build a 5 MW PEM electrolyzer that will be able to use excess electricity from one of the PUDs' hydropower dams to create green hydrogen. The project is expected to be operational in 2021.²¹

BloombergNEF estimates that scaling up the hydrogen economy globally will require an estimated USD \$150 billion in subsidies through 2030. There are few policies in place to support PtG and hydrogen development in the U.S. Thus, while the technology used in PtG is established and there are

few technical barriers to further commercialization, the larger challenge of cost to develop PtG at scale is significant. Low- or zero-cost electricity is likely a requirement to make the technology cost effective in many, though not all, applications. The opportunities for this are currently limited; lacking subsidies or incentives, future availability will largely depend on the degree to which renewable electricity is added to the system.

Non-Energy Implications

One of the most significant non-energy implications of PtG is that it can reduce GHG emissions across multiple sectors. Green hydrogen can replace grey hydrogen created using fossil fuels (either through reformation or electrolysis powered by fossil electricity) as well as supplement or even replace direct-use natural gas and petroleum in buildings, replace gasoline and diesel fuel in the transportation sector, and in heavy industry applications. According to a recent study by the Fuel Cell and Hydrogen Energy Association, by 2050 PtG and hydrogen could reduce U.S. GHG emissions by 16 percent while also reducing NOx (nitrogen oxides) emissions by 36 percent and providing 3.4 million jobs.²²

**Energy jobs:
PtG and hydrogen tech
could reduce GHG
emissions and provide 3.4
million jobs.**

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