ENERGY RESOURCE & TECHNOLOGY REVIEWS

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 COVID-19 pandemic 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.

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. Technologies like electric vehicles 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 to address in 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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Energy Resource & Technology Review: Electricity-Generating Technologies

Timeline

- **1907** – The 6.2 MW Faraday hydropower facility on the Clackamas River opens. The facility remained in operation until 2019 when it was retired.[1]
- **1911** – The 6.6 MW River Mill hydropower facility on the Clackamas River opens. Today, it is the oldest electricity generator still operating in Oregon.[1]
- **1938** – The first two generators at the Bonneville Dam on the Columbia River are brought online. Together they generate over 100 MW of power.[1]
- **1949** – The first wood waste biomass facility begins operation in Springfield.[1]
- **1953** –The first generator at the McNary Dam is brought online. Four additional generators follow in 1954, bringing the total capacity at McNary to 350 MW.[1]
- **1957** – The first four generators at The Dalles Dam are brought online.[1]
- **1968** – The first four generators at the John Day Dam are brought online. Additional generators brought online through 1971 bring the total capacity at John Day to 2,160 MW, Oregon's largest.[1]
- **1974** – The Beaver natural gas facility in Columbia County, Oregon's first fossil fuel power plant, is installed.[1]
- **1980** – The 642-MW Boardman Coal facility begins operations.[1]
- **1998** – The 25-MW Vansycle wind facility in Umatilla County, Oregon's first commercial wind farm, begins operating.[1]
- **2011** – The Bellevue and Yamhill solar facilities, Oregon's first utility scale solar facilities with a combined capacity of 2.6 MW, begin operation in Yamhill County.[1]
- **2012** – The 4.4-MW Outback solar facility near Christmas Valley becomes the first utility scale solar project in Eastern Oregon.[1]
- **2017** – The Solar Star Oregon II facility near Prineville becomes the first solar facility in Oregon to exceed 50 MW of nameplate capacity.[1]
- **2020** – The Boardman coal facility closes operations.[1]
- **2020** – The first 300 MW of wind capacity comes online at the Wheatridge facilities, which combine wind, solar, and battery storage in Morrow County. An additional 50 MW of solar and 30 MW of battery storage capacity are added in 2022.[1]

Electricity Generation in Oregon

There are **459 utility-scale generators in Oregon** that provide electricity for homes and businesses throughout the Pacific Northwest.[1] These facilities use a variety of resources, including hydroelectric, natural gas, wind, solar, biomass, municipal waste, landfill gas, and geothermal resources. **Hydropower makes up 40 percent** of the electricity generated in Oregon, followed by natural gas at 21 percent and wind at 11 percent.

Are Batteries an Electricity Generation Technology?

While batteries do not directly generate electricity, they provide electricity to the grid by acting as a pass-through using stored energy that was previously generated by some other resource like wind, solar, or natural gas. Batteries, or other energy storge technologies such as pumped hydro, are charged during times of surplus generation on the grid and later discharged when needed. Charging and discharging energy storage devices results in some of the energy being lost. These losses are known as round-trip efficiency losses and are improving as battery technologies advance.

Figure 1: Total Technology Nameplate Capacity (MW) of Electricity Generation Facilities in Oregon[1] [11]

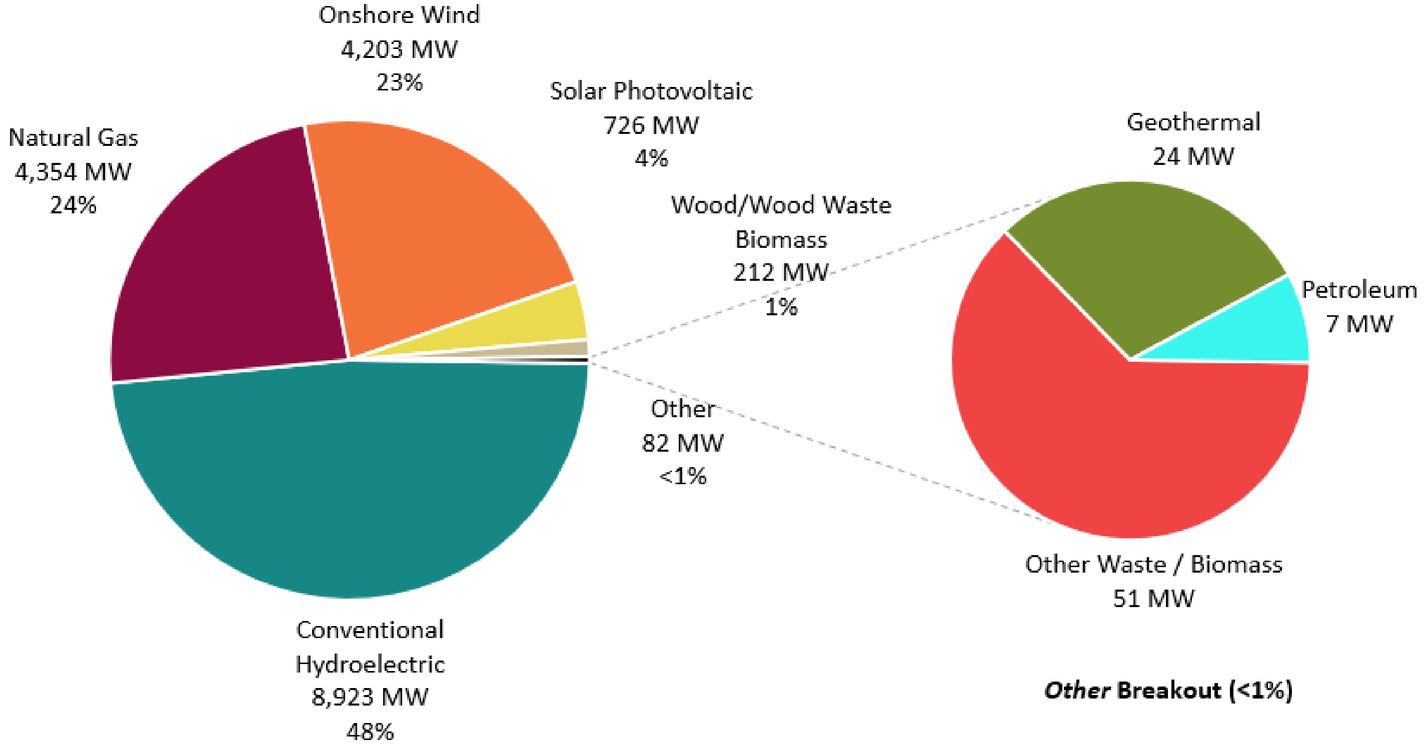
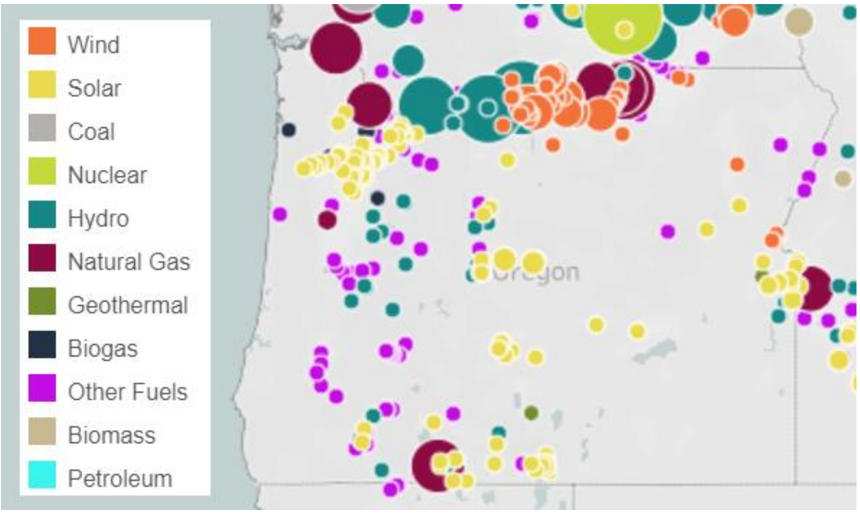


Figure 2: Electric Generation Sources in Oregon



Dot sizes correspond to the amount of energy generation, not physical size of facilities.

Megawatts, Megawatt-hours, and Average Megawatts

Megawatts. This section describes facilities according to their nameplate capacity, which is expressed in units of megawatts. Megawatts of nameplate capacity describes the amount of power a facility can generate under peak operating conditions. It is an indication of the size of a facility but not necessarily the amount of energy that it generates over the course of a year. For example, some natural gas facilities are referred to as "peakers" and only operate when needed to meet peak demand on the grid. Similarly, solar facilities may have large nameplate capacities but only operate during the daytime. To see the annual electricity consumption and generation from different facility types in Oregon see the *Energy by the Numbers* section of this report.

Megawatt-hours. Megawatt-hours (MWh) is a measure of energy produced by a facility. If a facility with a power rating of one megawatt operates continuously for one hour, it will generate one megawatt hour of energy. One megawatt-hour of electricity is about how much a typical Oregon home will consume in a month.

Average Megawatts. Like megawatt-hours, an average megawatt (aMW) is a unit of energy. If a facility with a power rating of one megawatt operates continuously, 24 hours a day, for a whole year, it will generate one average megawatt of energy. Because there are 8,760 hours in a year, an average megawatt is equal to 8,760 megawatt-hours

Electricity generation in Oregon has evolved over the last century from a largely hydropower-based system, to one that included more coal and natural gas, followed by more carbon-free resources like wind and solar. From 1911 to 1949, hydroelectric dams were the sole source of electricity in Oregon, with new or upgraded generators added at existing dams to increase electricity generation over the years. The first biomass generation facility was added in 1949, and the first natural gas facility in 1974. In 1980, the Boardman power plant began operation in Morrow County, becoming the only coal fired electricity generator in Oregon. By the time the 585 MW Boardman coal plant was retired in 2020, there was already 3,772 MW of wind capacity operating in Oregon. Today, many different types of generation resources in Oregon contribute to the state's electricity resource mix. Figure 3 shows a timeline of electricity generation facilities in Oregon.

From 1911 to 1949, hydroelectric dams were the sole source of electricity in Oregon

Figure 3: Total Nameplate Capacity of Electricity Generators in Oregon – 1911-2019

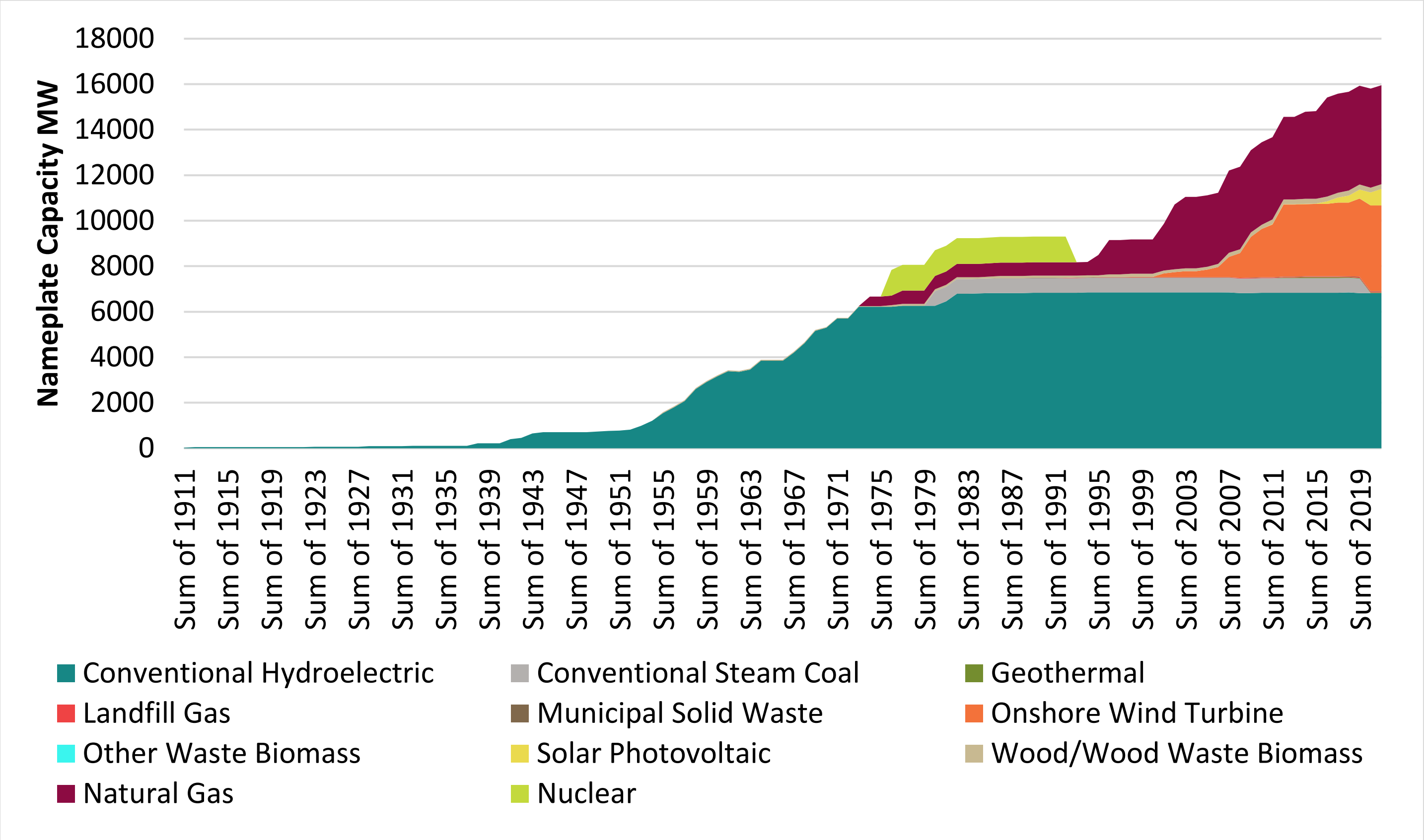


Table 1: Oregon Generator Type, Capacity, Generation, and Exports[1] [11]

Generator Type	Nameplate Capacity (MW, 2021)	Generation (MWh, 2020)	Exports (MWh 2020)
Conventional Hydroelectric	8,923	31,920,643	10,972,309
Natural Gas	4,354	19,019,913	7,447,738
Onshore Wind	4,203	8,777,254	5,002,338
Solar Photovoltaic[i]	726	1,077,902	179,671
Wood/Wood Waste Biomass	212	631,206	413,898
Other Waste / Biomass	51	373,279	174,546
Geothermal	24	192,101	144,455
Petroleum	7	2,339	0
Coal[ii]	0	1,630,145	0

Trends and Potential

In 2021 the Oregon Legislature strengthened the state's clean energy goals, which will transform the makeup of energy facilities in Oregon. House Bill 2021 requires electric companies to reduce the greenhouse gas emissions associated with serving retail electricity customers by 80 percent by 2030

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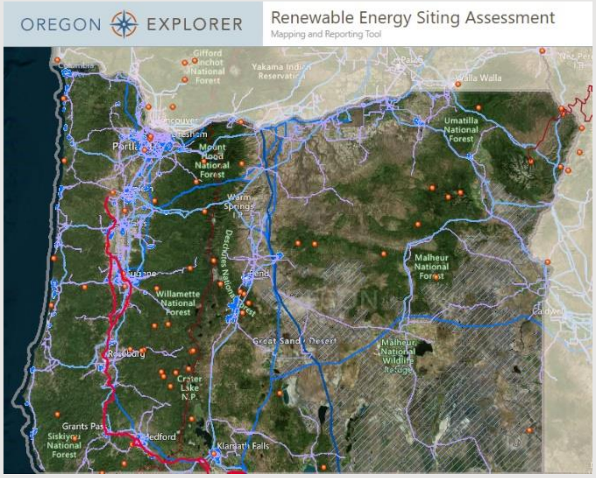
[i] EIA data contains 726 MW of utility-scale solar in Oregon through 2021. There is an additional 156 MWdc of net metered installations in Oregon that are not reflected in the generation or export data.

[ii] The Boardman coal plant closed in October 2020. This results in zero nameplate capacity in 2021 but significant generation in 2020.

and 100 percent by 2040 from a 2010-2012 average baseline.[2] Meeting this standard will require unprecedented development of renewable energy facilities over the next 20 years. Although PGE and PacifiCorp, with oversight from the OPUC, will determine the specific mix of electricity-generating technologies to meet their customers' demands, one 2021 study identified the need to develop 10,000 MW of new solar capacity and 20,000 MW of new offshore wind capacity to meet the state's 100 percent carbon free electricity target.[3] PGE and PacifiCorp are required to submit Clean Energy Plans (CEPs) to the OPUC.

The Oregon Renewable Energy Siting Assessment: A Resource for Renewable Energy Development



The Oregon Renewable Energy Siting Assessment (ORESA) project developed educational resources for users to explore data and information on renewable energy development in Oregon. The ORESA project goals were to develop baseline data and gather stakeholder perspectives to create a collection of information to support communities, policy makers, energy developers, tribes, and government agencies interested in potential projects or renewable energy policies. The key deliverables of this project (below) were developed to encourage early coordination and notification among cross-sector stakeholders, and to promote a better understanding of potential opportunities and challenges.

The ORESA Report summarizes key findings, data, stakeholder perspectives, and analysis on renewable energy siting opportunities across the state. The report acknowledged that renewable energy development to meet Oregon's clean energy and climate goals presents both opportunities and challenges. Sustainably accessing and developing renewable energy while avoiding or mitigating conflict with other important values requires careful consideration of a multitude of factors and acknowledgement that there may be trade-offs across these factors.

The Mapping and Reporting Tool includes data on renewable energy, military training areas, economic development, land use, natural and cultural resources, and other important considerations. Users can interact with and browse spatial data, create site-specific reports to support early coordination on potential projects, and review additional information such as regulatory process maps, reports, and tools that are not reflected in the spatial data.

The ORESA project was funded through a $1.1 million U.S. Department of Defense Office of Local Defense Community Cooperation grant awarded to the Oregon Department of Energy, working with the Department of Land Conservation & Development and Oregon State University's Institute for Natural Resources.

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

Wind and solar generation are expected to meet much of the Pacific Northwest's future energy demands. Wind is already a proven resource with more than 4,000 MW of in-state capacity online as of 2021 (for a complete accounting of energy consumed and generated in Oregon see the *Energy by the Numbers* section of this report). Utility-scale solar generation is rapidly increasing as well, rising from less than 100 MW in 2016 to 726 MW in 2021. Storage options are also becoming more prevalent, especially when combined with renewable generation because it can help store the energy from these resources at times when their full generation capacity is not needed. Oregon's Energy Facility Siting Council approved the state's first solar application, for the 75-MW Boardman Solar facility, in 2018. There are now more than 800 MW of solar approved with more than 2,500 MW under review.

Hybrid renewable energy facilities, which use more than one type of renewable energy resource, are also increasingly being planned and developed in Oregon. The Wheatridge renewable energy facilities in Morrow County, have combined 300 MW of wind, 50 MW of solar, and 30 MW of battery storage.[4] In February 2022, the Council approved the Obsidian Solar Center in Lake County, which will have a peak generating capacity of 400 MW and may include up to 50 MW of battery storage.[5]

Wheatridge Energy Facilities, Morrow County
Photo: Portland General Electric

Oregon's clean energy targets will affect the electricity generation resource mix in Oregon and other western states. Natural gas is currently the second largest electricity generation resource in Oregon, including 13 facilities with a combined generating capacity of 4,354 MW. These facilities generated a third of the electricity in Oregon in 2020 (for a complete accounting of energy consumed and generated in Oregon, see *Energy by the Numbers*). House Bill 2021's clean electricity requirements mean these facilities will no longer be able to serve Oregon markets beginning in 2040. The bill also prohibits the building of any new fossil fuel facilities or expansions of existing facilities that would result in a significant increase in carbon emissions. Oregon's natural gas plants may continue to operate beyond 2040 by exporting electricity to neighboring states that do not have the same clean energy targets as Oregon.

Energy storage facilities are also expected to play a large role in Oregon's energy future to help integrate increasing variable wind and solar resources. One of the challenges with resources like wind and solar is the variability in electricity generation output depending on the weather, the season, and time of day. One solution to variability is to install systems that can store surplus energy when it is plentiful and make it available when generation is limited or during periods of high demand. Oregon's Energy Facility Siting Council has approved applications for more than 400 MW of battery storage, with over 2,300 MW under review. In Klamath County, the proposed 400 MW Swan Lake pumped hydropower facility, which is under federal permitting jurisdiction, would use surplus electricity to pump water into an elevated reservoir, which could then be released through turbines to generate energy when needed. For more information on Electricity Storage, see the Electricity Storage Resource & Technology Review.

A diverse portfolio of energy generation facilities will be needed to meet the seasonal variation in Oregon loads. Batteries and pumped hydro facilities help solve short-term variability issues, but there are also longer-term seasonal variations in Oregon's renewable resources. Onshore wind resources are strongest in the spring but may be greatly diminished in late summer and mid-winter – on some days, production drops to zero. In the Willamette Valley, solar output is more than four times higher in July than in December. Seasonal variations may be partially addressed through a diverse regional portfolio of facilities. New technologies, such as floating offshore wind turbines and ocean wave energy generators, can provide more reliable winter generation and are being explored by utilities and electricity planners as long-term options to help balance renewable electricity generation in the region. Upgrades to electricity transmission infrastructure will be needed to deliver energy from remote generation facilities to load centers. Long-term storage, such as hydrogen generation and storage, may also play a role in seasonal variation. These new technologies and existing clean generation assets, like geothermal, will help Oregon meet clean electricity targets.

Beyond Energy

The development of any electricity generation resource has environmental, social, and economic effects on local and global communities. The effects may be positive, negative, or a combination of these, and their relative weight may be seen and felt differently by different communities. Positive effects include local construction and operations jobs, increased local property tax revenues, and in some cases community control of energy resources. Negative effects have traditionally included degradation to local air quality, other health and safety hazards associated with siting energy facilities near Oregon communities, and end of life recycling and disposal issues. Disadvantaged communities are often most affected by local environmental and economic effects of facility siting decisions. Additional financial risks are associated with investments in new facilities and technologies that may not result in good value for utilities and ratepayers.

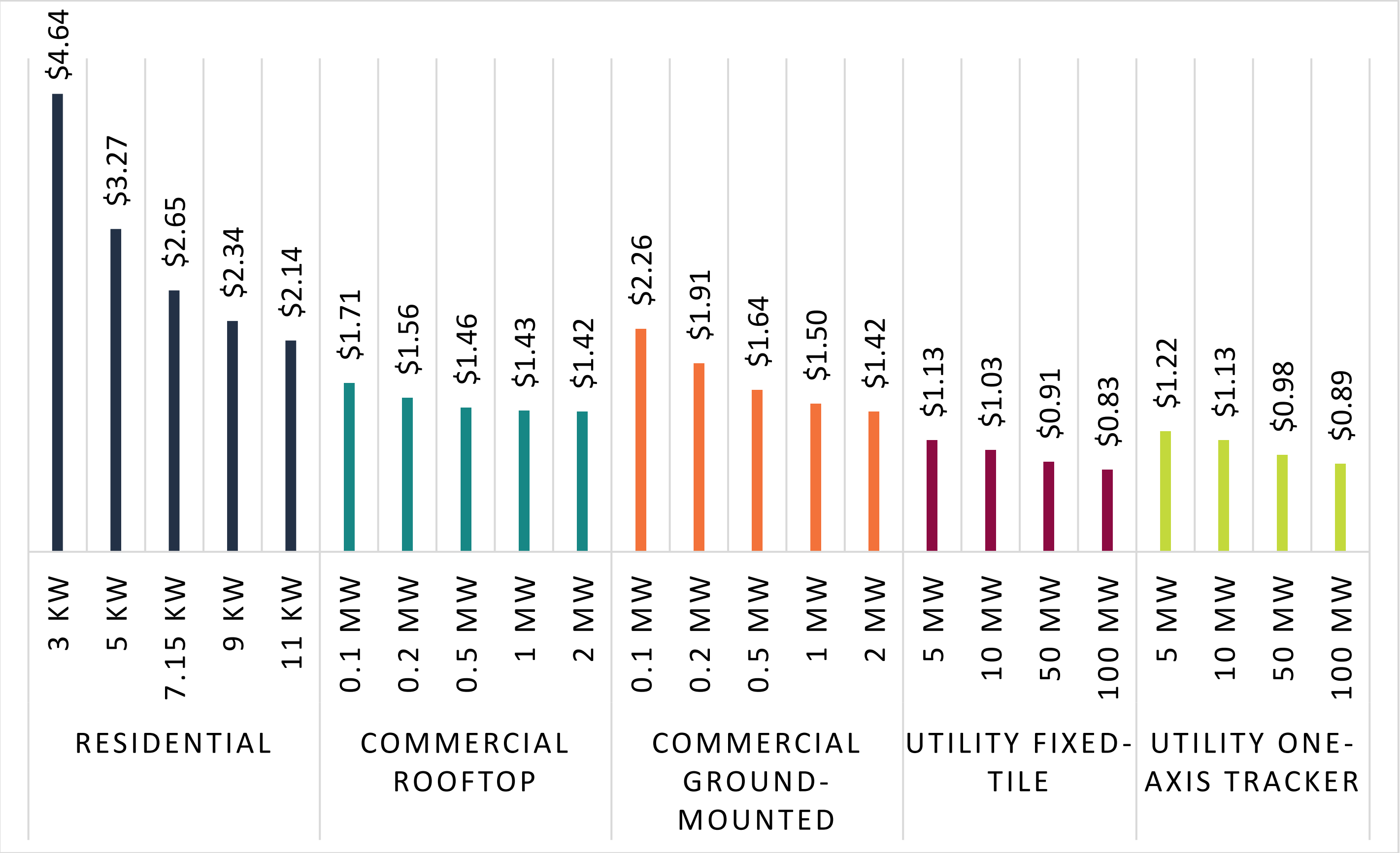
All electricity generation projects require some amount of land or water area for development. Some renewable resources such as hydropower, wind, and solar can have large geographic footprints. New transmission infrastructure, necessary to connect new resources to the grid, also has land requirements. Renewable energy facilities are not unique in requiring large development footprints. Extraction of coal and natural gas have significant land use impacts where they are extracted, transported, and refined. These negative effects are borne by local, often rural communities, many of which are located far from the large load centers that use most of the energy created.

Clean energy technologies can reduce the state's greenhouse gas emissions and demonstrate Oregon's commitment to mitigate climate change. Climate change directly affects Oregon communities by increasing the frequency and severity of extreme weather-related events, including the devastating wildfires of 2020, the unprecedented heat wave in June 2021, and the severe ice storms in February 2021. According to the National Atmospheric and Oceanic Administration, wildfires in Oregon resulted in an estimated $2 to $5 billion in damage costs in 2020[6] and $500 million to $1 billion in 2021.[7] Droughts in Oregon resulted in as much as $100 million in damages in 2020 and $100 to $250 million in 2021. Meanwhile, winter storms caused an estimated $250 to $500 million in damages in 2021.[7] Oregon may only represent a small percentage of global emissions, but combined with other states and countries taking action, greenhouse gas reductions can add up.

Distributed energy resources, like rooftop solar and residential battery storage, can reduce land impacts associated with large ground mounted systems but are higher in cost than utility-scale solar and storage projects. Chart 3 below demonstrates how solar costs are affected by economies of scale for residential, commercial, and utility-scale solar projects.[8]

Local solar and storage microgrids could improve community emergency preparedness by providing an electricity resource for critical operations when the main power system is not operating. Many of these projects are currently funded by home and business owners or local communities that provide much of the up-front capital costs. Programs like ODOE's Solar + Storage Rebate Program and the Community Renewable Energy Grant Program offer incentives that help offset this cost. Even with higher incentives, many low-income Oregonians may not have the financial resources to invest in these renewable projects.

Figure 4: Cost Per Watt DC of Solar Installations by Sector and Project Size (Derived from the NREL U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks: Q1 2021)[8]



Alongside economic, environmental, transmission, and geographic constraints, resource capacity constraints may also be an important factor in determining Oregon's future access to new electricity generation technologies. Presently, manufacturing of electricity generation technologies is highly dependent on foreign mineral resources. Copper and aluminum are critical resources needed to build solar panels, wind turbines, transmission lines, and batteries. Nickel, lithium, and cobalt are all essential to current battery technologies.[9] Most of these minerals have limited mining or refining operations in the U.S., and many of the countries that support the development of these resources do not have protections for communities and workers.[10] Where protections exist, they may not be applied consistently. The growing demand for these minerals is already prompting more international cooperation to ensure supply chains and policies address social and environmental equity, but continued efforts in this area are needed to help address these issues. Without domestic mines and refining operations, the U.S. will have to continue to rely on foreign materials to meet the demand for resources, and be subject to foreign environmental and labor practices.[10]

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Energy Resource & Technology Review: Transportation Fuels

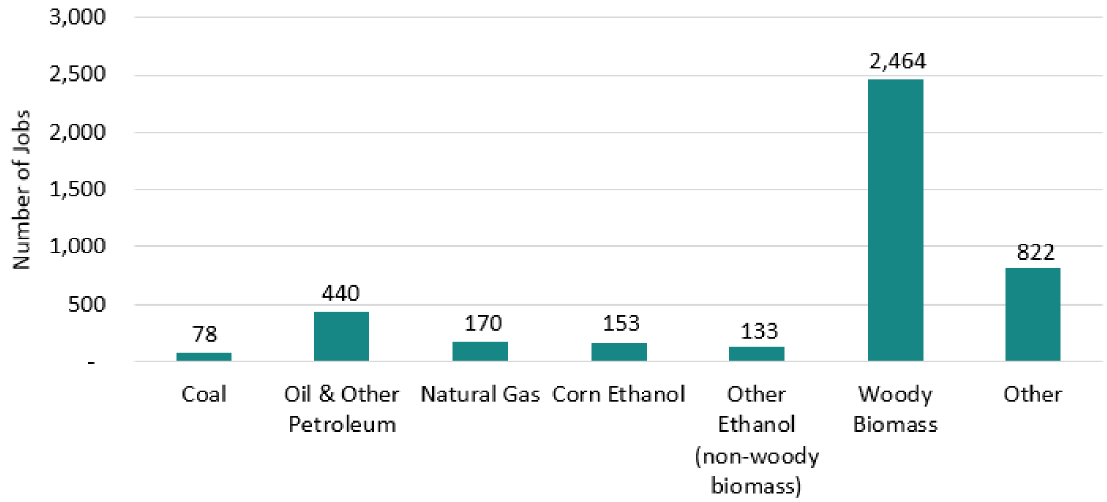
Timeline

- **1892** – With the invention of the automobile, gasoline was recognized as a valuable fuel.[1]
- **1899-1912** – Electric cars are popular in the United States, representing a third of the vehicles on the road. They are quiet, easy to drive, and don't emit pollutants compared to the gas and steam-powered vehicles available at the time.[2]
- **1920** – There were about nine million gasoline-powered vehicles in the United States, and gas stations were opening across the country to fuel the growing number of cars and trucks.[3]
- **1970** – Congress passes the first major Clean Air Act, requiring a 90 percent reduction in emissions from new automobiles by 1975.[4]
- **1971** – EPA begins testing the fuel economy of cars, trucks, and other vehicles, the first step toward informing consumers about the gas mileage of their vehicles.[4]
- **1983** – Portland Public Schools, one of the largest districts in the Pacific Northwest, converted its school bus fleet to propane power.[5]
- **1996** – Leaded gasoline was completely phased out of on-road transportation fuels in the U.S.[1]
- **2000** – Toyota launches the first mass-produced hybrid vehicle called the Prius.[2]
- **2005** – The U.S. Congress enacted a Renewable Fuel Standard that set minimum requirements for the use of renewable fuels, including ethanol, in motor fuels.[1]
- **2006** – The U.S. Environmental Protection Agency issued requirements to reduce the sulfur content of diesel fuel sold for use in the United States. Sulfur in diesel fuel produces air pollution emissions that are harmful to human health.[6]
- **2009-2013** – The U.S. Department of Energy invests in electric vehicle charging infrastructure, installing 18,000 chargers across the country.[2]
- **2016** – Oregon's Department of Environmental Quality launches its Clean Fuels Program.[7]
- **2016** – Clean Energy opens the first public natural gas station in Central Point, Oregon on September 22, which connects California to Washington with natural gas fueling.[8]
- **2016** – Oregon's Clean Fuels Program provides first credits for renewable natural gas as a transportation fuel.[9]
- **2017** – Oregon's Clean Fuels Program provides first credits for renewable diesel.[7]
- **2021** – On June 8, the Oregon Public Utility Commission issues the final rules for the large Renewable Natural Gas program under Senate Bill 98, which was passed in 2019 by the Oregon legislature and gave NW Natural the regulatory framework for procuring RNG for its customers and investing in RNG projects.[10] NW Natural has subsequently purchased RNG from multiple operating projects around the country as well as developed its own RNG projects utilizing waste methane resources.

Transporting people and goods made up about 26 percent of total U.S. energy consumption in 2020 – in Oregon, it was 29 percent.[11] [12] Oregonians consumed 2.4 billion gasoline gallon equivalents of transportation fuels in 2020 and petroleum-based products accounted for 92 percent of the total.[11] These fuels provide power for the 3.2 million registered passenger vehicles and 8,930 trucking companies located in Oregon.[13] [14]

As shown in Figure 1, Oregon employs 4,260 workers within the fuels sector; 440 workers supporting the distribution of petroleum fuels, 153 workers creating and distributing corn ethanol, and 133 workers in ethanol and other non-woody biomass alternative fuel manufacturing and distribution.

Figure 1: Oregon Fuels Jobs by Technology[15]



Woody biomass is the fuel that employs the most Oregonians at 2,464 people or 58 percent of the fuel sector.[15]

Oregon employs 4,260 workers within the fuels sector

What is a Gasoline Gallon Equivalent?

GGEs are a standardized way of comparing different transportation fuels. The energy content of all other fuels can be compared to the energy content of gasoline to produce the GGE or the comparable amount of that fuel that would move the same vehicle the same distance as a gallon of gasoline.

Oregonians spent almost $5.7 billion on transportation fuels in 2020, and because only 2 percent of transportation fuel consumed in Oregon is produced in Oregon, most of that money is sent to other states.[16] Alternative fuel options are growing, and many of these fuels could be produced in Oregon, offering an opportunity to capture greater economic benefit to the state.

Crude oil is a global commodity, and Oregon’s petroleum fuel prices are affected by worldwide events. In 2021, Egypt’s Suez Canal – a critical route for crude oil transport between the Middle East and Europe – was temporarily blocked by a container ship, slowing global trade. Crude oil prices rose by 4 percent in international markets leading to increased transportation fuel prices around the world.[17] In 2022, Russia invaded Ukraine, leading to dramatic increases in the cost of oil around the globe. Russia is the third-largest producer of oil in the world and the United States elected to ban the import of oil, natural gas, and coal as part of economic sanctions. This conflict and other petroleum supply factors led to Oregon fuel prices rising from an average price of $3.431/gallon for gasoline in June 2021 to $5.266/gallon in June 2022.[18] This was a 53 percent increase in the average price of gasoline in Oregon and demonstrated the risk in relying so heavily on imported fuels.

Transportation fuel use is the state's largest source of greenhouse gas emissions, primarily from direct combustion of petroleum fuels, including emissions from on- and off-road vehicles (construction, aviation, marine, rail, industrial, agricultural, or commercial). The transportation sector produced about 23 million metric tons of CO2 equivalent in 2019 – nearly 36 percent of total emissions.[19] About 62 percent of transportation emissions come from the combustion of gasoline in passenger cars and trucks, while about 27 percent are from diesel in heavy-duty vehicles.[20] In 2022, the Oregon Department of Environmental Quality began the Climate Protection Program, which established a declining cap on GHG emissions from petroleum fuels used in Oregon. This program will affect the future transportation fuel mix in the state by accelerating the transition from petroleum-based transportation fuels to lower carbon emission fuels.[21]

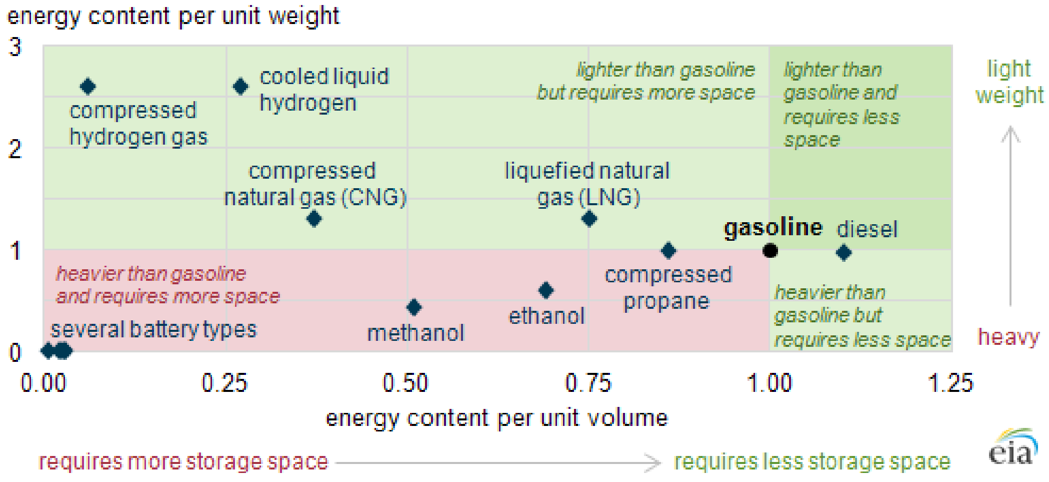
Energy content is the amount of energy released by combusting a fuel.[22]

Energy density is the amount of energy by a given mass or volume of fuel.[23] Transportation fuels have different energy densities, affecting the storage, weight, cost, and range of vehicles that use them.[24]

The use of alternative fuels – including electricity, renewable diesel, propane, and biofuels – is 8 percent of all transportation fuel use in Oregon. These fuels provide Oregonians with a variety of options and an increasingly more diverse landscape of transportation fuels. Alternative fuels generally have the benefit of lower greenhouse gas emissions and lower tailpipe emissions of other air pollutants. The energy density of transportation fuels varies. A fuel with a lower energy density means more of it would be needed to move a vehicle a certain distance than a high-energy density fuel. In some cases, reduced energy density is a trade-off for overall lower greenhouse gases. Some lower energy density fuels may need greater onboard fuel storage to achieve the same distances. Fuels such as ethanol and biodiesel are blended into most petroleum gasoline and diesel respectively, and are widely used in all vehicles and sectors. As shown in Figure 2, ethanol has less energy per unit volume than gasoline and is a little heavier, so the blended fuel is slightly less energy dense and heavier than pure gasoline, but ethanol supports gasoline burning more cleanly, reducing harmful emissions.[24] Compressed natural gas (CNG) is lighter than gasoline but requires more storage space to deliver the same amount of energy. Fuels that need greater storage capacity or have shorter ranges may have different applications and should be accounted for when comparing fuel options[24]

Figure 2: Energy Density Comparison of Transportation Fuels

(indexed to gasoline = 1)



Drop-in fuels are renewable fuels that can use existing fueling infrastructure and can be added to the tank of an existing fossil fuel vehicle without needing to modify it. Renewable diesel is an example of a drop-in fuel, it can be used in existing diesel engines and transportation infrastructure but can be challenging to find locally, especially in areas of Oregon outside the Willamette Valley. Some fuels, such as electricity and natural gas, require buying a new vehicle capable of using the fuel and may require new fueling infrastructure.

Transportation fuel choices are usually based on convenience, cost, and access. Gasoline and diesel fueling stations are everywhere. Most Oregonians own and are familiar with gasoline and diesel fuel internal combustion engine vehicles, vehicle replacements are easy to find, they are available in a wide variety of makes and models, and they can be the most affordable option. Electric vehicles have great potential for adoption because they are becoming increasingly available and fueling can be accessible at a driver's home or business. Renewable diesel and renewable gasoline offer ease of transition because they can use existing petroleum-based infrastructure and can be used directly by any fossil fuel vehicle, without changes to the vehicle. Alternative fuels, such as natural gas and hydrogen, require new transport and delivery infrastructure. Creating a network for fuel delivery with access for all Oregonians is potentially an expensive and challenging endeavor for new alternative fuels entering the transportation market. Hydrogen could be added to existing gasoline stations since the fueling process and infrastructure is quite similar (e.g., a storage tank, fuel pump, and nozzle) but retrofitting Oregon gas stations to include hydrogen would require significant capital.[25]

Oregon policymakers are increasingly assessing policy options that support the adoption of cleaner transportation fuels to meet state greenhouse gas reduction goals, and Oregonians are seeing more fuel and vehicle options available. This section evaluates and compares what the different transportation fuels are, where they come from, how they work, current and future benefits, and how they may play a role in Oregon's greenhouse gas emissions now and going forward.

Oregon Transportation Decarbonization Policies

- Oregon Department of Transportation's five-year Climate Action Plan to reduce greenhouse gas emissions from transportation, improve climate justice and make the transportation system more resilient. https://www.oregon.gov/odot/Programs/Pages/Climate-Action-Plan.aspx.
- Oregon Department of Environmental Quality's Climate Protection Program sets a declining limit, or cap, on greenhouse gas emissions from fossil fuels used throughout Oregon in transportation, residential, commercial, and industrial settings. https://www.oregon.gov/deq/ghgp/cpp/Pages/default.aspx
- Oregon Department of Environmental Quality's Clean Fuels Program supports a market-driven credit and debit system that incentivizes lower carbon fuel use and establishes a goal to reduce the carbon intensity of Oregon's Transportation Fuels. https://www.oregon.gov/deq/ghgp/cfp/Pages/default.aspx
- Oregon Department of Energy's Biennial Zero Emission Vehicle Report provides information on zero emission vehicle adoption in Oregon. https://www.oregon.gov/energy/energy-oregon/Pages/BIZEV.aspx

- Oregon Department of Transportation, Department of Land Conservation and Development, Department of Environmental Quality, and Department of Energy's Every Mile Counts Initiative is a multi-agency approach to reducing greenhouse gas (GHG) emissions and implementing the Statewide Transportation Strategy: A 2050 Vision for Greenhouse Gas Reduction. https://www.oregon.gov/odot/Programs/Pages/Every-Mile-Counts.aspx.

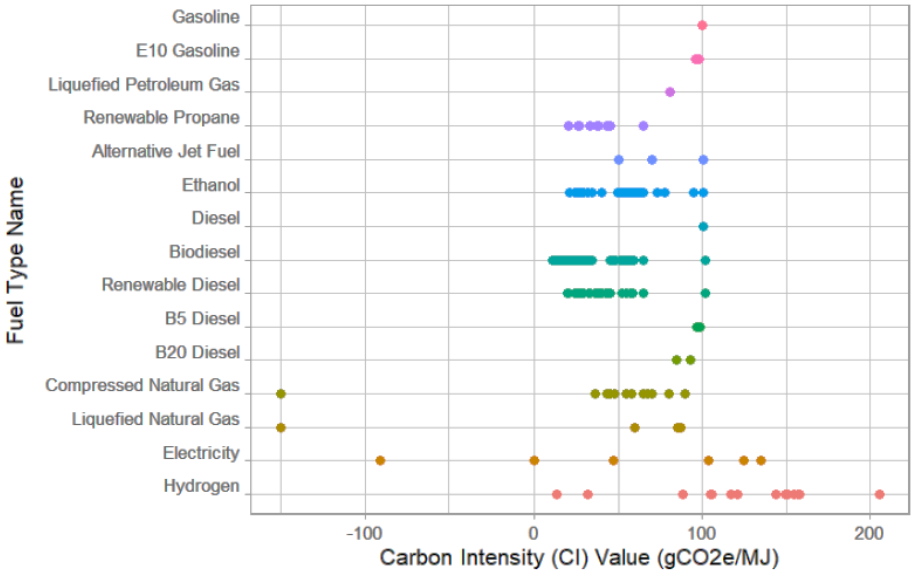
Carbon dioxide equivalent, or CO2e, is a standardized metric that converts all forms of greenhouse gases into an equivalent amount of metric tons of CO2 emissions, and therefore, the same global warming potential as one metric ton of CO2.

Megajoule is a unit representing the amount of energy – it is like calories, which represent the energy content of food.

There are two different ways to examine greenhouse gas emissions from transportation fuels. Measuring tailpipe GHG emissions refers to the emissions associated with using the finished fuel. If someone is driving around town burning gasoline to propel a vehicle, the exhaust contains emissions from that fuel combustion. An electric or zero-emission vehicle does not produce tailpipe emissions. Another method of measuring emissions is lifecycle analysis of transportation fuels, which is a more comprehensive evaluation and includes the associated emissions from the extraction, production, transportation, and use of the fuel. The example electric vehicle may not emit GHGs from its tailpipe, but resources used to create the electricity fueling the vehicle may have associated GHG emissions—although in Oregon these emissions are less than a comparable gasoline or diesel vehicle. Oregon DEQ's Clean Fuels Program assesses carbon intensities based on the lifecycle GHG emissions of transportation fuels.

One way to assess the effects on greenhouse gas emissions is to examine the carbon intensity of each fuel, which shows an apples-to-apples comparison of carbon emissions (represented in grams of carbon dioxide equivalent) compared to the amount of energy produced (represented in megajoules). Higher carbon intensities mean more greenhouse gas emissions are produced to move a vehicle the same distance than a fuel with a lower carbon intensity. The Oregon Department of Energy uses carbon intensity values set by DEQ's Clean Fuels Program.

Figure 3: Carbon Intensity Values of Transportation Fuels[80] *



*Electricity and hydrogen CIs do not include the Energy Efficiency Ratio included in the calculation of CFP credits. Electricity's EER is 3.4 and hydrogen is 1.9 - 2.1. The CI of electricity after considering the EER is 3.4 times less and hydrogen is 1.9 – 2.1 times less.

Oregon's Transportation Fuels – Quick Facts[11, 52, 80, 95]

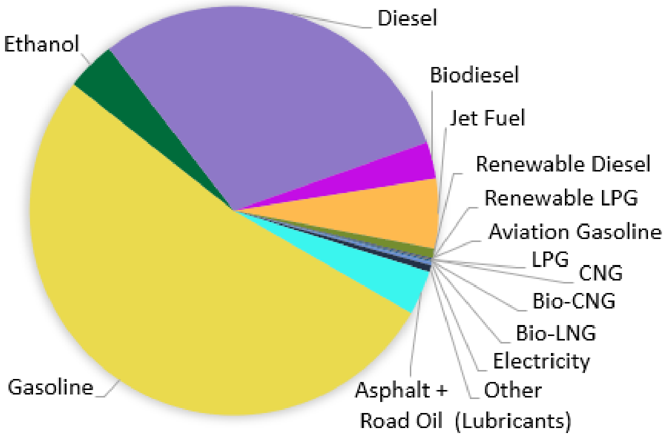
Fuel	Total Estimated Consumption in Oregon GGE (2020)	Estimated Production in Oregon GGE (2020)	Average Carbon Intensity in gCO2e/MJ (2021)	Estimated No. Public and Private Fuel Stations in Oregon	Section Page Number
Gasoline	1,265,440,694	0	100.14	1,849	**92**
Diesel	726,634,560	0	100.74	1,352	**94**
Compressed Natural Gas (CNG)	407,359	†	79.98	15	**97**
Liquid Natural Gas (LNG)	84,880,477	†	86.88	2	**97**
Propane	549,102	0	80.88	44	**100**
Ethanol	94,340,735	43,062,160	53.72	4	**103**
Biodiesel	70,292,133	12,878,161	41.84	33	**107**
Hydrogen	0	0	74.68 - 82.54***	0	**111**
Electricity	6,495,585	63,624,782	25.35**	2,193	**113**
Renewable Gasoline	0	0	TBD	0	**118**
Renewable Diesel	18,617,155	0	36.98	43	**119**
Renewable Natural Gas	3,205,366	†	20.55	5	**125**
Renewable Propane	530,416	0	34.66	42	**128**

†*Comprehensive production data isn't available.*

***Includes the 3.4 Energy Efficiency Ratio*

****Includes the 1.9 to 2.1 Energy Efficiency Ratio*

Oregon Transportation Fuels Consumption (2020)



Petroleum Fuels

- Gasoline
- Diesel
- Natural Gas
- Propane

Blended Fuels

- Ethanol
- Biodiesel

Zero Tailpipe Emission Fuels

- Hydrogen
- Electricity

Renewable Fuels

- Renewable Gasoline
- Renewable Diesel
- Renewable Natural Gas
- Renewable Propane

This transportation fuel resource overview provides a variety of information on conventional fuels currently being used in Oregon, low carbon intensity alternatives, and some potential fuels that may come to Oregon in the future. The fuels are organized into four categories based on their use and value to Oregon's transportation sector:

- **Petroleum** fuels include petroleum-based fossil fuels like gasoline and diesel.
- **Blended fuels** are fuels added to petroleum fuels to reduce emissions like ethanol and biodiesel.
- **Zero tailpipe emission fuels** produce zero tailpipe emissions, though there may be emissions from the production of that fuel depending on how it is produced like electricity.
- **Renewable transportation fuels** are a lower carbon intensity version of commonly used petroleum fuels like renewable diesel.

Each transportation fuel description will include Oregon's consumption, production, carbon intensity, and available fueling locations to compare each fuel. Asphalt, road oil, lubricants, or other petroleum-based transportation fuels are not addressed. These fuels are similar to — and have many of the same benefits and environmental challenges as — gasoline and diesel fuels but are largely used in road construction and industrial processes rather than to fuel a vehicle. Jet and aviation fuels are also not included, but as new alternative fuels are more available to fuel aircraft, these fuels may be addressed in future versions of this report.

Petroleum Fuels

Petroleum is the most common energy resource used for transportation in the United States. Gasoline, diesel, natural gas, and propane are all petroleum fuels extracted from beneath the earth's crust as crude oil or natural gas.[12] [20] In 2021, petroleum fuels represented 90 percent of fuel consumed by the transportation sector in the U.S., but gasoline and diesel fuel's combined share is expected to decrease to an estimated 74 percent in 2050.[12] [26]

Oregon's geographic location affects the cost and carbon intensity of petroleum fuels consumed in the state. Oregon pays more for petroleum-based transportation fuels than most parts of the country due to its lack of regional petroleum resources. The Pacific Northwest has no crude oil resources and is located far from North America's major petroleum production regions in Texas, North Dakota, and Alberta, Canada. Over the last 10 years, the mix of crude resources that feeds northwest refineries has changed, resulting in changes to how Oregon's crude oil is transported and in the overall carbon intensity of the state's transportation fuels. Since 2011, Washington refineries have seen increased amounts of crude from the Canadian oil sands.[27] [28] This crude has a much higher carbon intensity than other resources, meaning more greenhouse gas emissions are emitted per gallon of fuel because it requires more greenhouse gas-emitting energy to extract and process.[27]

Fuel spills associated with fossil fuel extraction, transport, and storage can be devastating to the environment. More crude is now delivered by rail, and most crude rail shipments travel through the Columbia River Gorge and Portland before moving up to Washington refineries. Trains carrying oil are a safety risk to Oregon communities, in 2016 an oil train derailed in the town of Mosier, three rail cars caught fire and four were found to be discharging oil.[29] Underground fuel storage tank systems used by service stations for public or private fleets corrode over time, and without proper maintenance leak fuel into the environment, possibly contaminating groundwater.[30] Sites with significant spills in communities have become brownfields – properties that are limited in use because of the presence of a hazardous substance, pollutant, or contaminant.[30] Cleaning up and reinvesting in these facilities can be an economic burden to communities. The U.S. Environmental Protection Agency determined that "of the estimated 450,000 brownfield sites in the U.S., about half are thought to be impacted by petroleum, much of it from leaking underground storage tanks at old gas stations."[31]

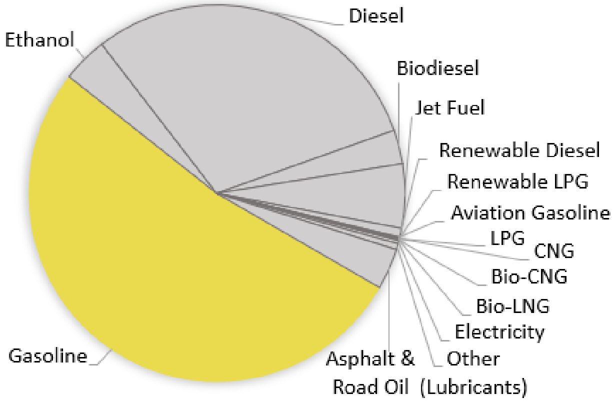
Mosier 2016 Oil Train Derailment[29]

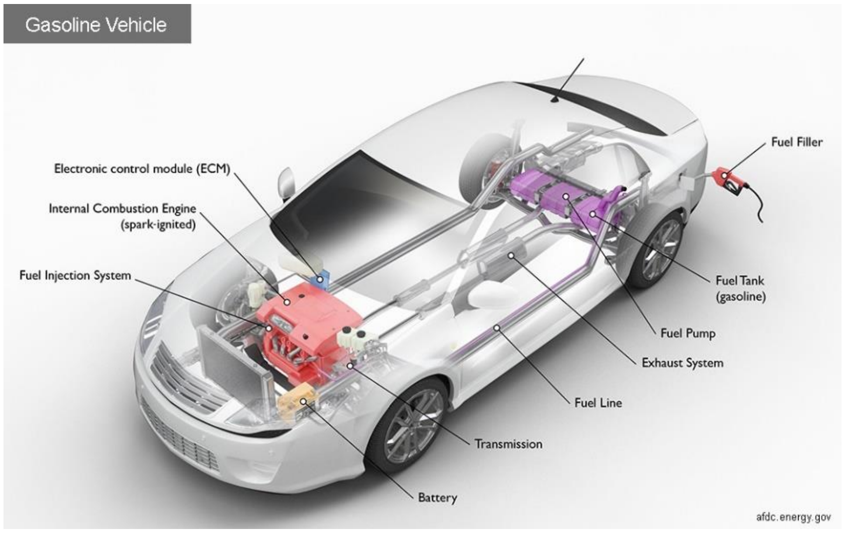
Gasoline

- **1,265,440,694** – Total gasoline consumed in Oregon (2020) GGE[11]
- **0** – Total gasoline produced in Oregon (2020) GGE[16]
- **100.14** – gasoline carbon intensity (2021) in gCO2e/MJ[9]
- **1,849** – Public and private fuel stations in Oregon[32]

Gasoline is the most widely used transportation fuel in the United States and Oregon, powering cars, motorcycles, light trucks, airplanes, and boats. Gasoline accounts for fifty-two percent of Oregon's total transportation fuel consumption. Oregon's renewable fuel standard requires that nearly all commercially available gasoline for light-duty vehicles has a 10 percent ethanol blend, called E10. To learn about ethanol and how it is blended with gasoline, please visit

Figure 4: Gasoline Share of Oregon Transportation Consumption in 2020

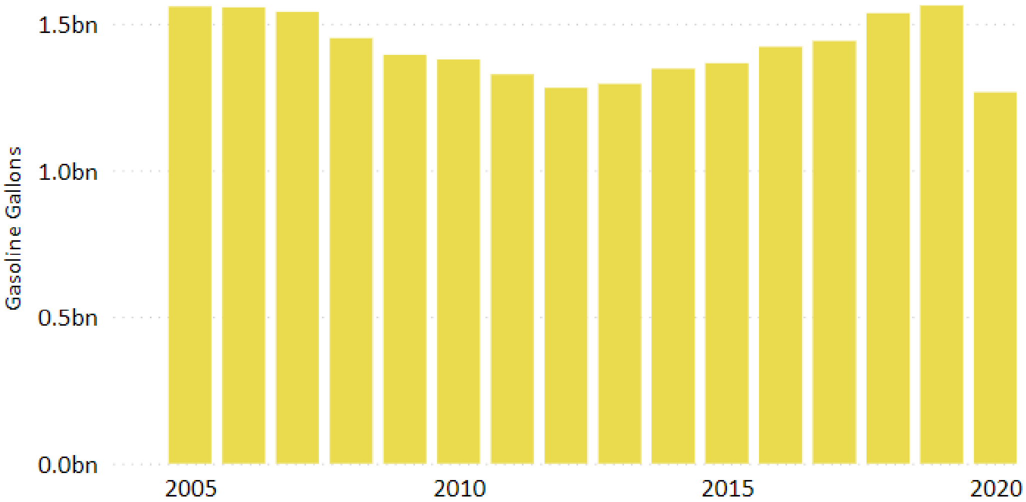




the ethanol section. Crude oil is refined through a process called fractional distillation in which a variety of petroleum fuels are created, including gasoline, distillate oil and many others.[20] U.S. petroleum refineries produce about 19 to 20 gallons of gasoline from a 42-gallon barrel of crude oil.[33] Petroleum refineries and blending facilities in Washington produce and transport 90 percent of motor gasoline for sale at retail gasoline fueling stations in Oregon.[27]

Trends and Potential

Figure 5: Oregon On-Highway Gasoline Consumption by Year[11]



In 2020, nearly 1.3 billion gallons of gasoline powered vehicles on Oregon roads, or about 296 gallons per Oregonian.[11] Prior to the COVID-19 pandemic, gasoline consumption in Oregon had been steadily increasing since 2012, largely due to significant economic growth over the last 20 years. The state's population has increased by 23 percent and employment by 18 percent. The average vehicle-miles-traveled also increased by 13 percent.[34] There are more people doing more jobs and driving more per person, leading to greater use of transportation fuels. This is in spite of the growth of electric and other alternative fuel vehicles.[34] Oregon's aggressive EV mandates, coupled with state efforts to reduce overall vehicle miles traveled and improvements in the efficiency of gasoline vehicles, will eventually lead to steep declines in gasoline-powered vehicles and gasoline consumption longer term.[35] [36] In April 2022, the Oregon Department of Transportation completed a Passenger Vehicle Stock Forecast and estimated gasoline-powered vehicle registrations will peak in 2027 and then begin a steady decline.[37] The U.S. Department of Energy's 2022 Annual Energy Forecast indicates that gasoline consumption will not surpass 2019 levels going forward, potentially indicating that gasoline consumption is currently peaking with anticipated overall drops in consumption going forward.[38]

Beyond Energy

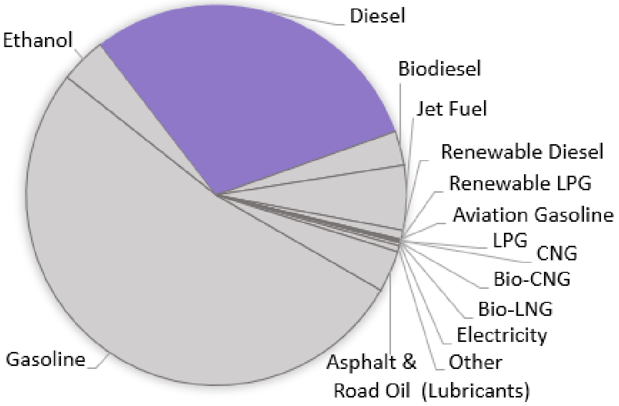
Crude oil products are a global commodity and events outside Oregon's and the United States' control can have a big impact on the price of gasoline. History and recent events confirm that the global crude oil market can be highly volatile. After Russia invaded Ukraine, the cost of gasoline in Oregon rose from $3.431/gallon in June 2021 to $5.266/gallon in June 2022.[18] This increased an average Oregonian's annual fuel costs by over $1,100 per year, a 53 percent increase[i]. Since most Oregon households use gasoline for their daily transportation needs, large changes in fuel costs like this can create additional financial hardships, especially for low-income Oregonians. In most parts of Oregon, particularly rural parts of the state, the costs for transportation exceed 30 percent of average income, and large increases in fuel costs may affect Oregonians' ability to pay for other household expenses.

Gasoline produces the largest amount of greenhouse gas emissions in Oregon — over 15.5 million metric tons of carbon dioxide equivalent in 2020.[11] Burning a gallon of gasoline without ethanol produces about 19 pounds of carbon dioxide. Gasoline exhaust also contains carbon monoxide, nitrogen oxides, particulate matter, and unburned hydrocarbons, which have been linked to substantial respiratory health effects and cancer.[41] This affects communities located in areas with high traffic usage, which are often low-income households and communities of color.[42]

Diesel

- **726,634,560** – Total diesel consumed in Oregon (2020) GGE[11]
- **0** – Total diesel produced in Oregon (2020) GGE[16]
- **100.74** – Diesel carbon intensity (2021) in gCO2e/MJ[10]
- **1,352** – Public and private fuel stations in Oregon[32]

Figure 6: Diesel Share of Oregon Transportation Consumption in 2020



Diesel fuel is second only to gasoline in fuel consumption in Oregon.[6] It is commonly used by trucks, buses, automobiles, and locomotives, as well as farm and construction equipment.[43] While both gasoline and diesel start as crude oil, they are separated into their component parts and blended with other fuels at a refinery. Diesel is typically blended with biodiesel at 5, 20, and 99 percent amounts. In Oregon, all diesel fuel that is sold or distributed must contain at least a 5 percent blend of biodiesel or renewable diesel called B5. A 20 percent blend, called B20, is also widely available in Oregon. Additional blends of petroleum diesel, biodiesel, and renewable diesel are used to cut lifecycle greenhouse gas emissions of diesel fuel consumption and are available in some parts of the state.[44] Learn more in the Biodiesel and Renewable Diesel sections below.

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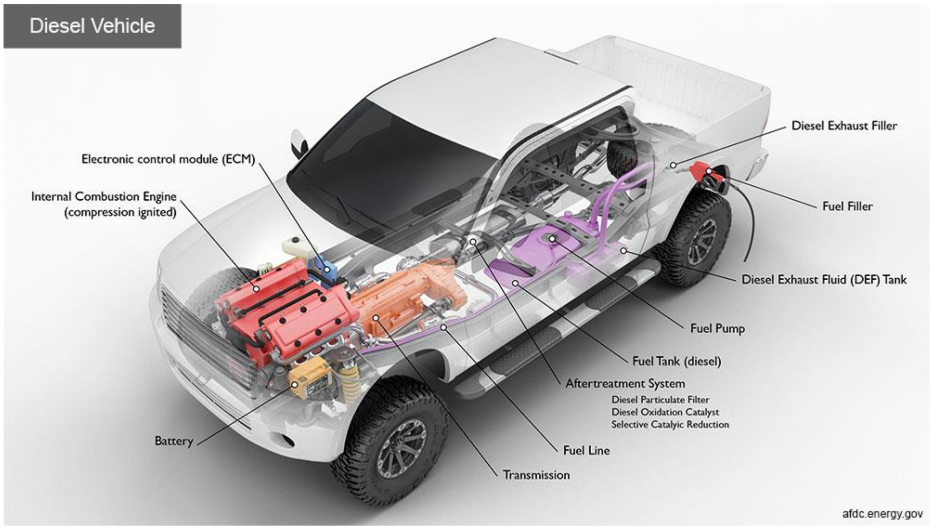
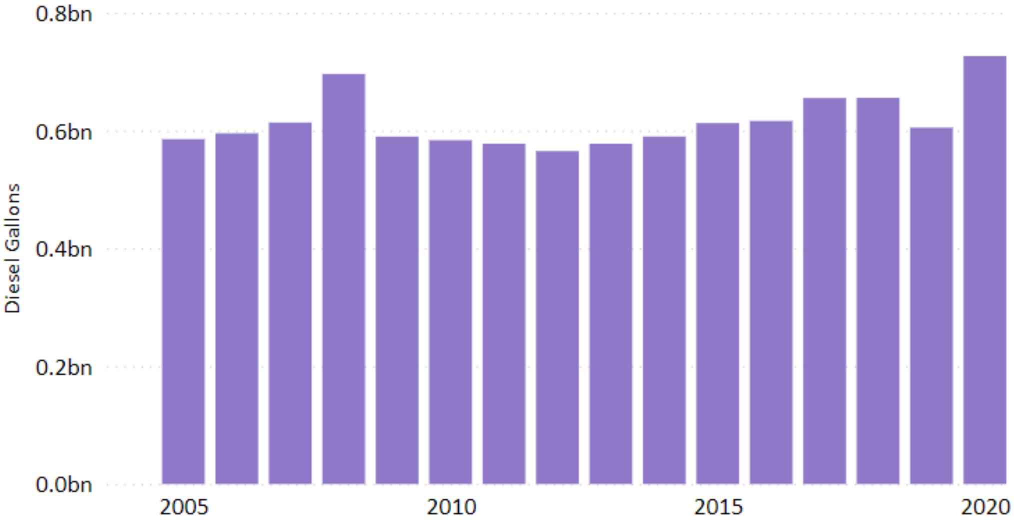
[i] Based on the average 14,032 Oregon vehicle miles traveled per year and an average passenger vehicle fuel economy of miles per gallon. [39,40]



U.S. petroleum refineries produce an average of 11 to 12 gallons of diesel fuel from each 42-gallon (U.S.) barrel of crude oil.[6] There are no petroleum reserves or crude oil refineries in Oregon, meaning all petroleum-based fuel must be imported into the state. Over 90 percent of diesel at Oregon service stations comes from refineries in Washington state. While it typically costs more, diesel contains more energy per gallon than gasoline, so a diesel engine requires less energy to accomplish the same amount of work.[45]

Trends and Potential

Figure 7: Oregon On-Highway Diesel Consumption by Year[11]

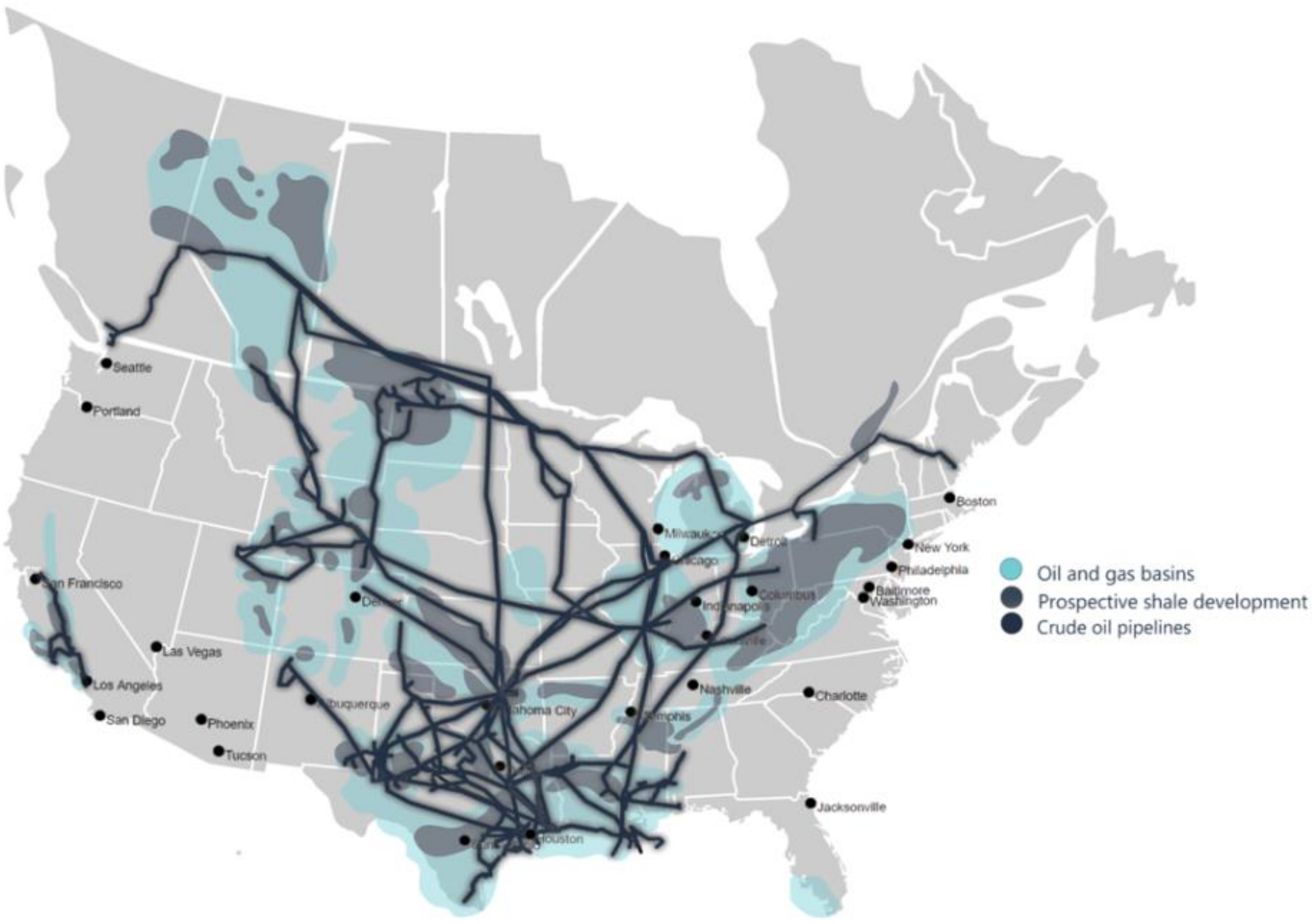


In 2010, Oregonians consumed 551 million gallons of diesel fuel and in 2020, consumption increased to 726 million, a 32 percent increase. Approximately 80 percent of all freight is moved by diesel engines in trucks, trains, and ships in the United States.[46] Some passenger vehicles also use diesel. The number of these vehicles using diesel is projected to continue to increase, depending on the effects of diesel prices on the market and the market penetration of alternatives, such as hybrid and electric vehicles.[43] The Oregon Department of Transportation's State Highway Fund Transportation Revenue Forecast in April 2021 found that diesel use by light and almost all medium-heavy vehicles increased in comparison to 2019. This was attributed to the use of diesel-powered delivery trucks and vans to support increased online retail shopping as a result of COVID-19.[47] Increased availability of diesel alternatives, such as renewable diesel and biodiesel, are increasingly a larger proportion of all diesel-type fuel consumption (see Renewable Diesel and Biodiesel sections below).

Beyond Energy

Diesel fuel consumption is one of the largest sources of greenhouse gas emissions in the state, creating almost 10 million metric tons of carbon dioxide equivalent in 2020. Black carbon particulate – about 70 percent of the particulate emitted by a diesel engine – also contributes to climate change by absorbing light and heat that warms the air and melts snow and ice.[46 48] Combustion of diesel emits more carbon dioxide than an equivalent amount of gasoline, as well as other tailpipe air pollutants, including nitrogen oxides and particulate matter.[49] Diesel exhaust is a known carcinogen that disproportionately affects the health of people in communities near heavily trafficked roads – often historically underserved and lower-income communities – leading to a higher likelihood of poor lung function.[50] Diesel air pollution in Portland, Oregon has been shown to be 10 to 20 times higher than the state's health-based air quality benchmarks.[51] Short and long-term exposure to diesel exhaust can lead to negative cardiovascular, respiratory, and nervous system effects.[50]

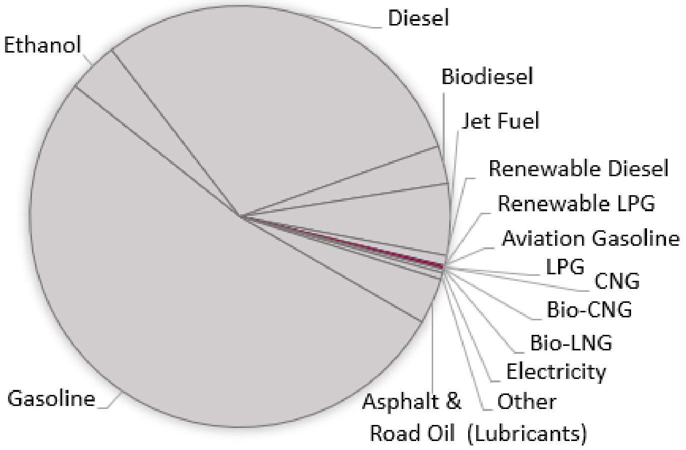
Figure 7: North American Oil and Gas Basins and Crude Oil Pipelines



Natural Gas: Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG)

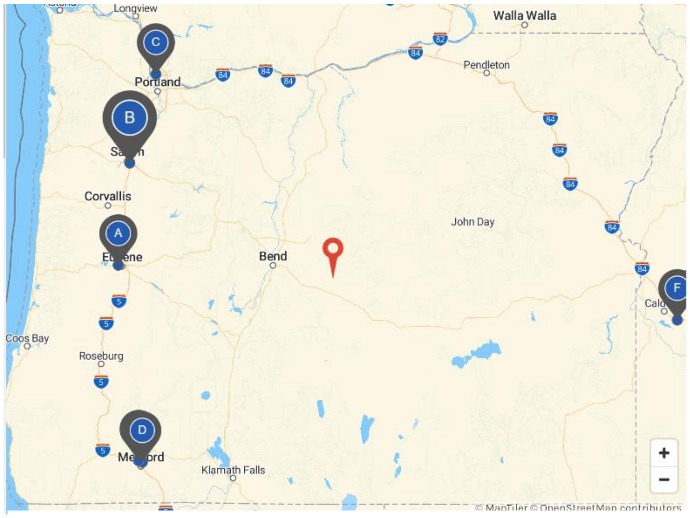
- **407,359** – Total compressed natural gas (CNG) consumed in Oregon (2020) GGE[11]
- **84,880,477** – Total liquefied natural gas (CNG) consumed in Oregon (2020) GGE[11]
- **0** – Total natural gas produced in Oregon for transportation (2020) GGE[16]
- **79.98** – natural gas carbon intensity (2021) in gCO2e/MJ[9]
- **4 CNG and 1 LNG** – Public and private fuel stations in Oregon[52]

Figure 8: Natural Gas/CNG/LNG Share of Oregon Transportation Consumption in 2020



Natural gas is an odorless, colorless gas that is largely comprised of methane but also includes many different compounds. Oregon imports most natural gas through pipelines from Canada and the Rocky Mountain states. Although more commonly used in Oregon to generate electricity and heat buildings, natural gas is also used as a transportation fuel.[53] About 2.6 percent of natural gas was consumed as a transportation fuel in Oregon.[54] There are two forms of natural gas currently used to fuel vehicles: liquefied natural gas and compressed natural gas. Natural gas vehicles exist for on-road and off-road vehicles, and many existing vehicles can be retrofitted to run on CNG and LNG.[55] Of the major auto manufacturers, only Ford offers light-duty CNG fueled vehicles, and these are retrofitted models of diesel pickups. There are few models available for the light-duty sector, and a limited number of models available in medium- and heavy-duty vehicles, such as garbage trucks, semi-tractors, and transit buses.[55]

A compressed natural gas vehicle gets about the same fuel economy as a conventional gasoline vehicle but with reduced greenhouse gas emissions.[56] CNG is produced by compressing natural gas to less than 1 percent of its volume. This means CNG has 100 times as much energy as the same volume of uncompressed gas, and this compression – up to 3,600 pounds per square inch – makes CNG fuel tanks compact enough to support adequate driving ranges for light-, medium-, and heavy-duty vehicle applications. Almost all natural gas consumed in Oregon is imported and there are only four public CNG fueling depots in the state.[52] Where available, the retail price of natural gas is generally much less than gasoline or diesel.[55]

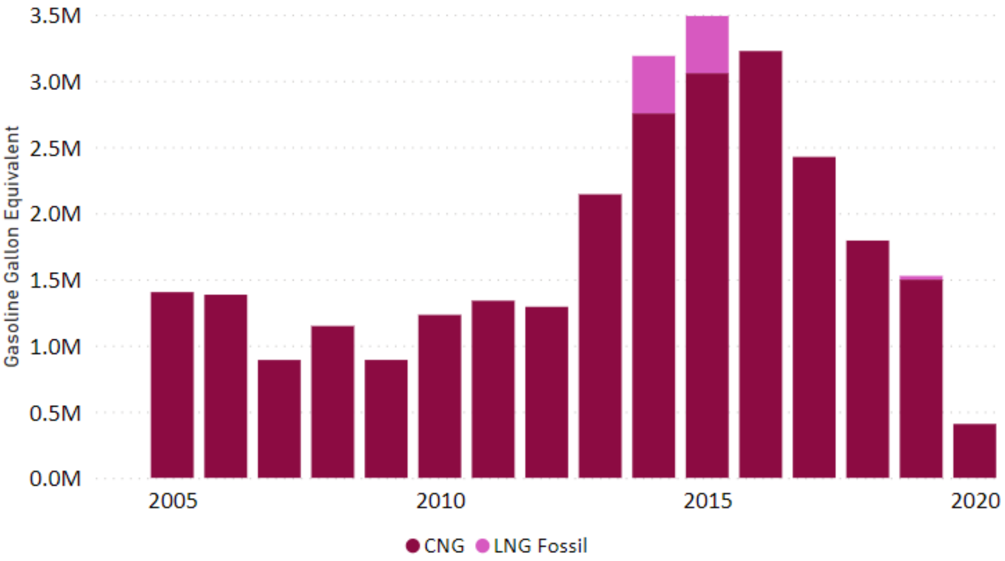


Oregon has four CNG fueling stations.[52]

LNG is natural gas that has been cooled to about -260° Fahrenheit, which converts the gas into its liquid state. More compressed than CNG, it is about 600 times smaller than in its gaseous state and therefore contains more energy per volume than CNG. LNG requires special containers to properly store the cold liquid, usually in double-walled and insulated tanks. Because of its higher energy density, it is more suitable for vehicles that require longer ranges, including ships, trucks, and buses.[58] However, the relatively higher cost to produce LNG has limited its use in commercial applications.[56]

Trends and Potential

Figure 9: Oregon On-Highway Natural Gas Consumption by Year[11]



In 2020, natural gas represented 0.2 percent of Oregon's total transportation fuel consumption. Natural gas use declined from 1.2 million GGE in 2010 to 407 thousand GGE in 2020 – a decrease of 67 percent. Renewable natural gas, a fuel created from biogas collected from waste, more than doubled natural gas use as a transportation fuel, Oregonians consumed over 3 million GGE in 2020. With the growth of renewable natural gas producing facilities in Oregon, DEQ's Clean Fuels Program has forecasted expected annual increases in the blend rates of renewable natural gas being used as a transportation fuel, replacing fossil natural gas.[7]

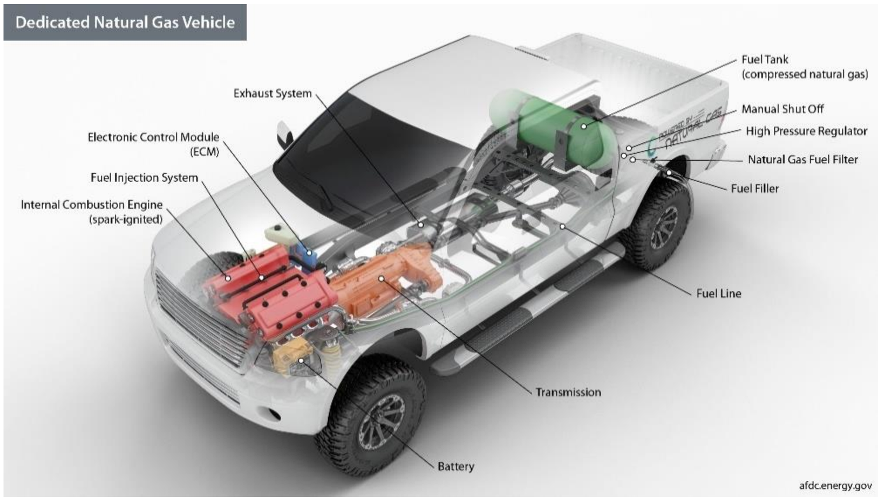
Oregon did not consume any fossil liquid natural gas as a transportation fuel in 2020, but it did consume 317 thousand GGE of renewable LNG. CNG has seen slightly greater adoption within Oregon with four fuel stations while there is only one LNG station.[52]

In 2018, more than 90 percent of the natural gas the United States consumed was produced in the U.S.[59] Oregon receives most of its natural gas from transmission pipelines from the Rockies, Northern Alberta, and Northern British Columbia, Canada. Overall, the United States is building more LNG export terminal infrastructure to support growing demand in Asia and Europe. As exporting capabilities increase, natural gas may become more of a global commodity, leading to domestic natural gas prices being subject to global supply and demand conditions, similar to crude oil. Oregon natural gas utilities can insulate themselves from potential price volatility with local natural gas storage and purchasing future contracts at lower market rates with domestic suppliers.[60]

Rogue Disposal & Recycling's hauling trucks are powered by Compressed Natural Gas.

With stronger regulations on fuel emissions, some shipping companies are adopting LNG as an alternative to residual fuel oil or diesel that are used as bunker fuels. Bunker fuel is any fuel used to power marine vessels.[61] In 2020, the International Maritime Organization implemented new regulations limiting the use of higher sulfur content maritime fuels such as bunker fuel, and low-sulfur marine fuels are significantly more expensive.[62] LNG meets these and other emission requirements for the shipping industry, and is being adopted by some shipping companies. Because using LNG requires new ships and fuel storage infrastructure, the up-front costs to convert may be a barrier for some applications despite lower fuel costs. However, LNG production and storage technology is developing quickly. The shipping industry is also investing in the design of more efficient ships, as it anticipated the potential of LNG as a long-term solution for reducing emissions.[56]

Adoption of natural gas as an alternative road transportation fuel in Oregon can be cost-effective depending on how frequently and how far the vehicles are driven. CNG- and LNG-fueled vehicles have similar power, acceleration, and cruising speeds to equivalent diesel-powered vehicles, but the driving range is lower because CNG and LNG are less energy dense than diesel.[24] Medium- and heavy-duty fleets with daily routes to and from a fueling hub such as a warehouse or bus fueling depot, are some of the best candidates for natural gas fuel adoption. Oregon fleets that have invested in natural gas vehicles and fueling include the City of Salem (Cherriots) and Medford's (Rogue Valley Transportation District) transit agencies, waste management companies like Gresham Sanitary Service, and Kroger.[63–66] The purchase price of new CNG vehicles is greater than a comparable gasoline- or diesel- powered version, and conversion of existing vehicles may cost $6,500 to $12,000. Limited existing fueling infrastructure in Oregon also requires a home or business fueling compressor, which costs $3,500 or more for a single personal vehicle. CNG storage tank costs and needs are dependent upon the size of the fleet and the needed speed of the fill-up.[67 68] Although CNG is 30 to 40 percent less expensive than gasoline or diesel, to offset the initial investment in the vehicle in a reasonable timeframe, fuel use must be relatively high.[69] Commercial fleets that are in continuous use and servicing local areas may be best positioned to take advantage of the lower costs of CNG.



afdc.energy.gov

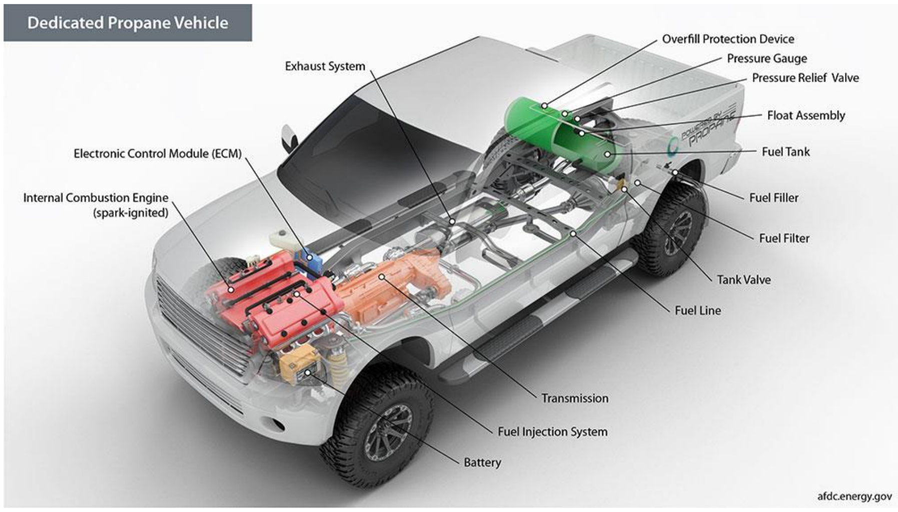
Beyond Energy

Natural gas has lower carbon emissions as a transportation fuel than gasoline and diesel, but its production and use do affect the environment. Carbon intensities for fossil natural gas vary depending on extraction and delivery methods, but on average lifecycle greenhouse gas emissions are approximately 20 percent less than gasoline or diesel.[7] Natural gas is predominantly methane, a powerful greenhouse gas that is the largest contributor to the formation of ground-level ozone, a hazardous air pollutant and greenhouse gas. Exposure to ground-level ozone can result in a variety of negative health outcomes and is estimated to be the cause one million premature deaths globally every year. Methane is 80 times more potent at warming the Earth than carbon dioxide over a 20-year period.[70] The U.S. Environmental Protection Agency estimates that in 2019, methane emissions from natural gas and petroleum systems and abandoned oil and natural gas wells were the sources of about 29 percent of total U.S. methane emissions and about 3 percent of total U.S. greenhouse gas emissions.[71] The EPA also estimates an average of 1.4 percent of natural gas is lost due to pipeline leaks as it travels from extraction to its end-use.[72] Extraction of natural gas, which includes hydraulic fracturing, may also negatively affect local wildlife, people, and water resources.[73]

Propane

- **549,102** – Total propane consumed in Oregon (2020) GGE[11]
- **0** – Total propane produced in Oregon (2020) GGE[16]
- **80.88** – propane carbon intensity (2021) in gCO2e/MJ[9]
- **44** – Public and private fuel stations in Oregon[52]

Propane is a gas at atmospheric pressure and a liquid – called liquified petroleum gas or LPG – under higher pressures or cold temperatures. Its versatility and high energy density in liquid form make it useful for many purposes, including as a feedstock for petrochemical plants, as a heating or cooking fuel, and as a transportation fuel. New vehicles and conversion kits to retrofit existing vehicles are becoming increasingly available and vehicles can be built as dedicated propane vehicles or bi-fuel vehicles that can run on propane or gasoline.[74] [75] Propane is used in Oregon to power buses, locomotives, forklifts, taxis, farm tractors, and Zamboni machines at ice skating rinks. The Pacific Propane Gas Association estimates that more than 95 percent of the propane consumed in Oregon is sourced from natural gas processing plants in Alberta and British Columbia, Canada.[76] Propane does not degrade as quickly as gasoline and diesel when being stored, making it a good transportation fuel for vehicles that are not in regular use.


Dedicated Propane Vehicle

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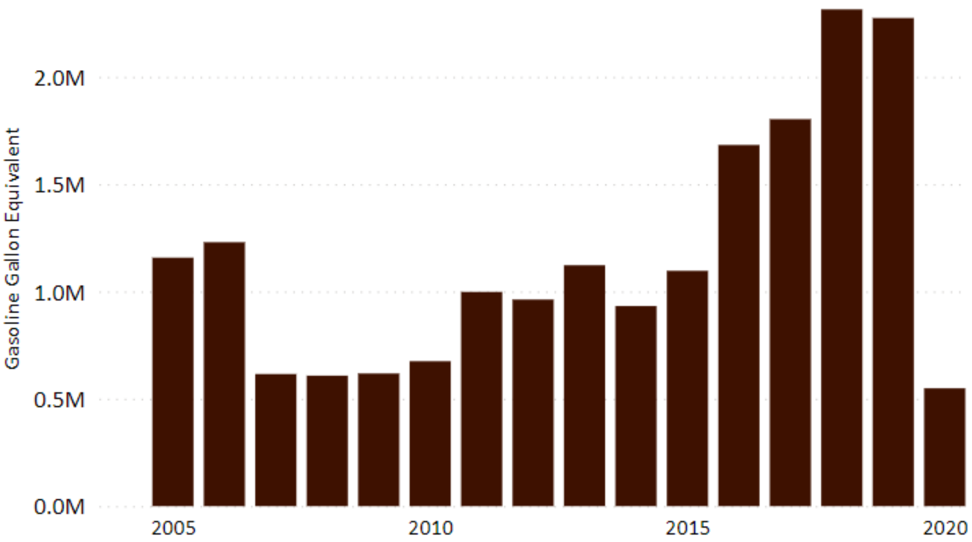
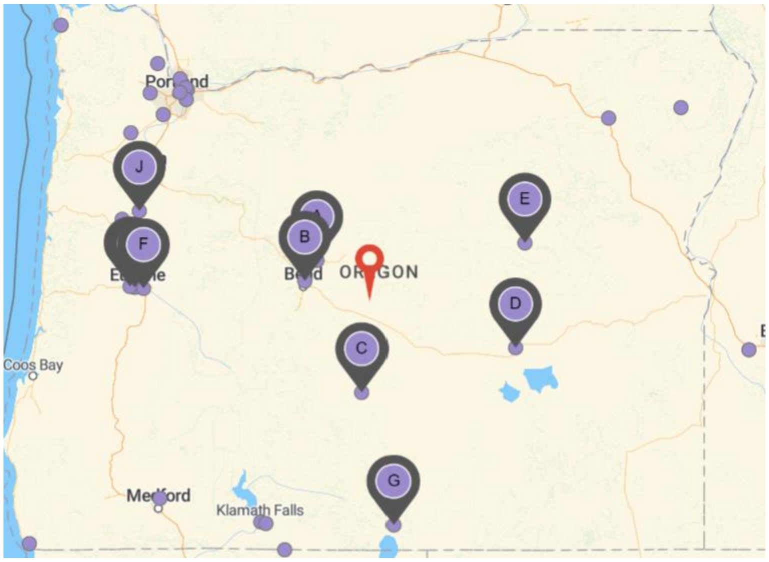
Trends and Potential

Figure 10: Oregon On-Highway Propane Consumption by Year[11]



Oregonians consumed 549,000 GGE of propane in 2020 as a transportation fuel, which was 0.02 percent of Oregon's total transportation consumption. All propane consumed in Oregon is imported.[77] As U.S. natural gas production increased, the supply of propane as a by-product of natural gas processing has followed, making it increasingly more available in the market. Total Oregon propane consumption was 6 trillion Btu in 2010 and 8 trillion Btu in 2020, a 30 percent increase. Although it is a small share of fuels reported to the Oregon Department of Environmental Quality's Clean Fuels Program, its use has steadily increased.[7]

Propane fueling infrastructure currently exists with 44 fueling stations in Oregon, largely supporting private and public fleets.[78] Propane is used by public and private local commercial fleets with light- or medium-duty trucks or delivery vans. Many Oregon school districts use propane as a fuel for bus fleets. In 1983, in response to rising fuel prices and air quality regulations, Portland Public Schools turned to propane as a fuel source for its fleet of buses.[79] There were an estimated 8,257 school buses in Oregon in 2019, and 1,159 — about 14 percent — were fueled by propane (the national average is 4 percent).[76] Using propane requires buying a new vehicle, but unlike many other fuels that require new fueling infrastructure, often the rental of a fueling pallet from a propane distributor is included in the price of the fuel. This reduces the initial investment burden on customers interested in adopting the fuel. Return on investment is reasonably fast without incentives and the fuel is available throughout Oregon.



Oregon has 44 propane fueling stations.[52]

Medium- and heavy-duty fleets with daily routes to and from a fueling hub such as a warehouse or bus fueling depot, are the most amendable to propane fuel adoption. In addition to some school districts, many other Oregon fleets have invested in propane vehicles and fueling, including Franz Bakery, Benton County, Polk County, and Jackson County.[74] For longer routes, most conversion systems allow for bi-fuel use, alleviating concerns about fuel availability. Long haul trucking fleets, however, have not adopted propane because of the greater fuel storage space needed. Propane is less energy dense than gasoline or diesel – one gallon of propane has 27 percent less energy than a gallon of gasoline. To achieve the same fuel range, fleet owners would need to expand each truck's fuel storage space, which would reduce overall cargo space.[75]

Beyond Energy

Propane production has similar air and land quality effects as other petroleum-based fuels because it is a byproduct of natural gas production and crude oil refining. Propane has lower tailpipe emissions than many older diesel and gasoline vehicles, reducing harmful air pollutants that negatively affect the health of Oregonians. Many Oregonians living or working near industrial areas or heavily trafficked areas are particularly vulnerable to the effects of diesel emissions and are disproportionately low-income communities and communities of color.[42] Propane has lower lifecycle greenhouse gas emissions in comparison to other petroleum transportation fuels. Oregon's Clean Fuels program estimated the carbon intensity of propane to be about 19 percent less than gasoline and diesel fuel.[80] Although propane is produced domestically, the propane consumed in Oregon is imported from Canada, meaning propane consumption in Oregon does not improve the state's or country's energy independence.[81]

Blended Fuels

In 2020, 2 percent of the transportation fuel used in Oregon was produced in the state, including 6.5 trillion Btu of biodiesel and fuel ethanol. Biodiesel and fuel ethanol are transportation fuels created from organic plant and animal material called biomass. Biofuels can be used on their own, but in Oregon and the U.S. they are more commonly blended with petroleum-based transportation fuels at varying concentrations. The federal Renewable Fuel Standard requires all transportation fuel sold in the United States to contain a minimum volume of renewable fuels with annual escalating amounts. Oregon adopted a state RFS in 2007; all diesel fuel sold in the state must be a blend with 5 percent biodiesel and all gasoline must be blended with 10 percent ethanol[82] Both federal and state standards increase the development and incorporation of biofuels to reduce total lifecycle GHG emissions of the fuels, reduce reliance on imported petroleum, and improve engine performance.[83]

City of Portland Renewable Fuel Standard

Many of Oregon's local governments have developed climate plans to reduce harmful GHG emissions in their communities. Oregon's transportation sector was responsible for almost 36 percent of GHG emissions in 2019 and communities are exploring local solutions to reduce the impact of transportation.[84] The City of Portland has a renewable fuel standard (Portland City Code Title 16.60) requiring all gasoline and diesel fuels sold in the city be blended with renewable fuels, reducing the carbon intensity and emissions of the fuel. In 2022, city staff proposed a code amendment to gradually increase the minimum renewable fuels blended with petroleum diesel fuel to support the city's climate and renewable energy goals. The draft was in public review at the time

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of printing, but if this amendment passes as proposed, in the first year of implementation, all diesel sold in the city would have a minimum blend of 15% biodiesel or renewable diesel starting in 2023. The blend percentage would increase each year until it reaches 99 percent four years after the effective date.

Staff proposal:

- 2023- minimum blend of 15 percent biodiesel or renewable diesel
- 2024- minimum blend of 35 percent biodiesel or renewable diesel
- 2025- minimum blend of 65 percent biodiesel or renewable diesel
- 2026- minimum blend of 99 percent biodiesel or renewable diesel

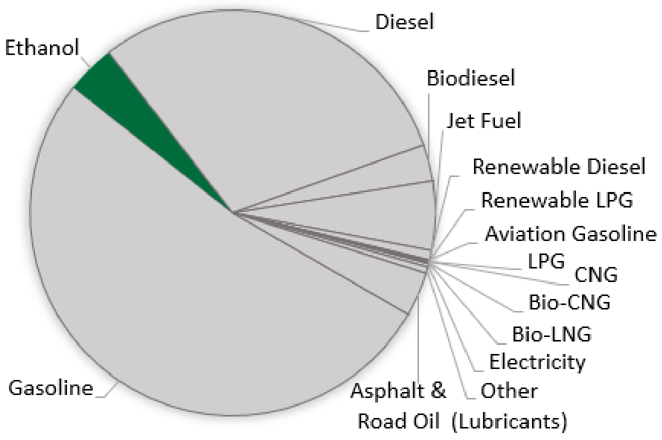
In addition to blend requirements, the proposed amendment limits the lifecycle carbon intensity of biodiesel and renewable diesel to 40 gCO2e/MJ, a value that most diesel substitutes in DEQ's Clean Fuels Program currently meet. A minimum carbon intensity is important because it creates a threshold that excludes feedstocks that are higher carbon across their lifecycle, especially feedstocks from agricultural products like soybeans and canola.[85]

Ethanol

- **94,340,735** – Total Ethanol consumed in Oregon (2020) GGE[11]
- **43,062,160** – Total Ethanol produced in Oregon (2020) GGE[16]
- **53.72** – Ethanol carbon intensity (2021) in gCO2e/MJ[9]
- **4** – Public and private E85 fuel stations in Oregon[52]

Ethanol is the most common gasoline substitute, with more than 98 percent of U.S. gasoline containing some amount of ethanol. It is a renewable, alcohol-based fuel, made by fermenting and distilling crops, such as corn, sugar cane, sorghum, and wheat. It can also be made by using some agricultural waste products which reduces the carbon intensity of the fuel even more[86] Ethanol oxygenates the gasoline, causing it to burn hotter and cleaner and reducing air pollution and greenhouse gas emissions. Ethanol contains about 30 percent less energy than gasoline per gallon.[ii] Ethanol's impact on vehicle fuel economy is dependent on the ethanol content in the fuel and whether an engine is optimized to run on gasoline or ethanol. [87]

Figure 11: Ethanol Share of Oregon Transportation Consumption in 2020

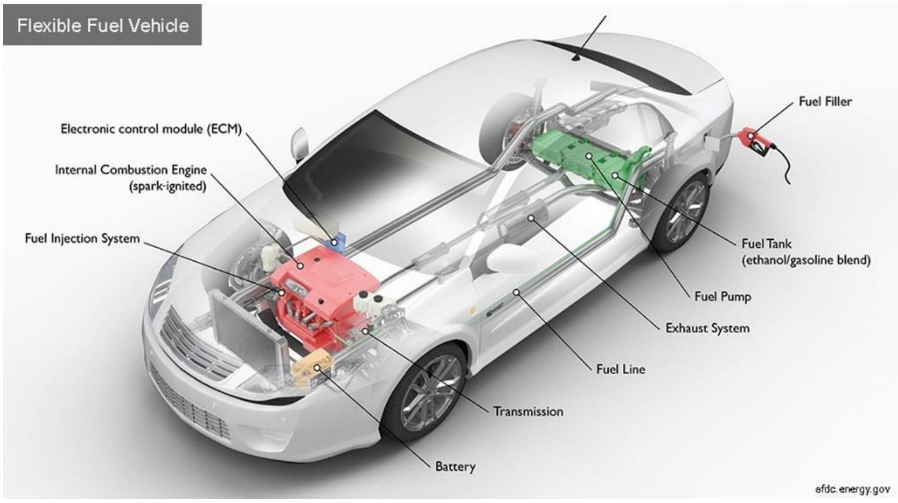


[ii] Based on 98 percent denatured ethanol.

Why do we put ethanol in gasoline?

Ethanol was a replacement for methyl tert-butyl ether (MTBE), which was blended with gasoline from 1979 to 2005. Both ethanol and MTBE improve fuel octane ratings and support more complete combustion of gasoline. MTBE was itself a replacement for lead, added to gasoline by automotive engineers starting in the 1920s to reduce engine knock and improve performance. Health research in the 1960s determined vehicle engine exhaust was exposing the population to lead, leading to chronic negative health effects, particularly in children.[88] In 2005, fuel refiners switched from MTBE to fuel ethanol due to groundwater contamination concerns. [89,90]

Oregon's renewable fuel standard requires that nearly all commercially available gasoline for light-duty vehicles has a 10 percent ethanol blend, called E10. Ethanol is added to gasoline to help oxygenate the gas, causing the fuel to burn more completely. Thus, ethanol-infused gases produce cleaner emissions with less GHG emissions, leading to better air quality.[91]



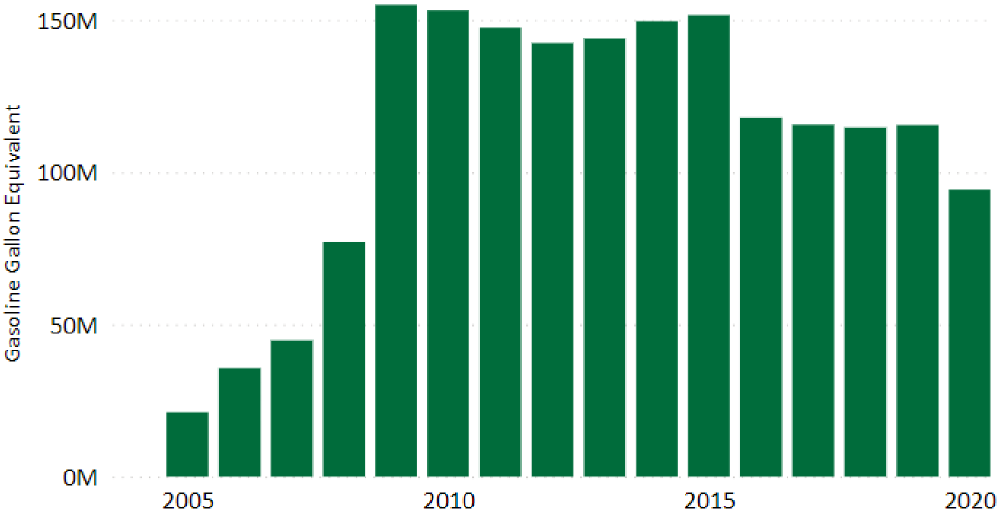
The most common use of ethanol is as a blending agent for gasoline. Oregon's renewable fuel standard requires most gasoline sold in Oregon to be a 10 percent ethanol and 90 percent gasoline blend called E10.[92] Ethanol is also available as E85 or flex-fuel, which is a gasoline blend with 51 to 83 percent ethanol. E85 can be used in flexible fuel vehicles, which are designed to operate on any blend of gasoline and ethanol up to 83 percent.[93] Another blend, E15 with up to 15 percent ethanol, was approved for use in passenger vehicle model years 2001 and newer.[86] The Oregon Legislature passed HB 3051 in 2021, allowing retailers to offer higher ethanol blends like E15 for commercial sale. In 2022, President Biden issued an executive order allowing E15 to be sold from June to September 2022 to reduce price pressures at the pump due to rising global crude oil prices resulting from the war in Ukraine.

Table 1: Comparing Carbon Intensities of Pure Gasoline vs. Ethanol Blends[9]

	gCO2e/MJ	CI Reduction from Gasoline	Percent Change
Pure Gasoline	100.14	-	-
E10	95.50	4.64	5%
E15	93.18	6.96	7%
E85 (51%)	76.46	23.68	24%
E85 (83%)	61.61	38.53	38%
Ethanol	53.72	46.42	46%

Trends and Potential

Figure 12: Oregon On-Highway Ethanol Consumption by Year[11]



Ethanol consumption and production have steadily increased in the United States, matching increased use of gasoline. In 2020, U.S. ethanol production reached 1,886 trillion Btu, a 3 percent increase from the 1,823 trillion Btu produced in 2010. Ethanol has lower tailpipe emissions than gasoline, but the lifecycle emissions of ethanol can vary widely depending on the feedstock and processing method. California, Washington and Oregon have enacted low carbon fuel standards for transportation fuels that encourage lower carbon ethanol production methods. To meet these standards, many first-generation production facilities are investing in energy and production efficiency improvements as well as carbon capture technologies to lower the carbon intensity of the ethanol they produce.[94]

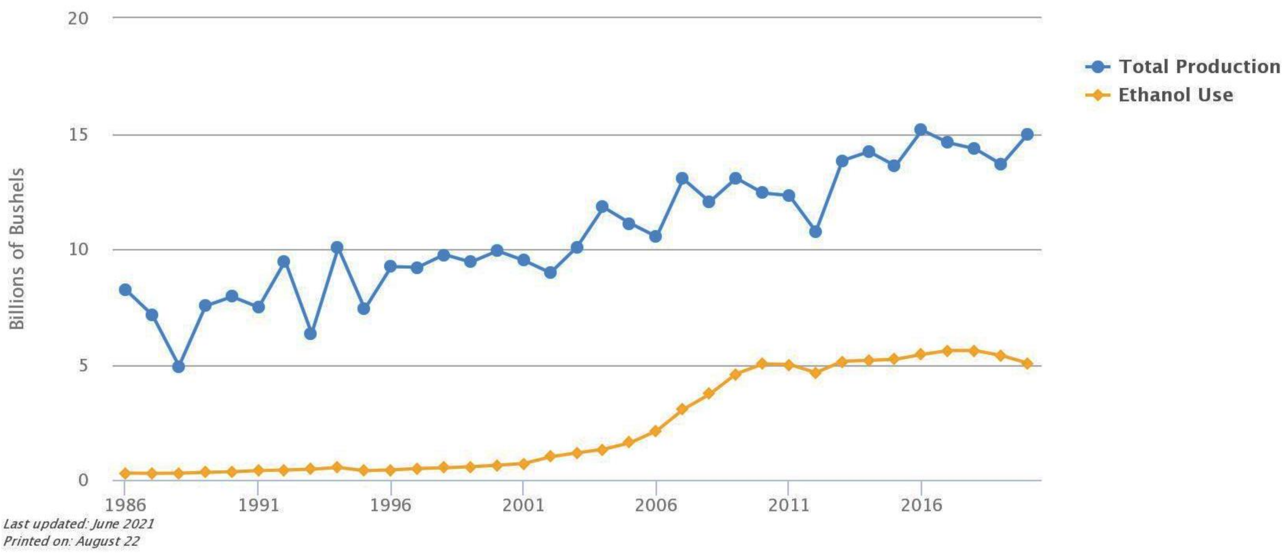
Ethanol plant in Clatskanie, OR.

A small amount of ethanol is produced in Oregon. Oregon began producing fuel ethanol in 2007 and had its largest production year in 2008 with 10.3 trillion Btu of energy created. In 2020, Oregon produced five trillion Btus or 43 million gallons of ethanol.[95] The Alto Columbia production plant in Boardman is the largest transportation fuel and commercial ethanol producer in the state. The plant uses corn as its feedstock and captures the associated carbon dioxide emissions for use by the local food and beverage industry. The carbon dioxide is used to create a beverage-grade liquid used to carbonate soft drinks and make dry ice.[96,97]

Beyond Energy

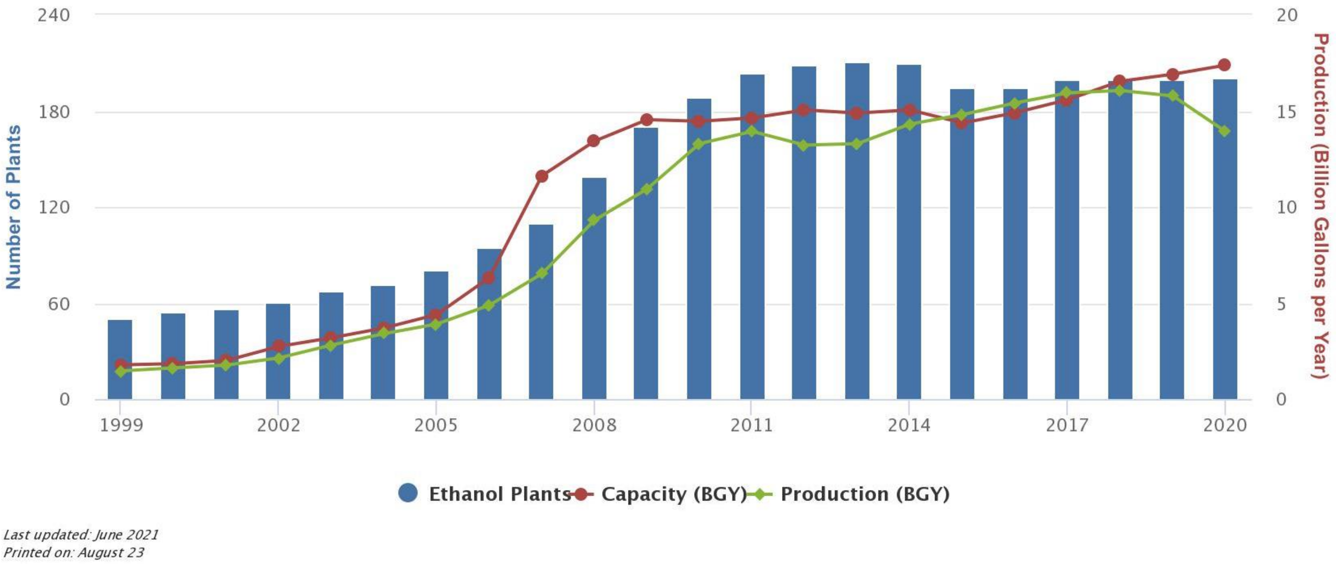
Ethanol production plants are commonly located in rural areas, offering local employment and economic opportunities. However, crop-based feedstocks such as corn and soybeans could compete for land resources that might otherwise be used for food crops. The U.S. Department of Energy estimates that 94 percent of ethanol currently produced in the United States is derived from domestically grown corn. This reduces the United States reliance on foreign crude oil and improves energy security but the tradeoff is that this agricultural land could have been used for food production.

Figure 13: U.S. Corn Production and Portion Used for Fuel Ethanol[98]



The United States Department of Agriculture chart above shows total U.S. corn production and the corn used to produce ethanol from 1986 to 2020. Corn used for ethanol production increased between 2001 and 2010, as nearly all gasoline was transitioned to a blend with 10 percent ethanol.[98] Analysis has found increased land used for ethanol and biofuel production in the U.S. may increase global GHG emissions, due to higher crop prices motivating farmers in other countries to convert forest and cropland. Deforestation releases carbon stored in vegetation, preventing the future storage of carbon in those plants. A potential solution may be to use more waste products to generate the fuel.[99] The United States agriculture sector has taken steps to address concerns around acreage attributed to corn as an ethanol feedstock by improving processing efficiencies to produce more ethanol per bushel.[100] Processing capacity is increasing while mitigating the acreage needed to keep up with domestic demand. The chart below shows the number of ethanol plants operational in the United States from 1999 through 2020. Plant capacity has increased while the number of operational plants has leveled off; average plant sizes are increasing and production is becoming more efficient.[101]

Figure 14: U.S. Ethanol Plants, Capacity, and Production[101]

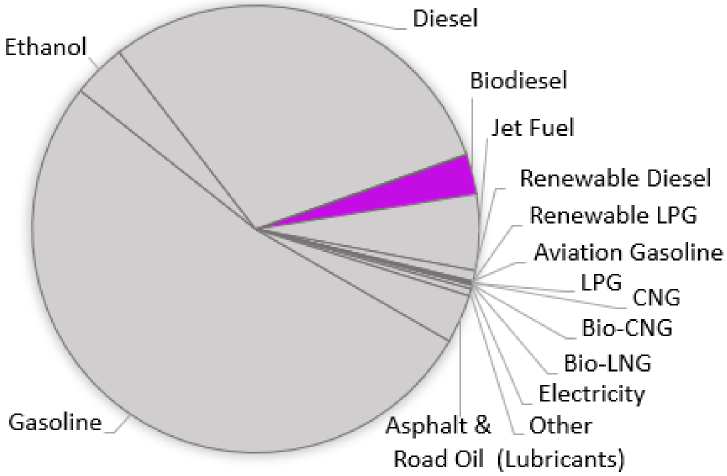


Increasing the amount of ethanol in a gasoline blend reduces the carbon intensity of the fuel. On average, corn-based ethanol produces 45 percent lower emissions than pure gasoline. Other feedstocks can support further lifecycle greenhouse gas emission reductions, improve the sustainability of ethanol as a transportation fuel, and reduce competition for agricultural land. Cellulosic ethanol—created using waste products such as wood or corn kernel fiber or from dedicated crops that need less water or fertilizers to grow like switchgrass or poplar and willow trees—is now available in commercial quantities. Cellulosic ethanol feedstocks are estimated to reduce GHG emissions by between 88 and 108 percent, compared with gasoline and diesel production and use.[86,102]

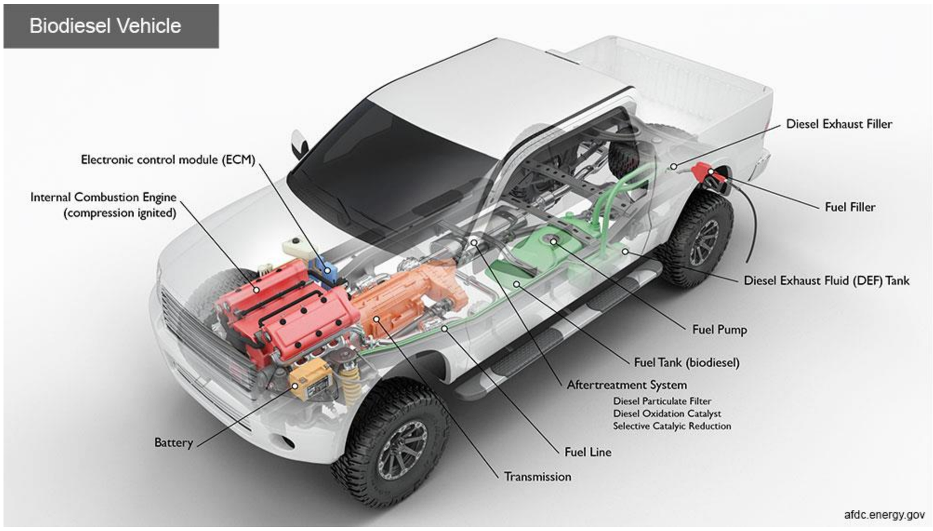
Biodiesel

- **70,292,133** – Total biodiesel consumed in Oregon (2020) GGE[11]
- **12,878,161** – Total biodiesel produced in Oregon (2020) GGE[16]
- **41.84** – Biodiesel carbon intensity (2021) in gCO2e/MJ[9]
- **33** – Public and private fuel stations in Oregon[52]

Figure 15: Biodiesel Share of Oregon Transportation Consumption in 2020



Biodiesel is created from fats, oils, and greases and is currently the predominant form of biomass-based diesel. Rudolf Diesel, the inventor of the diesel engine, originally considered vegetable seed oil as the fuel to run his engine, an idea that eventually led to biodiesel production as an alternative to petroleum diesel fuel.[6] When blended with diesel fuel it can be used by standard diesel trucks, buses, trains, and boats. Oregon's Renewable Fuels Standard requires all diesel fuel sold in the state to include a 5 percent biomass-based diesel blend, known as B5. Similarly, a 10 percent biodiesel blend, B10, 20 percent biodiesel, B20, and any blend up to B99 are also offered in the state.



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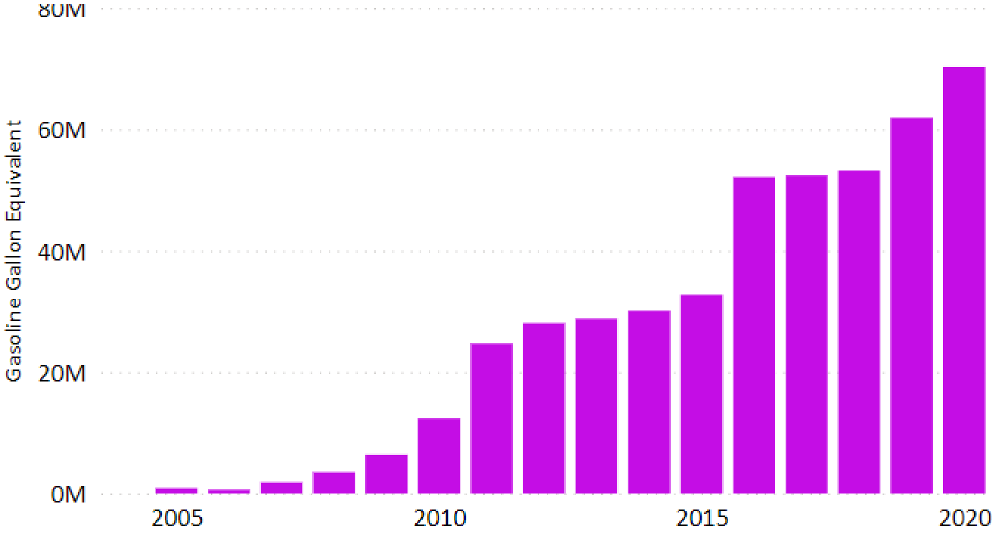
In 2020, Oregonians consumed 19 million gallons of B5 and 77,000 gallons of B20. Growth in B20 consumption in Oregon can be attributed to federal and state renewable fuels standards, Oregon's tax credit for in-state-produced B20 and the Clean Fuels Program. In some cases, retail B20 in Oregon costs less per gallon than B5 because Oregon Department of Environmental Quality's Clean Fuels Program reduces costs for fuel providers to below standard B5 costs.[7]

Biodiesel tends to gel at lower temperatures, so it is usually blended with renewable or petroleum diesel at a ratio of no more than 20 percent for use in most diesel vehicles. For this reason, biodiesel is not generally used as a full replacement for diesel unless the engine has been modified for higher blends, and most vehicle manufacturers recommend that their engines use up to a B20 blend. Biodiesels may also absorb water when stored, resulting in potential microbial growth in the fuel.[103] Not all petroleum product pipelines can transport biodiesel, but in Oregon the Kinder Morgan pipeline carries B5 to Eugene.[43]

Trends and Potential

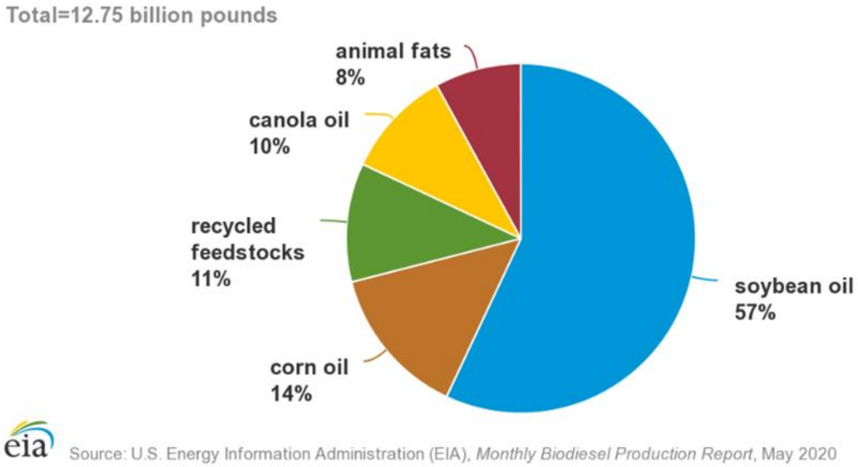
Figure 16: Oregon On-Highway Biodiesel Consumption by Year[11]



In 2020, Oregon produced 1.5 trillion Btu or almost 13 million gallons of biodiesel. SeQuential Pacific Biodiesel in Salem is the largest producer of biodiesel and the second-largest producer of transportation fuels in Oregon. SeQuential produces biodiesel from used cooking oil collected from local restaurants and businesses.[104] About 85 percent of the fuel SeQuential produces is sold in Oregon as part of a biodiesel blend, while the remainder is exported to regional neighbors Washington, California, Hawaii, and British Columbia.[105]

In the U.S., the production of biodiesel reached almost 235 trillion Btu in 2020. EIA estimates that 57 percent of the biodiesel in the United States is produced from soybean oil. Animal fats, used cooking oil, canola, and corn oil largely make up the rest of the feedstock.[106] Soybean production is projected to grow, but the biodiesel industry is hoping to achieve higher output through advanced technologies and new feedstocks such as algal oil from marine algae. The U.S. Department of Energy estimates that algae could produce 30 times more energy per acre than other biofuel crops.[107]

Figure 17: Feedstock Inputs to U.S. Biodiesel Production (2019)[106]



Source: U.S. Energy Information Administration (EIA), *Monthly Biodiesel Production Report*, May 2020

Biodiesel consumption has increased in Oregon. In 2015, Oregonians consumed 3.9 trillion Btu of biodiesel fuel and in 2020, Oregonians consumed 8.8 trillion Btu, an 122 percent increase over that span. Biodiesel consumption growth in Oregon may be affected by the production and supply of renewable diesel, an alternative petroleum diesel fuel that also qualifies under the federal and state renewable fuel standards. Oregon's Clean Fuels Program estimates regional production and available supply of renewable diesel will increase.

Beyond Energy

Producing biodiesel in Oregon can lead to retaining more transportation dollars in the state and reduce reliance on imported petroleum fuels. Greater production and storage of fuels in Oregon could improve energy security, support energy resilience during future catastrophic events, and create local employment and economic opportunities. Although biodiesel is flammable, it is safe to handle, store, and transport, potentially creating less damage than petroleum diesel if spilled or leaked into the environment.[108]

Blending biodiesel with petroleum diesel reduces the lifecycle greenhouse gas emissions compared to diesel fuel combustion—and where the fuel can be produced close to where it is consumed also reduces the carbon emissions associated with transporting fuel. In 2020, the Oregon Clean Fuels Program estimated biodiesel to have an average carbon intensity of 58 percent less than petroleum diesel.

Table 2: Comparing Carbon Intensity of Diesel, Biodiesel, and Blends[9]

	gCO2e/MJ	CI Reduction from Diesel	Percent change
Diesel	100.74	-	-
Biodiesel	41.84	58.90	58%
B5	97.79	2.95	3%
B10	94.85	5.89	6%
B15	91.90	8.84	9%
B20	88.96	11.78	12%
B50	71.29	29.45	29%

Because biodiesel is generally created from soybeans, canola, and other starch-producing crops, there is the potential for competition with food crops. If producing fuel is more lucrative than growing food, land historically used to produce food may transition to fuel crops. There is a risk that demand for more low-carbon fuels may increase deforestation in other countries to create arable land for fuel crops. In the United States, production yield of edible oils and animal feed have steadily increased with existing acreage, mitigating some land allocation concerns, as biofuel production facilities improve efficiency. There is also a greater potential for waste-based feedstocks such as used cooking oil and tallow to be a primary source of biodiesel. Several biofuel companies are looking at growing algae in brackish and saltwater to mitigate land-use effects. Although this feedstock is far from being available at a commercial scale, algal oil presents an opportunity to mitigate the land and resources needed to create biofuels as it can be grown on land not appropriate for farming and uses saltwater or brackish wastewater, although other potential environmental effects are not known.

Zero Tailpipe Emission Fuels

For the transportation sector to meet Oregon's clean energy goals, the state will need to transition to an entirely zero-emission fleet powered by hydrogen and electricity. These fuels have zero tailpipe emissions, though there may be emissions from the production of that fuel depending on how it is produced. For the entire lifecycle of these fuels to be zero emission, they would need to be produced from zero-emission resources such hydropower, wind, and solar. These resources are abundant and can be produced and supplied in Oregon. Fueling infrastructure, which will need to be operated and maintained, is also needed to support greater adoption of these fuels. The development of renewable energy and fueling supports more transportation fuel jobs in the state and retains more transportation fuel dollars. Producing more transportation fuels improves Oregon's energy security by reducing dependence on petroleum-based fuels that are extracted and processed outside the state. This can also reduce the volatility of transportation fuel costs due to global impacts on crude oil prices, such as the Russian war in Ukraine or OPEC crude production agreements.

Zero emission tailpipe fuels not only reduce greenhouse gas emissions, they also reduce other harmful air pollutants, such as small particulates and oxides of nitrogen. These pollutants are so small they can enter a person's bloodstream through the lungs, and lead to greater incidences of respiratory ailments, heart attacks, and premature death.[109] The effects of these pollutants contribute to increased hospitalizations and absences at work and school. Greenpeace Southeast Asia and the Centre for Research on Energy and Clean Air (CREA) quantified the annual economic costs of air pollution from petroleum fuels to be $600 billion for the United States alone.[110] Further, the health effects of poor air quality are not evenly shared, but more often affect children, the elderly, people of color, and people with lower incomes.[111]

Every Mile Counts

Zero-emission and renewable fuels are an essential piece of Oregon's plan to reduce greenhouse gas emissions in the transportation sector. Every Mile Counts is a collaboration of the Oregon Departments of Transportation, Energy, Environmental Quality, and Land Conservation & Development to develop and implement interagency actions that address greenhouse gas emissions. Agencies focus on three core strategies: supporting use of cleaner vehicles and fuels, reducing vehicle miles traveled per capita, and considering GHG emissions in state decision-making, with priority efforts focused on transportation electrification and cleaner fuels, in addition to supporting transportation options and local GHG reduction planning. Agencies coordinate on regulatory actions, planning activities, data collection, and developing metrics to track progress on GHG reductions.

Hydrogen

- **0** – Total hydrogen consumed in Oregon (2020) GGE[11]
- **0** – Total hydrogen produced in Oregon (2020) GGE[16]
- **156.83** – hydrogen carbon intensity (2021) in gCO2e/MJ[80]
- **0** – Public and private fuel stations in Oregon[7]

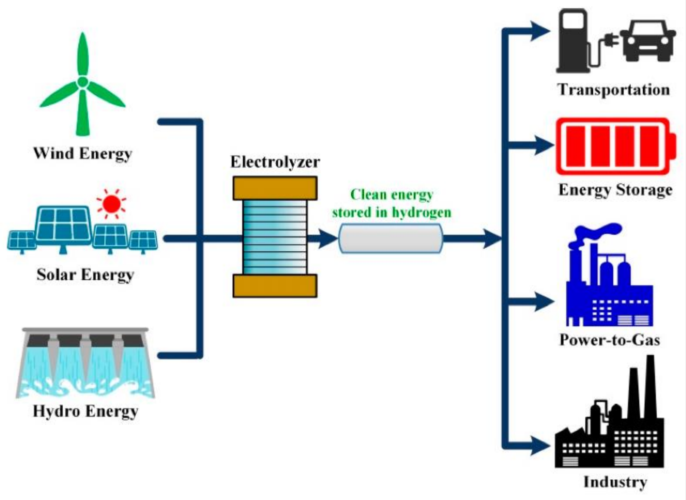
Hydrogen is the most abundant element on Earth, but extracting it efficiently from source materials can be challenging. Currently, about 95 percent of hydrogen produced in the United States is made from natural gas through a process called steam-methane reforming. This process is one of the most cost-effective for producing hydrogen, but also one of the most carbon intensive. There's growing interest globally in pairing steam-methane reforming with carbon capture and storage to produce low-carbon hydrogen. Hydrogen can also be produced using electricity to power an electrolyzer, which splits water into hydrogen and oxygen; when the electricity used is from renewable sources, the resulting hydrogen is also considered renewable.

What is a steam-methane reforming?

Steam-methane reforming is a process to produce hydrogen from natural gas. Methane, usually from natural gas, reacts with steam under pressure and in the presence of a catalyst to produce hydrogen, carbon monoxide, and a relatively small amount of carbon dioxide. Steam reforming can also be used to produce hydrogen from other fuels, such as ethanol, propane, or even gasoline.[112]

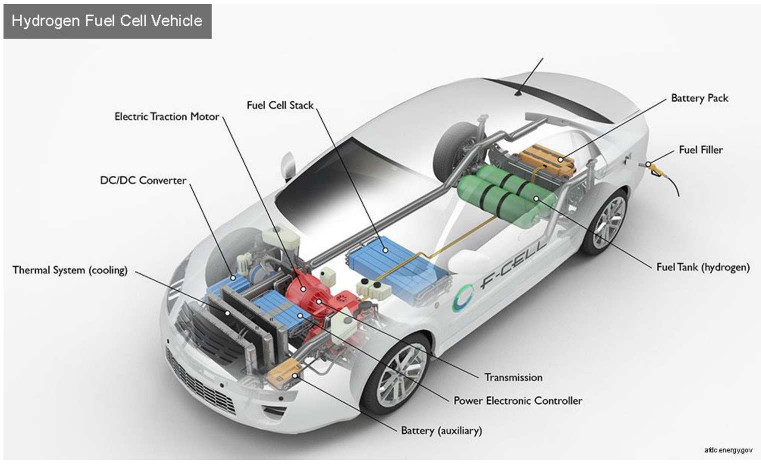
What is an electrolyzer?

Electrolysis is the process of using electricity to split water into hydrogen and oxygen. The reaction takes place in an electrolyzer. They range in size from small, appliance-size equipment for small-scale distributed hydrogen production to large-scale, central production facilities that could be tied directly to renewable electricity production like hydroelectric dams, solar or wind farms.



Today, most hydrogen is used for industrial applications such as oil refining, steelmaking, and production of ammonia and methanol.[113] However, low-carbon and renewable hydrogen are increasingly seen as important decarbonization options, especially for so-called "hard to abate" sectors where there aren't a lot of options to reduce emissions, like the industrial and transportation sectors.

Trends and Potential



It's unclear how large a role light-duty fuel cell electric vehicles (FCEVs) will play in reducing transportation greenhouse gas emissions in Oregon given the current strong adoption of electric vehicles and growing charging infrastructure. Currently, there are only a few models of light-duty FCEVs available, and they have higher upfront costs and maintenance costs than battery electric vehicles. However, hydrogen is more attractive as a fuel for medium- and heavy-duty applications, including transit buses and long-haul trucking. FCEVs offer longer ranges, quicker refueling times, and do not have performance issues in cold temperatures. The Portland metropolitan area's public transit system, TriMet, completed a feasibility study to consider hydrogen fuel cell buses. TriMet's Zero Emission Bus Transition Plan, completed for the Federal Transit Administration in May 2022, includes hydrogen fuel cell buses as part of the fleet transition plan, assuming a source of green hydrogen becomes available. Lane Transit District has also indicated interest in hydrogen fuel cell buses because of their extended range as compared to battery electric buses.

Two challenges associated with use of hydrogen as a transportation fuel in Oregon are the lack of fueling infrastructure and the lack of local hydrogen production. Oregon is working with the Federal Highway Administration to successfully designate its portion of I-5 as an alternative fuels corridor, which could support development of hydrogen fueling stations. Additionally, Oregon and Washington are collaborating on a joint application for up to $1 billion in funding from U.S. DOE for a regional clean hydrogen hub. A successful award would help finance additional production of hydrogen in the region, some of which would be available for transportation end uses.[114]

Hydrogen refueling station in Berkeley, CA.

Learn more about vehicles in Oregon using hydrogen in the Clean and Efficient Vehicles Technology Review.

Beyond Energy

Hydrogen presents new economic opportunities in Oregon,[iii] but the infrastructure development needed to produce and supply hydrogen around the state is a significant barrier to widespread adoption. Hydrogen production is not currently cost-competitive with petroleum fuel, but given the interest in hydrogen and renewable hydrogen in Oregon and new funding available from the federal government, it's likely that production will ramp up in the coming years.

[iii] For more information, see the Oregon Department of Energy's *2022 Renewable Hydrogen Report* (Available November 15, 2022): https://tinyurl.com/ODOE-Studies

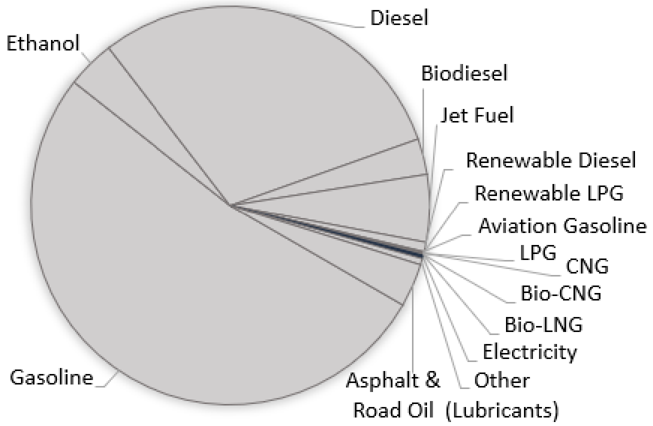
Hydrogen has the potential to reduce air pollution and lifecycle greenhouse gas emissions in Oregon. No matter how the hydrogen is produced, using hydrogen in a fuel cell electric vehicle creates zero local air pollution or tailpipe greenhouse gas emissions. Like many alternative fuels, however, the amount of lifecycle greenhouse gas reductions depends on the resources used to create the hydrogen. Where hydrogen can be produced from renewable or low-carbon electricity sources—such as producing renewable hydrogen using an electrolyzer powered by renewable electricity—the overall emissions are much lower.

Electricity

- **6,495,585** – Total electricity consumed for transportation in Oregon (2020) GGE[11]
- **63,624,782** – MWh of Total electricity generated in Oregon (2020)[115]
- **25.35** – electricity carbon intensity (2021) in gCO2e/MJ[9]
- **2,193** – Public and private fuel stations in Oregon[116]

Electricity used as a transportation fuel is growing rapidly in the passenger vehicle sector and is increasingly used for medium- and heavy-duty trucks, port equipment, construction equipment, and other non-road vehicles. Electricity is produced from a variety of energy sources, including hydropower, natural gas, coal, nuclear, wind, and solar. Electric vehicles (EVs) use this electricity to charge battery packs on the vehicle that discharge the electricity to electric motors, which propel the vehicle.[117] Most EVs are charged at home or at a business, but chargers are increasingly available for the public to use across the state to fuel electric vehicles quickly when needed. To learn more about vehicles in Oregon using electricity, please visit the Clean & Efficient Vehicles Technology Review.

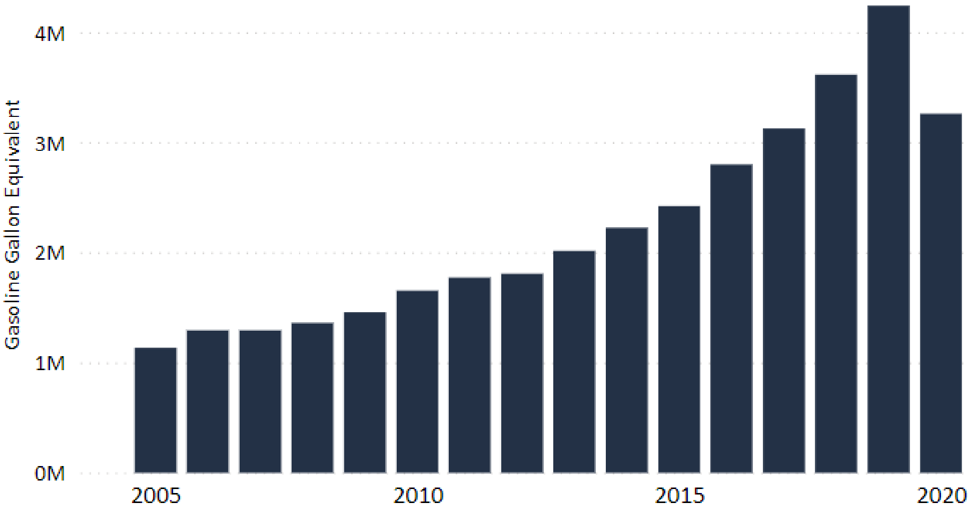
Figure 18: Electricity Share of Oregon Transportation Consumption in 2020



Trends and Potential

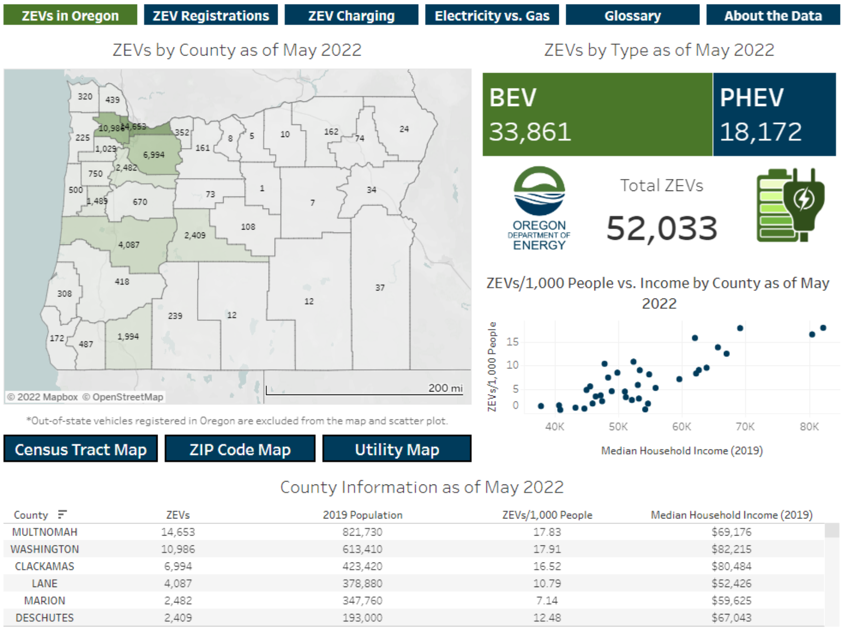
Electricity is expected to quickly become a larger portion of Oregon's transportation fuel mix. In 2010, only 0.08 percent of Oregon's transportation fuel consumption came from electricity. In 2020, 0.27 percent of Oregon's transportation fuel consumption came from electricity, demonstrating steady market growth. Electric charging stations are being installed

Figure 19: Oregon On-Highway Electricity Consumption by Year[11]



around the state, with more than 2,193 publicly available stations as of July 2022 to support the 50,000+ registered electric vehicles on Oregon roads.

As electric vehicles become more popular, demand for electricity will increase and Oregon's electric utilities must plan to meet this market change. While the average electric passenger vehicle generally draws similar amounts of power as household appliances, widespread adoption of EVs will require utilities to plan for this growth in their forecasting of distribution system-level needs.



ZEVs by County as of May 2022

ZEVs by Type as of May 2022

Total ZEVs 52,033

ZEVs/1,000 People vs. Income by County as of May 2022

*Out-of-state vehicles registered in Oregon are excluded from the map and scatter plot.

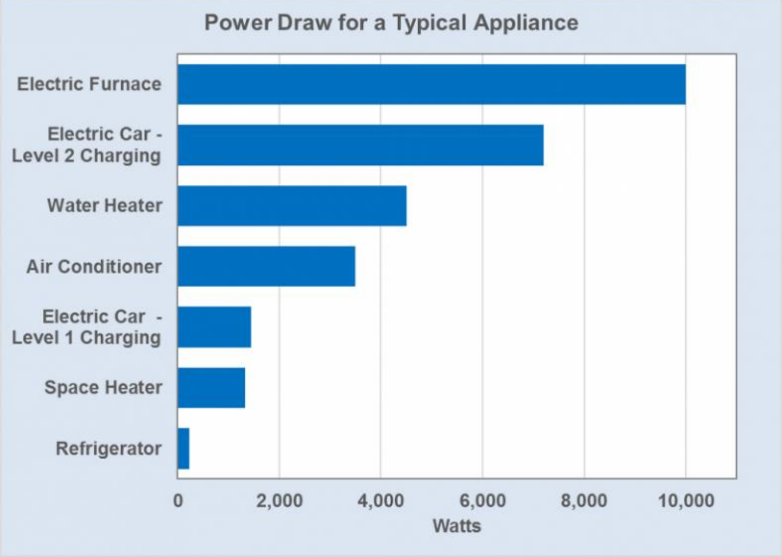
County Information as of May 2022

County	ZEVs	2019 Population	ZEVs/1,000 People	Median Household Income (2019)
MULTNOMAH	14,653	821,730	17.83	$69,176
WASHINGTON	10,986	613,410	17.91	$82,215
CLACKAMAS	6,994	423,420	16.52	$80,484
LANE	4,087	378,880	10.79	$52,426
MARION	2,482	347,760	7.14	$59,625
DESCHUTES	2,409	193,000	12.48	$67,043

ODOE's Electric Vehicle Dashboard: https://tinyurl.com/ODOEEVDashboard

In its transportation electrification plans for Oregon, Pacific Power forecasts to have approximately 29,000 EVs in its territory by 2025, and Portland General Electric expects around 30,000 light-duty EVs by the end of 2025. Both utilities are preparing multiyear Transportation Electrification Plans for PUC acceptance, including programs to assist customers with installing EV charging while managing added load on the utility system. Utility plans include developing market transformation strategies to promote electric vehicle adoption while planning to manage the new load on their systems.[119]

Figure 20: Power Draw for a Typical Appliance[118]



Many federal and state policies support increased EV adoption. The Inflation Reduction Act of 2022 expanded federal tax credits available for many individuals and businesses that purchase an EV, and businesses can get an additional tax credit for purchasing and installing chargers.[120,121] To learn more about EV incentives and the Inflation Reduction Act of 2022, please visit the Clean and Efficient Vehicles Technology Review. In 2021, President Biden signed an executive order directing the federal government to achieve 100 percent zero-emission vehicle[iv] acquisitions by 2035, including 100 percent zero-emission light-duty vehicle acquisitions by 2027.[122] At the state level, DEQ administers the low- and zero-emission vehicle standards which mandates an increasing percentage of sales be electric or fuel cell. This

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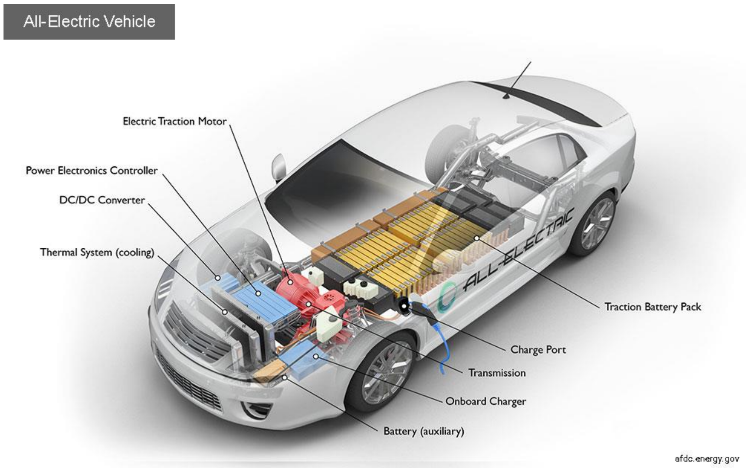
[iv] Zero-emission vehicles may also include hydrogen fuel cell electric vehicles.

applies to both passenger vehicles and trucks. Oregon has established ZEV adoption goals for the state, including 250,000 registered vehicles by 2025 and 90 percent of sales by 2035.[123] DEQ also administers a rebate program for the purchase or lease of passenger electric vehicles: https://www.oregon.gov/deq/aq/programs/pages/zev-rebate.aspx.



Several state agencies have programs that support EV adoption such as DEQ's Clean Fuels Program, which is a market-based credit and debit system that helps reduce the carbon intensity of Oregon's transportation fuel mix. Electricity is lower in GHG emissions than gasoline, so using electricity as a fuel generates credits in the program providing an incentive to use less carbon intensive fuels. DEQ is also developing a pilot program to provide grants for medium- and heavy-duty vehicle charging infrastructure through a $15 million program funded by the 2022 Legislature.[124] The Department of Transportation is Oregon's lead agency for the National Electric Vehicle Incentive Program – a program designated in the federal 2021 Infrastructure Investments & Jobs Act. ODOT will be overseeing $100 million in federal and state funding to support EV charging throughout the state.[125] This new effort will be informed by ODOT's Transportation Electrification Infrastructure Needs Analysis, which delivers an overview of EV charging infrastructure needs and policy options to enable access to electric fuel for all Oregonians.[126]

Zero Emission Vehicle Interagency Working Group

Transportation electrification is such an important step the state needs to take towards achieving long-term climate goals, Governor Kate Brown established the "ZEVIWG" to ensure that efforts are coordinated. The ZEVIWG is a multi-agency team that coordinates and plans actions to support access to zero emission vehicles, fueling infrastructure, and providing education and outreach on their use, benefits, and costs. This engagement helps agencies increase awareness, coordinate efforts, leverage work, address barriers, and find solutions. An annual workplan guides individual actions and acts to keep track of efforts that have been implemented.

Beyond Energy

Oregonians driving EVs will have lower overall greenhouse gas emissions than driving a gasoline or diesel vehicle no matter where they charge their electric vehicle in the state. Using electric fuel coupled with the greater efficiency of an electric motor reduces greenhouse gas emissions by 50 to nearly 100 percent. Customers of consumer-owned electric utilities have some of the cleanest electricity because they receive power mainly from Bonneville Power Administration's nearly carbon-free resources – hydropower and nuclear.[127] As Oregon's utilities work to meet the state's 100 percent clean electricity targets by 2040, driving an EV will continue to get cleaner. The Clean Fuels Program also has a provision that allows charger owners to purchase and retire Renewable Electricity Credits

(RECs) to claim carbon-free electricity which makes it easier for Oregon's EVs to charge with renewable electricity.

EVs also have zero tailpipe emissions, reducing local air pollutants such as particulate matter and oxides of nitrogen, which can cause negative health effects, especially to communities near industrial and heavily trafficked areas. These are often historically disadvantaged communities, such as low-income, elderly, disabled, and communities of color.[42]

Charging an electric vehicle at home can cost less than 20 percent of the fueling cost of a comparable fossil fuel vehicle, and other operational and maintenance costs are about half.[128] The Oregon Department of Energy's Electric Vehicle Dashboard provides Oregonians with a tool to calculate electric vehicle costs in comparison to gasoline-powered vehicles: tinyurl.com/ODOEEVDashboard. Electricity rates, when home-charging, have less price volatility than other transportation fuels as they are regulated by Oregon's Public Utility Commission or the governing boards of consumer-owned utilities. Fueling costs for publicly accessible EV chargers tend to be much more expensive. Public charging companies have widely different rates, fees and may include a monthly subscription plan. ODOE evaluated one of the leading EV charging companies as an example and determined the costs to charge a vehicle at a public station were still lower than gas – about 35 to 50 percent – but were two to three times more than an average Oregonian would pay charging at home.[128]

The growth of electric vehicles has dramatically increased the demand for batteries and the minerals like lithium, cobalt and nickel needed to produce them. Acquiring the volume of minerals needed will be difficult but also labor, economic, and environmental concerns have been raised about the mining and processing of these metals. These difficult supply chain and geopolitical barriers may hinder the U.S. auto industry's ability to meet the demand for electric vehicles.[129] To learn more about batteries in electric vehicles, please visit the Clean & Efficient Vehicles Technology Review.

Equitable access to the lower costs and environmental benefits of EVs is a growing concern. Using electricity as a transportation fuel requires investment in a new vehicle, a significant financial barrier for low-income Oregonians and smaller businesses. Where someone lives and works affects how easy it is to charge an EV. Not all Oregonians have convenient access to home charging where they park their vehicles and public charging is significantly more expensive. This has implications for Oregonians living in multi-unit dwellings or other locations without access to home charging, who are more often low-income and communities of color. To learn more about electricity charging infrastructure and potential policy challenges, see the Oregon Department of Energy's 2021 Biennial Zero Emission Vehicle Report: https://www.oregon.gov/energy/energy-oregon/Pages/BIZEV.aspx.

Renewable Transportation Fuels

Renewable transportation fuels are biomass-based fuels that typically have lower carbon intensities than their petroleum-based versions, offering significant reductions in carbon emissions. Produced from biomass sources, these fuels are nearly chemically identical to petroleum-based fuels and can be used in existing conventional vehicles and fuel infrastructure.[130] [131] In addition to lower greenhouse gas emissions, renewable fuels also have lower air pollutant emissions, including lower small particulate matter which can be a harmful air pollutant. Feedstocks for these fuels include fatty substances like vegetable oils, animal fats, greases, and algal products, or cellulosic materials such as dedicated energy crops, crop residues, and woody biomass.[131] Some of these feedstocks are waste that would otherwise end up in landfills, while others are created for the express purpose of providing a transportation fuel. These fuels could be produced in Oregon, offering the potential for local job creation and increased energy security.

Table 3: Comparing Carbon Intensities of Fossil-Based and Renewable Fuels

	Average Carbon Intensity (2021) in gCO2e/MJ	CI Reduction from Petroleum Fuel	Percent Change
Gasoline	100.14	TBD	TBD
Renewable Gasoline	TBD		
Diesel	100.74	63.76	63%
Renewable Diesel	36.98		
Compressed Natural Gas	79.98	59.43	74%
Renewable Natural Gas	20.55		
Liquid Natural Gas	86.88	66.33	76%
Renewable Natural Gas	20.55		
Propane	80.88	46.22	57%
Renewable Propane	34.66		

Often referred to as "drop-in" fuels, renewable fuels can use existing fueling infrastructure and can simply be added to the tank of an existing fossil fuel vehicle. Access to the fuels is largely driven by the availability of feedstocks, fuel processing facilities, and distribution points. Oregon's Clean Fuels Program provides a market that incentivizes lower-carbon fuels delivered into the state, making them more price competitive with petroleum fuels. This has led to increased availability and adoption of these fuels, particularly renewable diesel, in Oregon. Some renewable fuels, such as renewable propane, are blended with fossil propane by distributors because the supply is not yet consistent enough to sell separately to Oregon customers. Renewable diesel and renewable natural gas are more mature within the market and are created, distributed, and sold separately from their fossil counterparts, although they may still be blended in with petroleum fuels for transport and distribution.[132]

Even with the support of Oregon's Clean Fuels Program, the cost of some renewable fuels is greater than fossil counterparts due to the limited feedstock and production facilities of these relatively new transportation fuels—but as Oregon's market matures, the costs for these fuels are dropping.[7] California's Low Carbon Fuel Standard also provides credits to reduce the carbon intensity of transportation fuels used in that state. Many alternative fuel producers distribute their supply to

California and Oregon taking advantage of lucrative credit market prices.[133] Development of new or the expansion of existing renewable fuel production plants in the Northwest are increasing the availability of fuel supplies.[132] Other influences, such as world economies, oil prices, carbon markets, and the political climate play a role in determining renewable fuel prices, supply and demand.

Renewable Gasoline

- **0** – Total renewable gasoline consumed in Oregon (2021) GGE[11]
- **0** – Total renewable gasoline produced in Oregon (2020) GGE[16]
- **TBD** – renewable gasoline carbon intensity (2021) in gCO2e/MJ
- **0** – Public and private fuel stations in Oregon

Renewable gasoline is any fuel that is made from biomass and is compatible with and can be used by existing gasoline-fueled engines. There are no commercially available renewable gasoline alternatives that can fully replace gasoline in Oregon. Isobutanol, a renewable fuel that is similar to ethanol, can be blended with gasoline to reduce the carbon intensity of the fuel. Isobutanol has a higher energy content than ethanol, meaning isobutanol gasoline blends will power a vehicle further than ethanol gasoline blends.[134] In 2021, the U.S. Environmental Protection Agency approved the use of isobutanol as a blended fuel up to 16 percent of fossil gasoline.[135]

Trends and Potential

Renewable gasoline is not yet commercially available in Oregon but there is research and development currently going into potential production facilities.[130] Existing regional biofuel producers have expressed interest in developing a supply of renewable gasoline for the Northwest, but 2024 is likely the earliest Oregon would see commercially available product. Biofuel company Gevo began producing a renewable, corn-based isobutanol and fossil gasoline blend for the Seattle, WA area.[136] In 2019, Gevo was awarded a contract to supply at least 20,000 gallons per year of renewable isobutanol and 600,000 gallons per year of renewable isooctane to the City of Seattle to be used by its fleet of vehicles.[137]

Beyond Energy

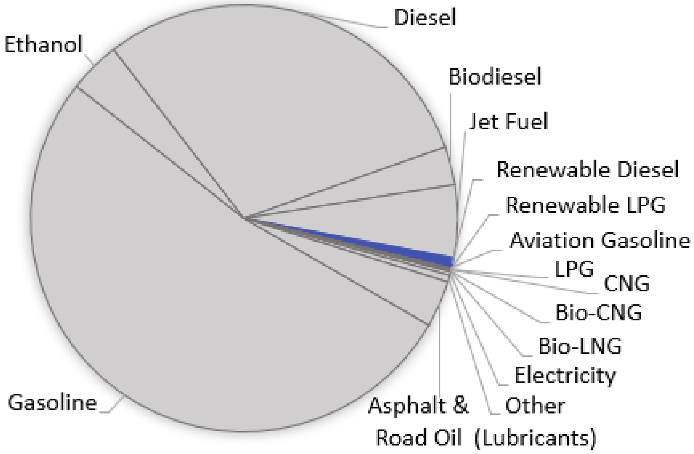
If a commercially viable renewable gasoline production method can be developed, there is potential for the product to be produced in Oregon or the Pacific Northwest from a variety of locally available biomass feedstocks. Regional production could offer increased energy security, job creation, and other economic benefits. Consumption of renewable gasoline, as an alternative to petroleum gasoline, would reduce greenhouse gas emissions because the carbon dioxide released from burning the renewable fuel is offset by the carbon dioxide captured by growing the feedstocks.[131] The EPA's lifecycle greenhouse gas analysis for the U.S. Renewable Fuel Standard program determined Isobutanol blends or renewable gasoline produce 65 to 130 percent fewer carbon emissions than gasoline, depending on the feedstock and production process.[138] Some of the feedstocks could be grown or collected in Oregon, supporting a transportation fuel economy in Oregon and increasing the state's energy independence.

Renewable Diesel

- **18,617,155** – Total renewable diesel consumed in Oregon (2020) GGE[11]
- **0** – Total renewable diesel produced in Oregon (2020) GGE[16]
- **36.98** – renewable diesel carbon intensity (2021) in gCO2e/MJ[9]
- **43** – Estimated public and private fuel stations in Oregon[139]

Renewable diesel fuel, sometimes called green diesel, is a low carbon intensity biofuel made from waste or renewable materials, including rendered tallow, fish waste, used cooking oil, inedible corn oil, soybean oil, canola oil, and other biomass resources.[140] It is chemically identical to petroleum diesel fuel and can be used in existing petroleum pipelines, storage tanks, and engines without modification or blending.[106] In 2020, the United States consumed over 960 million gallons, about a quarter of which was produced domestically and the rest is imported, mostly from Singapore-based refineries.[131]

Figure 21: Renewable Diesel Share of Oregon Transportation Consumption in 2020



While both renewable diesel and biodiesel are made from biomass feedstocks, they are produced using different manufacturing processes and create fuels with different characteristics. Renewable diesel production removes impurities and compounds that make the fuel cleaner and more stable than biodiesel.[103] These differences in production result in a colorless, odorless fuel that performs better at lower temperatures, reduces engine maintenance and costs, and improves overall vehicle performance.[140] Renewable diesel can fully replace fossil diesel in existing vehicles and fuel infrastructure, whereas biodiesel must be blended with petroleum diesel at no more than 20 percent to avoid engine performance and fuel degradation issues. It can also be stored for longer periods without the degradation in quality that can occur with other biofuels, making it a good option for backup fuel storage.[141] Renewable diesel is available as a standalone fuel called R100, or as a blend with petroleum diesel or biodiesel. A blend of 20 percent renewable diesel and 80 percent petroleum diesel is called R20, and a blend of 5 percent renewable diesel and 95 percent of petroleum diesel is called R5. A blend of 20 percent renewable diesel, 20 percent biodiesel, and 60 percent petroleum diesel is called RD20B20.[106]

Table 4: Renewable and Petroleum Diesel Blends

Blend	Name
Renewable Diesel	R100
Renewable Diesel 20% + Petroleum Diesel 80%	R20
Renewable Diesel 5% + Petroleum Diesel 95%	R5
Renewable Diesel 20% + Biodiesel 20% + Petroleum Diesel 60%	RD20B20

TriMet's Transition to R99 Renewable Diesel[172]

In December 2021, TriMet made the transition to renewable diesel (R99) for its fleet of 7,306 fixed-route buses after awarding a contract to Carson Oil Company, which partnered with Neste Renewable Diesel to secure a dedicated supply of R99 large enough to meet TriMet's operational requirements.

Five months later, TriMet announced a new contract for LIFT paratransit and WES commuter rail vehicles to switch to renewable diesel via a mobile fueling contract with Bretthauer Oil Company. Unlike the renewable diesel that is delivered for TriMet's fixed-route buses and stored in underground tanks at the garages, the fuel for TriMet's 265 LIFT vehicles and 6 WES trains comes directly from the delivery vehicles due to lack of on-site fuel storage at the LIFT and WES operations facilities. This fueling takes time for the truck driver to fuel each vehicle individually, and the fueling must be done overnight. This was a more challenging contract to procure due to the limited availability of additional, but not yet dedicated, renewable diesel in Oregon. Additionally, there is a persistent, severe national shortage of licensed HAZMAT-certified commercial truck drivers, making it impossible for most fuel distributors to be able to reliably meet TriMet's operational requirements on when fueling must be scheduled (365 nights per year, including weekends and all holidays) without exception.

The constrained supply of renewable diesel in Oregon limits the ability of other large users of diesel from taking this important step to reduce transportation emissions. Oregon state regulations lead to lower returns for renewable diesel manufacturers than California and Washington, so there is some risk of supply being diverted to those two states.

The move to renewable diesel in TriMet's fixed-route buses, and now LIFT vehicles and WES trains, combined with the shift to renewable electricity in June 2021 for MAX trains and all TriMet-owned facilities, reduces TriMet's greenhouse gas emissions by nearly 70 percent. TriMet estimates that with these climate actions, it will avoid more than 193 million pounds of greenhouse gas emissions each year. That is equivalent to taking almost 19,000 automobiles off the road, according to the Environmental Protection Agency.

Transit service inherently reduces GHG emissions by providing an alternative to driving alone. Frequent transit service and high-capacity transit projects like light rail, streetcar, and bus rapid transit encourage transit-oriented development that supports more walking, biking, and shorter driving trips, all of which reduces emissions. Nationally, the benefit in emissions reductions due to transit is estimated to be six times what is emitted in providing the service.[v] However, this change is important to TriMet because the agency was the largest consumer of diesel in the Oregon prior to making the shift to renewable diesel. Making this change reduces carbon emissions and directly improves air quality in the communities that TriMet serves.

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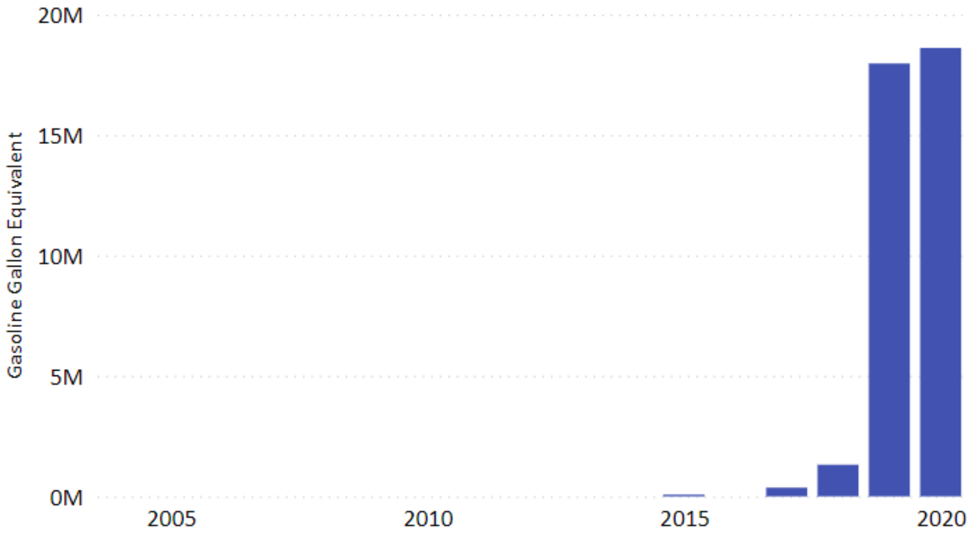
[v] https://nap.nationalacademies.org/catalog/26103/an-update-on-public-transportations-impacts-on-greenhouse-gas-emissions

Trends and Potential

Figure 22: Oregon On-Highway Renewable Diesel Consumption by Year[11]



Renewable diesel consumption is growing rapidly in Oregon as fleets that incorporate the fuel in their operations have positive performance results.[106] From 2018 to 2020, Oregon consumption increased from 1.2 million gallons to 17.6 million gallons or about 3 percent of all diesel fuel consumed in Oregon. The DEQ's Clean Fuels Program has driven this rapid growth, incentivizing delivery, and use of renewable diesel in the state. In CFP's 2022 program review to the Oregon Legislature, DEQ identified renewable diesel as the "primary drop-in fuel to generate credits and reduce deficits with the existing diesel vehicle fleet."

Oregon is an increasingly attractive market for renewable diesel distributors. Historically, California used nearly all the renewable diesel produced or imported into the U.S. because of the economic advantage provided by the California Air Resources Board's Low Carbon Fuel Standard. This program incentivizes the sale of lower-carbon fuels through a market-based credit and debit system, providing distributors with more revenue to offset the higher costs of selling lower carbon fuels in California. In 2016, Oregon became the second state to implement such a low carbon fuels standard – DEQ's Clean Fuels Program. Monetization of CFP credits helps offset the generally higher expense of providing lower carbon fuels such as renewable diesel, which is more expensive than petroleum diesel.[142,143]

Apart from ethanol and biodiesel, renewable diesel is the most widely adopted alternative transportation fuel in Oregon. CFP's forecast of 2022 fuel consumption in Oregon estimates consumption of renewable diesel will increase by 64.3 percent over 2020.[144] Renewable diesel demand in Oregon can exceed supply, and therefore many fleets must also have access to B5 and B20 diesel blends to supplement their fuel needs.[145] Access to renewable diesel outside of the Willamette Valley is limited due to additional delivery cost, demand volumes, and the number of storage tanks allocated to hold renewable diesel. Fleet demand for the fuel means renewable diesel is rarely available at retail stations, limiting access to the fuel, especially for smaller businesses that rely on commercial retail outlets for their fuel purchases, but availability is beginning to expand to other parts of the state.

Supply is largely constrained by limited production capacity in the U.S. and competition for global renewable diesel production. Five plants currently produce renewable diesel in the United States, with a combined capacity of over 590 million gallons per year, or just over 2 percent of all diesel consumed in the U.S. in 2020.[146,147] Production across the country is expected to grow with 2 billion gallons of capacity from six plants currently under construction and the expansion of three existing plants. The

BP Cherry Point plant near Bellingham, WA is the only renewable diesel refining facility operating in the Pacific Northwest. In October 2021, BP announced plans to invest $45 million in this refinery to double renewable diesel production capacity to an estimated 2.6 million barrels a year.[148] A renewable diesel production facility capable of processing up to 50,000 barrels per day is going through DEQ's air and water quality permit process in Port Westward, OR. It is likely that other domestic manufacturing facilities will be developed as demand grows.[149]

Increased use and storage of renewable diesel may improve Oregon's fuel resilience in response to an earthquake or other major disaster. Renewable diesel is chemically equivalent to fossil diesel and can fully replace fossil diesel in existing vehicles (patrol and fire trucks, heavy equipment, etc.), can be used in existing fuel infrastructure (storage tanks, pipelines, etc.), and can be mixed with fuels offering emergency responders valuable flexibility during an event. With a longer shelf-life than biodiesel, renewable diesel can support emergency preparation, response, and recovery activities. This will be important to keep in mind as state and local jurisdictions develop fuel storage capacity to improve Oregon's seismic disaster resilience as directed by SB 1567. The Oregon Department of Energy will be developing an Energy Security Plan for Oregon that will consider renewable diesel. The plan will be published in 2024.

Increased use and storage of renewable diesel may improve Oregon's fuel resilience in response to an earthquake or other major disaster.

Beyond Energy

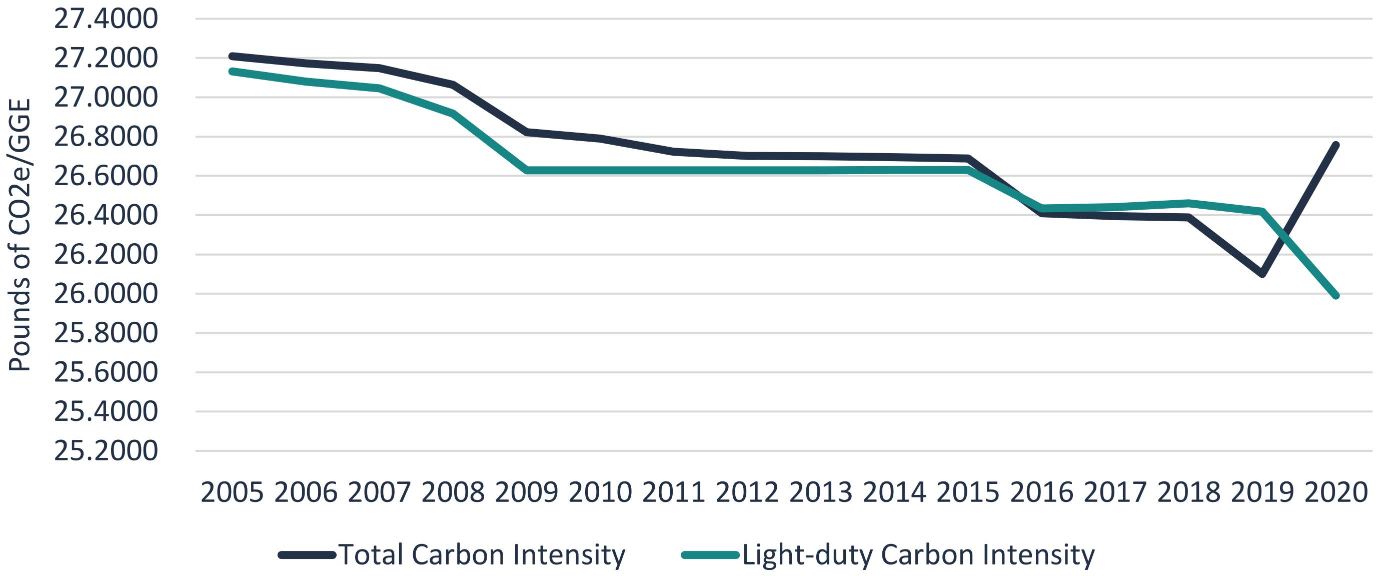
Renewable diesel can be created from a variety of feedstocks, so the resulting lifecycle of greenhouse gas emissions can vary widely. Emissions are calculated based on energy inputs to transport and process the feedstocks, transport the refined fuel, and final combustion. Greenhouse gas emissions are lower when renewable diesel feedstocks and processing is closer to the end-use and when the energy used to transport and process the feedstocks is cleaner, such as solar- or wind-generated electricity. Lifecycle greenhouse gas emissions of renewable diesel are up to 85 percent less than fossil diesel. Waste products such as tallow and used cooking oil offer the greatest reductions in emissions while vegetable oils are slightly less. Moreover, feedstocks such as animal fats and used cooking oil offer the benefit of producing renewable diesel from waste products that might otherwise end up in landfills or other waste streams.

The feedstocks used to produce renewable diesel can also have implications for land use and food production. Most renewable diesel produced today is created from animal fats or food waste as demand for the fuel has increased agricultural feedstocks like soy are being used. This could put transportation fuel crops in direct competition for land with food production.[150] In 2022, soy oil prices reached record highs, attributed to growth in renewable diesel and a constrained vegetable oil market resulting from the war in Ukraine (Russia and Ukraine are both leading grain suppliers).[151] Palm oil, another renewable diesel feedstock, may be grown in ways that contribute to unsustainable deforestation practices.[152] Deforestation practices can have greater negative environmental impacts than the benefits of producing renewable diesel from these sources. Palm oil plantations that do not meet EPA criteria for *existing* agricultural land do not qualify as renewable biomass for the federal

Renewable Fuel Standard because they cannot achieve a minimum 20 percent reduction in lifecycle emissions.[153]

Figure 23 shows that greenhouse gas emissions per gallon dropped more than 10 percent in Oregon from 2016 to 2019, largely driven by biodiesel and renewable diesel adoption in medium- and heavy-duty vehicles. The teal line shows relatively flat per gallon emissions in the passenger vehicle sector during that same period. In 2020, the trends reversed as transportation consumption changed due to the pandemic. Passenger vehicle use declined and medium and heavy-duty vehicle use increased.

Figure 23: On-Road Fuel Carbon Intensity (Pounds of CO2e/GGE) [154]



Combustion of renewable diesel produces less air pollution than fossil diesel because its chemical composition makes it burn more completely, reducing the particulate matter, nitrogen oxides, and carbon monoxide expelled from tailpipes. A blend of R50 – a 50 percent renewable diesel and 50 percent fossil diesel blend – reduces particulate matter from combustion by 15 percent. Using R100, or 100 percent renewable diesel, reduces particulate matter in emissions by 34 percent. This is significant because diesel fuel exhaust has been linked to various negative health outcomes including mortality, exacerbation of asthma, chronic bronchitis, respiratory tract infections, heart disease, and stroke.[155] Many vulnerable communities are located near high traffic areas and commercial and industrial facilities, causing greater exposure to diesel exhaust air pollutants.[42] A 2011 study of Portland air toxics discovered that, "In Multnomah County, census tracts with higher than average Black/African American, Asian/ Pacific Islander, and/or Latino residents have two to three times more exposure to diesel particulate matter than census tracts with 90 percent or more non-Latino white populations."[156]

Table 5: Pollutant and Reductions from Renewable Diesel Blends[157]

Pollutant	Pollution Reduction from R50 Blend	Pollution Reduction from R100
Particulate Matter (PM)	15%	34%
Nitrous Oxides (NOx)	5%	10%
Carbon Monoxide (CO)	8%	12%

Greenhouse Gas Emissions Study

In 2022, Oregon's Clean Fuels Program commissioned a study by University of California Davis' Policy Institute for Energy, Environment, and the Economy to evaluate potential fuel carbon intensity reduction targets that would need to be achieved by 2035. One modeled scenario expanded:

- The supply of renewable diesel to meet 25 percent of diesel market demand
- Passenger car electrification
- Adoption of other renewable fuels

This scenario demonstrated a robust 37 percent reduction in carbon intensity of transportation fuels in Oregon. The modeled air pollution reduction would decrease atmospheric carbon dioxide, ammonia, and sulfur dioxide from tailpipe emissions by 30 percent. The decrease in fossil diesel air pollution alone would have an economic value of over $19.5 million from avoided health impacts. Overall, the study determined Oregon's Clean Fuels Program targets will reduce pollutant emissions in Oregon and "reduce the incidence of air quality-related health impacts, thereby reducing anticipated premature mortality by around 12 deaths per year in 2035."[158]

Although the upfront cost of renewable diesel is more than petroleum diesel, vehicle maintenance cost savings and improved performance may offset or even overcome this higher cost.[10] The Eugene Water & Electric Board used renewable diesel in a portion of its fleet and determined it had less wear and tear on engines and particulate filter systems compared with fossil diesel, decreasing truck maintenance issues and costs.[159] In 2021, TriMet – Oregon's largest consumer of diesel – transitioned its entire bus fleet to renewable diesel. Although fuel costs increased by about $0.09 a gallon, TriMet anticipated renewable diesel would reduce bus maintenance labor and material costs by as much as $100,000 per year.[160] The 2020 Biennial Energy Report featured Titan Trucking, which converted its fleet and turned to 100 percent renewable diesel: https://energyinfo.oregon.gov/blog/2021/3/8/titan-freight-systems-goes-renewable-and-saves. Renewable diesel can also be blended with diesel at any ratio, allowing fleet owners the option to add renewable diesel in amounts that fit their budgets.

Development of new fuel production facilities within Oregon, even those focused on delivering renewable diesel, face significant barriers as they must address air and water quality, zoning, noise, traffic, and other concerns of the surrounding community. Renewable fuels produced at facilities may be used by fleets locally or shipped to other locations, so even if a facility produces a cleaner fuel, the local community may not realize the immediate air quality benefits.

ODOT and Renewable Diesel

In 2021, the Oregon Department of Transportation consumed 840,679 gallons of renewable diesel or 37 percent of the agency's total diesel use. ODOT started using renewable diesel in its fleet in 2016 and today it powers 10-yard semi-trucks, graders, loaders, tractors, sweepers, snow blowers, light trucks, and a variety of critical response vehicles. Consumption of renewable diesel has steadily increased and ODOT has discovered a variety of benefits without performance issues. The diesel engines require less forced regeneration, which occurs when emission particulates build up inside diesel engine filters to the point the vehicle is no longer operable. This leads to less maintenance needed from ODOT's technicians.

Renewable diesel can be stored for long periods like fossil diesel and does not separate over time or have the microbial growth that has been a challenge of some biofuels. Bulk storage tanks are cleaner, requiring less maintenance and cleaning of tanks, which is especially beneficial in remote locations that are used seasonally. ODOT uses renewable diesel even more in winter months as it performs better at colder temperatures with no gelling issues. Lower emissions and fuel odors have improved the air quality of service areas. The cost of renewable diesel to ODOT has been comparable to a winterized blend of B5, or an estimated $0.03 - 0.07 per gallon more, than standard non-winterized B5.

Greater adoption of renewable diesel has presented ODOT with logistic and supply challenges as not all locations are able to get renewable diesel. During some winter weather events, the demand of renewable diesel exceeds the amount allocated by the supply chain. ODOT staff have also needed to allocate time to training staff and vendors about renewable diesel. For example, technicians unfamiliar with the odorless and colorless fuel may mistake it for water in the fuel tank and misdiagnose engine problems. Overall, ODOT has discovered the benefits outweigh the challenges of incorporating a new fuel. The agency plans to use more renewable diesel as regional supply increases and work to get all of their locations access to it.[161]

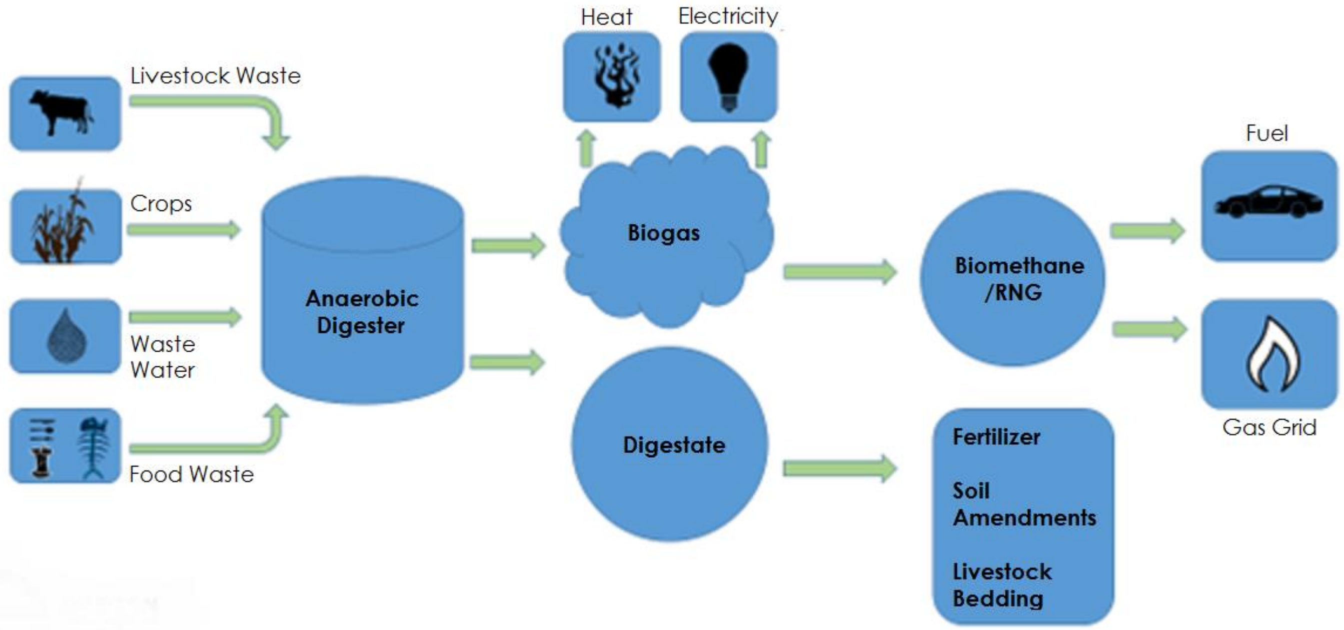
Renewable Natural Gas

- **3,205,366** – Total renewable natural gas consumed in Oregon (2020) GGE[11]
- **TBD*** – Total estimated renewable natural gas produced in Oregon (2020) GGE[16]
- **56.58** – renewable natural gas carbon intensity (2021) in gCO2e/MJ[9]
- **5** – Public and private fuel stations in Oregon[52]

**Comprehensive Oregon production data isn't available.*

Renewable natural gas, or biomethane, is a fuel derived from biogas, a methane byproduct of municipal waste streams such as garbage, wastewater, and waste food or agricultural waste streams like manure. Once collected, biogas can be processed to remove or reduce water, carbon dioxide, hydrogen sulfide, and other trace elements. This process, called conditioning or upgrading, results in a product that is referred to as renewable natural gas.[vi] RNG has a higher content of methane than raw biogas, making it comparable to conventional natural gas and suitable for vehicle applications. Like conventional natural gas, RNG can be used as a transportation fuel in the form of compressed natural gas (CNG) or liquefied natural gas (LNG) to power cars, trucks, or ships.[162]

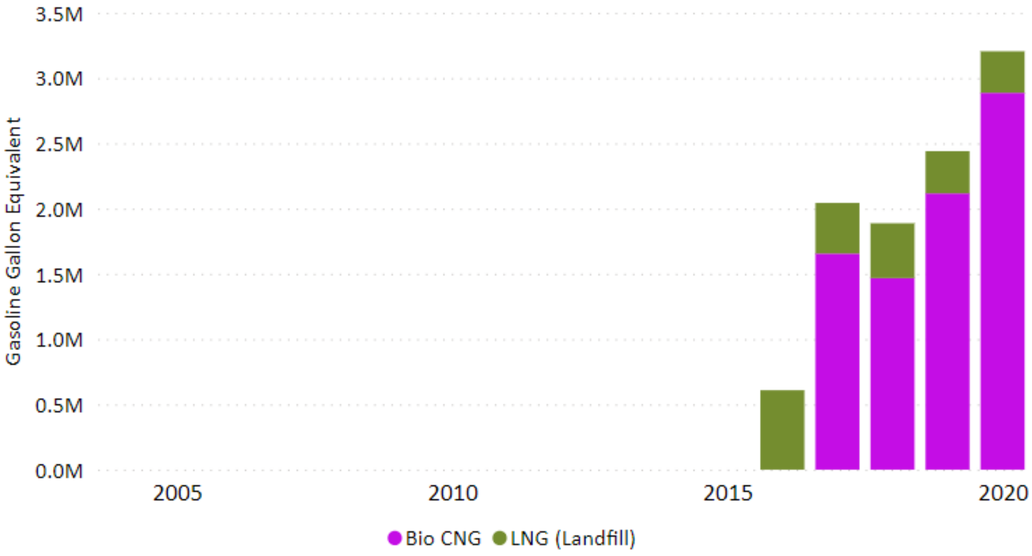
Figure 24: Potential RNG Pathways



Trends and Potential

Renewable natural gas consumption as a transportation fuel has grown in the last few years, with interest in RNG reducing greenhouse gas emissions and replacing natural gas. In 2017, Oregonians consumed 490 thousand GGE of renewable natural gas for transportation and in 2020, Oregon's consumption reached 3.2 million GGE, a 55 percent increase over that

Figure 25: Oregon On-Highway RNG Consumption by Year[11]



[vi] The differentiation between biogas and renewable natural gas is not clearly defined and is largely determined by the end-user needs and criteria.

span. Oregon is also a producer of renewable natural gas, with three projects operating in the state, one built but not yet operational, and five in development. The three operational facilities are converting the biogas they produce into RNG and injecting it into a natural gas pipeline.[163] Once in the pipeline, the RNG can be used as a transportation fuel, but may also be sold for other uses such as residential and commercial heating or industrial processing.

RNG availability is anticipated to increase as Oregon gas utilities invest in and contract for RNG production to reduce greenhouse gas emissions. RNG is a central pillar to these utilities meeting the requirements of the Oregon Department of Environmental Quality's Climate Protection Program, which establishes a declining cap on GHG emissions from petroleum fuels, including natural gas.[21] ODOE's 2018 Biogas and Renewable Natural Gas Inventory indicates about 4.5 percent of Oregon's natural gas needs could be met with renewable natural gas derived from commercially available technologies (anaerobic digestion) and an additional 17.5 percent from forest and agricultural residuals when advancements in gasification techniques become commercially viable.[167] The 17.5 percent from technological advancements could meet about 29 percent of all direct and transportation gas use (not including power generation) in the state.[54] As part of the *Vision 2050: Destination Zero Carbon Neutrality Scenario Analysis* report, NW Natural plans to invest $30 million annually to replace 5 percent of its fossil gas with renewable natural gas by 2024.[164] Avista and Cascade Natural Gas, Oregon's other two natural gas utilities, also plan to incorporate more RNG into their systems.[165] [166]

ODOE's 2018 Biogas and Renewable Natural Gas Inventory indicates about 4.5 percent of Oregon's natural gas needs could be met with renewable natural gas derived from commercially available technologies.

It is uncertain how much RNG will be available as a transportation fuel in Oregon. RNG can be used for fleets at fuel production sites, such as fueling garbage trucks with RNG derived from landfill biogas. ODOE's RNG inventory indicates significant financial incentives are available for the sale of RNG as a transportation fuel, largely provided through the monetization of credits received through state and federal clean and renewable fuels programs. However, lack of public accessibility to RNG limits the effectiveness of these incentives. ODOE's RNG inventory identified three major challenges for RNG to become widely available as a transportation fuel: the high cost of technologies necessary to clean and inject RNG into pipelines, the high cost to connect RNG resources to common carrier pipelines, and limited existing fueling depots. Few RNG production sites are located next to natural gas pipelines and building pipelines is expensive.[167] Biogas-to-electricity sites have been created in Oregon in locations where natural gas cannot be delivered directly into a truck fleet or pipeline. Biogas is collected and burned to generate electricity. The electricity produced can generate renewable energy credits and carry negative carbon intensities if the renewable electricity is used to charge electric vehicles. Biogas and renewable natural gas can also be stored and used as a renewable feedstock to create hydrogen, renewable diesel, or other fuels.

Beyond Energy

Renewable natural gas redirects existing methane waste streams into controlled processes for optimization, capture, and utilization of the biogas, offering economic, social, and environmental benefits.[168] Capturing and using RNG in Oregon's transportation fuels sector can provide local economic development opportunities. RNG production facilities could be located throughout the state at wastewater treatment facilities, landfills, large farms, and dairies. Local development of transportation fuels improves Oregon's energy security and helps retain more transportation-related dollars in the state, and as we decarbonize the economy, limited RNG may have a better use as a transportation fuel. Local production of RNG can also support transportation energy resilience by providing a local resource for transportation fuel in the event of fuel distribution disruptions. RNG combustion emits fewer air pollutants than petroleum-based fuels, improving local air quality in Oregon communities.[169]

Biogas facilities capture methane – a powerful greenhouse gas – from sources like landfills and animal waste, preventing them from being directly emitted into the atmosphere. Conversion to RNG and then combustion as a transportation fuel emits carbon dioxide, but lifecycle emissions for RNG (20.55 gCO2e/MJ) are considerably less than gasoline (100.14 gCO2e/MJ) and diesel (100.74 gCO2e/MJ). RNG created from the methane of confined animal feeding operations such as a dairy has a negative carbon intensity because capturing emissions at a facility far surpass the carbon emissions from producing the fuel. ODOE's Biogas and Renewable Natural Gas Inventory determined, "If the volume of RNG that could be potentially captured and utilized in Oregon displaced fossil fuel natural gas for stationary combustion, approximately 2 million metric tons of fossil fuel-based carbon dioxide would be prevented from entering the atmosphere."[167] Oregon's Department of Environmental Quality estimates that 64.5 million metric tons of carbon dioxide equivalent were emitted by Oregon in 2019.[19]

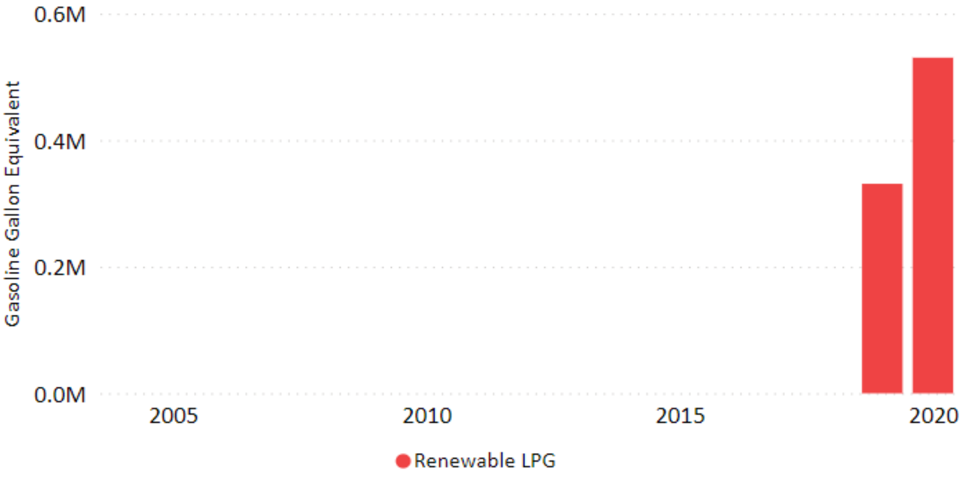
Renewable Propane

- **530,416** – Total Renewable Propane consumed in Oregon (2020) GGE[11]
- **0** – Total renewable propane produced in Oregon (2020) GGE[16]
- **41.95** – Renewable propane carbon intensity (2021) in gCO2e/MJ[9]
- **42** – Public and private fuel stations in Oregon[78]

Renewable propane is a lower carbon form of propane made from a mix of waste residues and sustainably sourced materials, including agricultural waste products, cooking oil, and animal fats. Renewable propane production is relatively new, with the first commercial production in the United States beginning in 2018. It is most often created as renewable diesel or sustainable aviation fuel is produced along with renewable naphtha and other co-products. Other methods for producing renewable propane are being studied and tested.[170] Imported into Oregon from production facilities in Los Angeles, California, it is currently available only in limited quantities and is typically mixed into existing propane supplies for distribution to propane vehicle fleets.

Trends and Potential

Figure 26: Oregon On-Highway Renewable Propane Consumption by Year[11]



As a byproduct of renewable diesel production, renewable propane supply will increase concurrently with renewable diesel production. Currently, only a fraction of the renewable propane is being delivered to the market because most of it is used on-site to fuel production plant operations.[38] Commercial availability is increasing, however, as low carbon fuel standards have created incentives for the fuel. U-Haul, the largest U.S. retailer of propane, procured one million gallons of renewable propane in 2020 and again in 2021 for retail sales at many of its California locations. U-Haul has indicated an interest in expanding this fuel to other states.[171] In 2020, Oregonians consumed 8 trillion Btu of propane for general use, .06 trillion Btu of this was renewable propane, about .77 percent. All renewable propane is imported into Oregon, but in-state production would occur if renewable diesel or sustainable aviation fuel production facilities are built.

Beyond Energy

Because of its relationship to renewable diesel production, renewable propane has many of the same economic and environmental benefits, in addition to the efficiencies of a single process to create both fuels. Production of renewable propane offers an opportunity to divert waste from landfills to be made into lower-carbon transportation fuels.[170] Renewable propane's average carbon intensity is 45 percent that of B20 diesel and fossil propane.[80] Oregon school districts or fleets who have already transitioned to use fossil propane in their school buses could transition to using renewable propane and reduce the carbon intensity of their fuels by another 45 percent.

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Energy Resource & Technology Review: Clean & Efficient Vehicles

Clean vehicles operate with fewer emissions than standard gasoline or diesel-powered vehicles, and ***efficient*** vehicles operate using less energy per mile. Zero-emission vehicles, such as battery electric, plug-in hybrid, and hydrogen fuel cell electric are the cleanest and most efficient vehicles available on the market today. Other vehicles with emissions lower than petroleum-fueled vehicles are also available, such as natural gas- and propane-fueled cars and trucks. In addition, standard internal combustion engine vehicles have largely become more efficient over time thanks to technological innovations spurred by regulations, such as the Clean Air Act.

Zero-emission vehicles, often called ZEVs, have no tailpipe emissions and are more than three times as efficient as internal combustion engine vehicles — meaning they can travel three times as far on the same amount of energy. As Oregon electric utilities decarbonize their systems to 100 percent clean by 2040, emissions associated with the electricity to fuel these vehicles will continue to go down.

Want to know more about zero-emission vehicle technologies, trends, and policies?

The *2020 Biennial Energy Report* included more background information on ZEVs and the *2021 Biennial Zero Emission Vehicle Report* includes deeper dives on ZEV trends and policies:

tinyurl.com/ODOE-Studies

Battery and Plug-In Hybrid Electric Vehicles

Timeline

- **1889** — William Morrison creates the first successful electric vehicle in the U.S. (Des Moines, Iowa).[1]
- **1935** — Electric vehicles have all but disappeared from use due to the discovery of cheap crude oil.[1]
- **1973** — The oil crisis spurs the next generation of electric vehicles (small, slow, and with limited range).[1]
- **1996** — GM introduces the EV-1, a two-seat aero-dynamic sports car with limited range. The car was discontinued in 2002.[2]
- **2008** — Tesla begins production of its first EV, the Roadster sports car, with a 245-mile range.[3]
- **2010** — Nissan releases the first modern battery electric vehicle by a major manufacturer.[1]
- **2022** — 50,000+ electric vehicle registrations in Oregon.

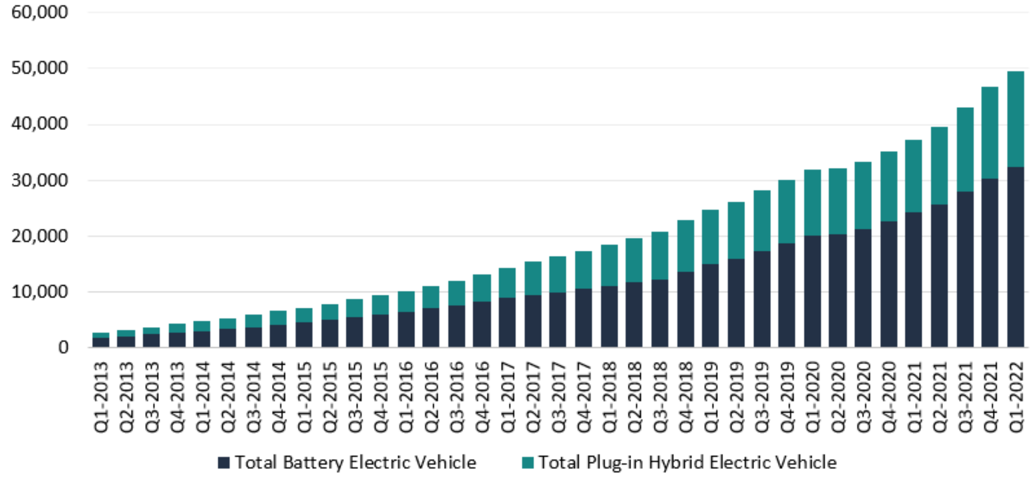
Electric Vehicles in Oregon

As of May 2022, there are **52,033 registered zero emission vehicles in Oregon**, including 33,861 battery electric EVs and 18,172 plug-in hybrids.

Battery electric and plug-in hybrid electric vehicles use batteries, either fully or in part, to supply electric fuel to the vehicle. The batteries power electric motors, which provide the force that propels the car. The vehicles are plugged into an outlet or EV charger to re-charge the battery. For more information on the technology, see the Electric Vehicles Technology Review from the *2020 Biennial Energy Report*.

Trends and Potential

Figure 1: Cumulative Registered Electric Vehicles in Oregon (2013-Q1 2022)[4]



Adoption of light-duty electric vehicles has been gaining traction in Oregon — and despite challenges of associated supply shortages due to the COVID-19 pandemic, electric vehicle adoption has continued to grow, achieving nearly 1.5 percent of total registrations as of May 2022.[4] While sales of all vehicles slowed overall during the pandemic, ZEV sales remained strong, taking over an increasingly larger market share of new vehicle purchases. At the end of 2021, ZEVs made up over 10 percent of all new vehicle sales in Oregon.[5] Much of the increase in ZEV adoption can be attributed to increased model availability, technological advancements that have increased vehicle range, and reductions in purchase cost.

In 2021, many vehicle manufacturers announced goals to produce more ZEV models, and in some cases pledged to go exclusively electric at a future date.[6] Oregon registered 14 new models of ZEV passenger vehicles in 2021 alone, including seven SUVs and the state's first registered electric pickup truck (see Table 1).[4] Technological challenges, such as microchip and other supply shortages, and control failures with battery management systems have caused delays in some models. Although demand for new electric pickup trucks was very high, delivery numbers for the two most prominent electric pickup manufacturers fell short of expectations.[7] There are also challenges for existing vehicle manufacturers to adjust their long-time business models to efficiently build and sell electric vehicles.[8] To address these issues, many auto manufacturers are committing to add their own battery manufacturing facilities, relying less on contracted subcomponents than they have for gasoline vehicles.[9] This trend will likely continue as federal funding slated for vehicle electrification requires American manufacturing and supply.[10]

EVs represent nearly 1.5 percent of total registrations in Oregon as of May 2022.

Learn more about electric vehicle models, costs, and incentives: **https://goelectric.oregon.gov**

Inflation Reduction Act Support for Zero Emission Vehicles

Tax Credits

The federal Inflation Reduction Act signed into law in August 2022 made changes to federal tax credits for electric vehicles.[11] The new law establishes a $7,500 tax credit[12] for new EVs and removes previous vehicle sales limits that had prevented Tesla and General Motors buyers from using the credit in the last few years. Tax credits are available to individuals with $150,000 taxable income or less, $225,000 for head of households, or joint households with $300,000. To be eligible, vans, pickups, or SUVs may not exceed $80,000 and all other vehicles may not exceed $55,000.[13] The law also allows for the tax credit to be made available at the point of sale beginning in 2024.[14]

One element of the new vehicle tax credit that has gained attention are requirements for sourcing supplies of minerals, locations of component processing, and workforce. To be eligible, final assembly of the vehicle must occur in North America.[12] For model year 2022, there are 26 models of EVs assembled in the U.S., including all Tesla models, Chevy Bolts, and Nissan LEAFs – the most popular models in Oregon.[15] The US DOE hosts a webpage listing qualifying models, and has a VIN tool for users to verify a vehicle meets the final assembly requirement.[i]

There are also requirements on the source of critical minerals used in the manufacturing of the EV battery. Through 2023, the battery must contain at least 40 percent of its critical minerals from domestic mines or from a country the U.S. has a free trade agreement with.[16] Resource sourcing requirements increase each year to a minimum of 80 percent by 2027. The bill also requires some domestic manufacturing of battery components. Through 2023, at least 50 percent of the *value* of battery components must be manufactured in North America. This percentage also increases by 10 percent each year until 2029, when all EV battery components must be manufactured in North America.[17] Failure to meet mineral resourcing or component manufacturing requirements will reduce the amount of the tax credit by $3,750 each.

The bill also created a tax credit of $4,000 or 30 percent of the vehicle price (whichever is lower) for used EVs. Income thresholds are $75,000 for a single filer, $112,500 for head of household, and $150,000 for joint filers. To be eligible, EVs cannot cost more than $25,000, and the used vehicle tax credit cannot be used more than once per vehicle, which must be sold by a dealership.[18] Used vehicles are not subject to the same battery and component manufacturing requirements as new vehicles.

The bill establishes a 30 percent tax credit for electric and other non-gasoline or diesel trucks. The credit for vehicles 14,000 pounds or more is capped at $40,000 or the incremental cost above the cost of a similar gas or diesel truck, whichever is lower. Vehicles under 14,000 pounds are capped at $7,500. Credits can be used by businesses through tax year 2032.[19] Tax exempt entities, such as state and local governments and many non-profit organizations are not

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[i] https://afdc.energy.gov/laws/inflation-reduction-act

eligible. The bill also reestablished a 30 percent tax credit for businesses that invest in alternative fueling installations, including electric chargers.[20,21]

Other Incentives

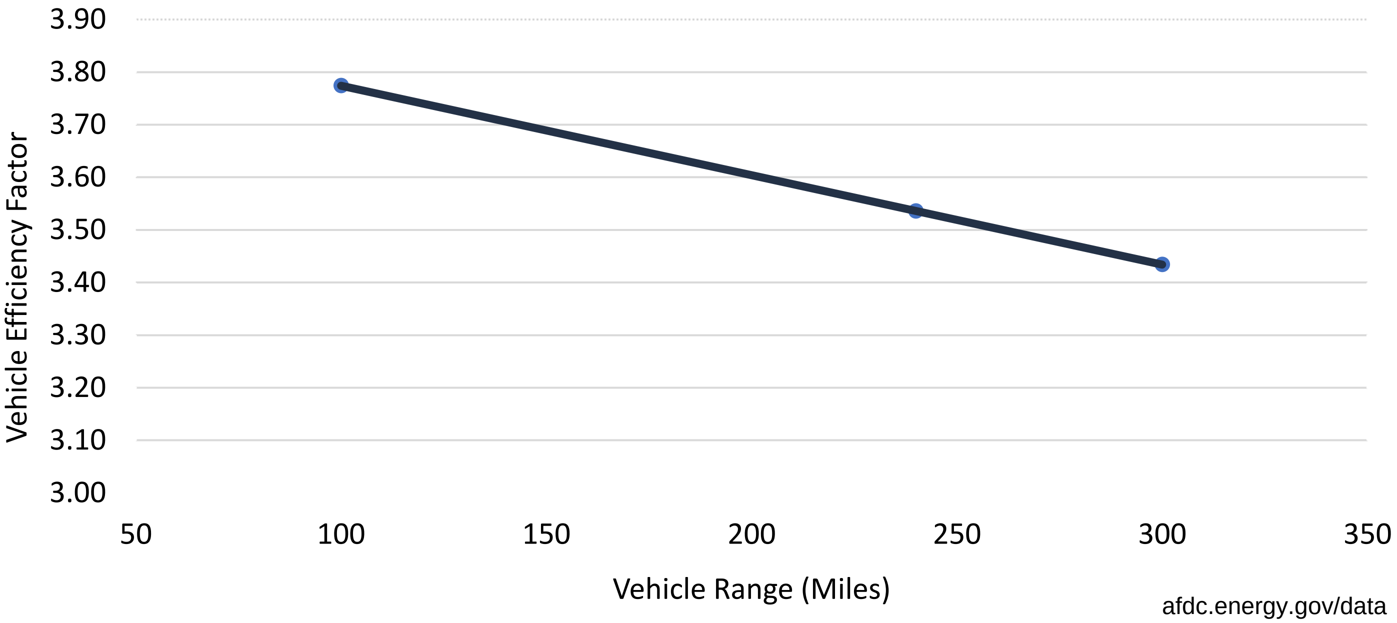
The IRA provides direct funding to support the conversion of clean heavy-duty vehicles. The new law provides $1 billion to the Environmental Protection Agency to award grants and rebates to cover the costs of converting existing gas and diesel vehicles to zero-emission vehicles. The funds can cover up to 100 percent of the incremental costs above and beyond the cost of a comparable diesel vehicle toward the purchase of a ZEV. The EPA can also use the funds to develop programs to fund heavy-duty EV charger or hydrogen fueling installations, workforce development to support heavy-duty zero-emission vehicles, and planning activities to support vehicle deployment.[22] Funds will be awarded to states, municipalities, Tribes, or non-profit school transportation associations or specified contractors. $400 million of these funds are set aside to replace heavy-duty vehicles in areas that do not meet certain federal air quality standards known as nonattainment areas.

Table 1: New ZEV Models Registered in Oregon in 2021

Make	Model	EV or PHEV	Type
Audi	A7	PHEV	Car
Audi	e-tron GT	EV	Car
Bentley	Bentayga	PHEV	SUV
Chevrolet	Bolt EUV	EV	Car
Ferrari	SF90 Stradale	PHEV	Car
Ford	Escape Plug-in Hybrid	PHEV	SUV
Hyundai	Santa Fe Plug-in Hybrid	PHEV	SUV
Hyundai	Tucson Plug-in Hybrid	PHEV	SUV
Jeep	Wrangler Unlimited	PHEV	SUV
Lincoln	Corsair	PHEV	SUV
Polestar	2	EV	Car
Rivian	R1T	EV	Truck
Volkswagen	ID.4	EV	Car
Volvo	XC40	EV	SUV

Figure 2 shows the variability of ranges in typical light-duty EVs, from 100 miles to 300 miles, and highlights the overall average of 240 miles.[ii] In 2020, the weighted average range for a new battery electric vehicle was about 218 miles, up from 124 miles in 2015.[23] Increasing the battery capacity in an electric vehicle will extend the range of the vehicle but increases the weight, reducing its energy efficiency. This tradeoff is expected as larger electric SUVs and pickups enter the market.

Figure 2: Relationship Between Average Range and Efficiency of U.S. Electric Vehicles[24]



afdc.energy.gov/data

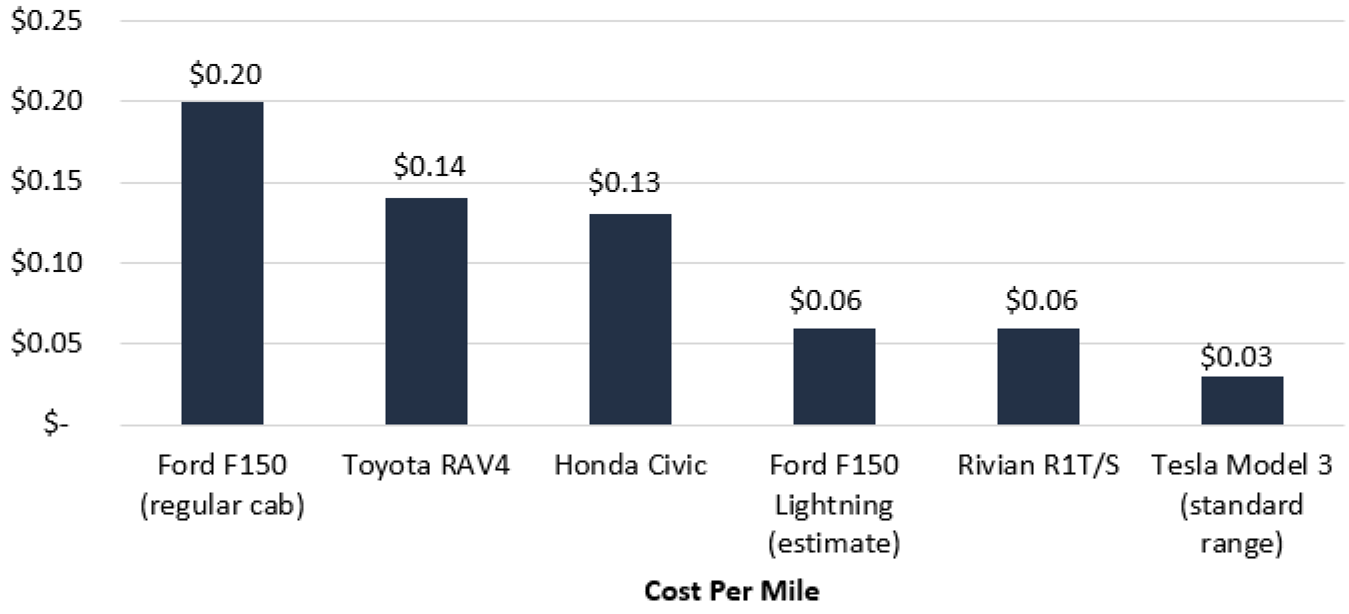
New battery chemistries are being studied today that may improve overall efficiency in future models. Solid-state batteries – so called because the material in the batteries is solid rather than the liquid used in today's EV lithium-ion batteries – are actively being developed and tested in a wide range of businesses and research settings, offering more charge per weight and per square inch of battery space.

Most studies and industry experts predict that passenger EVs will reach cost parity with internal combustion engine vehicles in the next few years. However, high global demand for EVs coupled with lagging raw material production capacity may create higher costs in the short term. The cost to produce EV batteries dropped from $1,200 per kWh in 2010 to about $130 per kWh in 2021.[25] Constraints on the availability of raw materials may push the cost to produce batteries up in 2022, and the exact timing of cost parity will depend on how quickly new mineral resources can be developed and brought to market. Oregon's EV rebates coupled with federal and other incentives reduce the initial up-front costs of an EV, in some cases to less than a comparable gasoline vehicle.[6]

While the upfront cost (without incentives) of an EV is currently higher than a comparable gasoline vehicle, much of this cost can be offset by the significantly lower cost to fuel and maintain an EV. On average, Oregonians will pay approximately 78 percent less for fuel when they can charge their vehicles at home.[6]

[ii] Average range is higher in the U.S. (240) than the global EV range (218).

Figure 3: Comparing the Total Operating Cost of Electric Vehicles vs. Gas-Powered Vehicles per Mile[26]



Maintenance costs are also lower for EVs, at approximately 60 percent of the cost to maintain a comparable gasoline-powered vehicle.[27]

The growth in publicly available charging stations is expected to spur EV adoption. Oregon will benefit from $52 million in federal investments (with a $13 million match) for public fast charging stations along Oregon's major corridors, as well as other incentive programs for EV charging offered by utilities and state agencies.

Medium- and heavy-duty zero emission vehicles are also becoming more widely available, and the adoption of California's Advanced Clean Truck Rule by the Oregon Department of Environmental Quality in 2021 will ensure that an increasing percentage of electric medium- and heavy-duty vehicles will be available for sale in Oregon. EV adoption has increased in the medium- and heavy-duty sector. More than four Oregon transit authorities and six school districts in Oregon have already deployed or are in the process of procuring electric buses.[28] Lane Transit District purchased 30 battery electric transit buses, representing nearly a third of its fleet,[29] [30] and Tri-Met is piloting several different formats of electric buses, including longer range buses, such as 60-foot articulated and double decker variants that not only reduce emissions but also carry more passengers per trip.[31, 32]

Procuring electric medium- and heavy-duty vehicles is more expensive than traditional diesel vehicles and requires additional expenditures to install the necessary charging infrastructure. Many utilities support electric medium- and heavy-duty adoption by providing technical assistance on cost effective charging installation and/or make-ready programs for fleets that cover some or all utility upgrades needed to accommodate charging infrastructure. In addition, through competitive grant programs, some Oregon utilities offer incentives for light-, medium- and heavy-duty vehicles as well as for charging infrastructure. For example, Oregon's two largest utilities, Portland General Electric and Pacific Power, offer EV charging station technical assistance to businesses that are electrifying fleets, offering workplace charging, or adding charging to multifamily properties.[33] [34] PGE also has a grant program to help pay the incremental cost of replacing a diesel school bus with an electric school bus.[35] The U.S. Department of Energy's National Renewable Energy Laboratory predicts that medium- and heavy-duty vehicles will achieve cost parity over the lifetime of the vehicle by 2035.[36]

Beyond Energy

Because much of Oregon's electricity is generated in state, driving an EV means more transportation dollars will remain in Oregon's economy.

Driving an electric vehicle offers many environmental and health benefits. In Oregon, the transportation sector accounts for nearly 40 percent of all greenhouse gas emissions. Driving an electric vehicle anywhere in Oregon reduces greenhouse gas emissions by 50 to 100 percent compared to driving a fossil fuel vehicle. Electric vehicles have no tailpipe emissions, and the associated emissions from the electricity generated will continue to decrease as utilities decarbonize their generation mix. Further, because much of Oregon's electricity is generated in state, more transportation dollars will remain in Oregon's economy. Driving an EV also improves local air quality, especially near busy roadways and places where vehicles may spend time idling. These communities are often low-income communities and communities of color that have been disproportionately affected by transportation pollutants and the effects of climate change. [37]

The raw materials to produce electric vehicle batteries are largely mined outside the U.S. For example, the U.S. produces only about 1 percent of lithium and 0.3 percent of cobalt, both critical minerals for EV battery production.[38–40] China supplies 85 percent of these and other rare earth minerals, and the mining practices have significant environmental impacts as well as human rights concerns.[41] Lower labor costs and fewer environmental regulations in China make it challenging for a critical mineral industry in the U.S. to compete. In June 2021 the Biden Administration released the National Blueprint for Lithium Batteries, which provides guidance on developing domestic battery supply chain components, domestic processing and manufacturing of battery components, and increased research on recycling and repurposing of these components. The blueprint is intended to reduce dependence on foreign mining and manufacturing, increase domestic jobs associated with the renewable energy sector, and further enable domestic decarbonization.[42]

The Oregon Department of Energy has an all-electric Chevrolet Bolt and a plug-in hybrid Chevrolet Volt in its small fleet.

Fuel Cell Electric Vehicles

Timeline

- **1998** — Chicago Transit Authority and BC Transit (Vancouver) each deploy three Ballard-powered fuel cell buses in revenue service for a two-year demonstration and testing program.[43]
- **2000** — Ballard Power Systems presents the world's first production-ready fuel cell for automotive applications at the Detroit Auto Show.[44]
- **2015** — Retail sales of the Toyota Mirai in the U.S. (California only) begin in August.[45]
- **2015** — FirstElement opens the first pipeline-fed, publicly accessible hydrogen fueling station in the U.S. in December (located in California).[46]

Fuel Cell EVs in Oregon

Oregon does **not yet have any registered fuel cell vehicles** in the state, nor does it have fueling infrastructure.

FCEVs are classified as zero-emission vehicles along with battery electric and plug-in hybrid electric vehicles. Rather than using batteries, the fuel cells in these vehicles convert hydrogen fuel to electricity when the vehicle is operating. Like other ZEVs, FCEVs have no tailpipe emissions, and any lifecycle greenhouse gas emissions are contributed by how the hydrogen is produced and transported. For more information on the technology, see the Electric Vehicles Technology Review in the *2020 Biennial Energy Report*.

Trends and Potential

There are no registered FCEVs and no dealerships sell them in Oregon, largely because there are no hydrogen fueling stations in the state. The capital cost to build a light-duty hydrogen fueling station is approximately $1.9 million, making investments in the fueling infrastructure significantly higher than for battery electric vehicles.[47] [48] However, a single hydrogen fueling station can service far more vehicles in one day than an EV charging station.

There are 61 retail hydrogen fueling facilities operating in the U.S., 60 of which are located in California and all of which support light-duty hydrogen fuel cell vehicles.[iii] [49] The catalyst for this hydrogen transportation economy in California was the California Energy Commission's sizable funding of retail hydrogen fueling stations ($20 million per year to fund up to 100 stations) and the magnitude of legislative, regulatory, incentive, procedural and structural efforts to support the hydrogen economy in the state. Washington has also committed funding to fuel the transition to hydrogen fuel cell vehicles: in 2021 the Washington State Legislature approved $2.55 million for the development of the state's first hydrogen fueling facility to be built along I-5 in Chehalis in 2023.[50]

[iii] The remaining facility is located in Hawaii.

They also created a hydrogen fuel cell electric vehicle pilot program to apply a partial sales and use tax exemption through SB 5000.[51]

The development of the Chehalis fueling site will likely generate more interest in Oregon hydrogen fueling stations that could link Washington and California and create a "Hydrogen Highway," similar to the West Coast Electric Highway that was foundational to EV adoption along the West Coast in the 2010s. Hydrogen fuel is significantly lighter and can be condensed into a smaller space than batteries. Because weight and range requirements for long-haul and heavy-duty trucking may limit the extent to which battery electric trucks can replace diesel vehicles, hydrogen fueling facilities along major freight routes may spur investments in hydrogen fuel cell vehicles.

The Oregon Department of Transportation completed a Hydrogen Pathway Study in May 2022, looking at potential hydrogen fueling needs and investments if hydrogen fuel cell vehicles represent a portion of ZEVs in the light-, medium- and heavy-duty sectors in Oregon by 2035.[52] If hydrogen fuel cell vehicles on the road mirror the assumptions outlined in the report, Oregon will need 47 public hydrogen fueling stations to serve hydrogen vehicles in the light-duty vehicle sector and 19 fueling stations to serve medium-duty and heavy-duty vehicles by 2035.

Beyond Energy

Driving an FCEV has lower associated greenhouse gas emissions than a comparable diesel or gasoline vehicle. Like other zero-emission vehicles, FCEVs have no tailpipe emissions, although there are often emissions associated with the production of hydrogen fuel. Currently 95 percent is made from natural gas, often as a byproduct of petroleum and fertilizer production.[43] The DEQ Clean Fuels Program carbon intensity for all fossil-derived hydrogen is higher than that of gasoline or diesel — but because FCEVs are 2.5 times more efficient than internal combustion engine vehicles, their use results in fewer overall emissions in most cases.

FCEVs can also be fueled with renewable or low-carbon hydrogen. Renewable hydrogen is created by splitting water molecules using electricity, and when the electricity used is zero-emission – like solar and wind power – the lifecycle emissions associated with the production of the hydrogen can be less than 10 percent that of gasoline and diesel. In 2021, the Oregon Legislature passed SB 333, which directed the Oregon Department of Energy to produce a study on the opportunities and challenges of producing renewable hydrogen in Oregon.[55] The study includes information on renewable hydrogen use and options for the transportation sector.[iv] Low-carbon hydrogen can be produced from fossil fuels paired with carbon capture and storage technology or from low-carbon sources of electricity that may not be considered renewable, such as nuclear power.

FCEVs can also be fueled with renewable or low-carbon hydrogen.

Switching to zero-emission vehicles can improve air quality, bringing health benefits to local communities, and helps address climate change, which disproportionately affects low-income communities and communities of color.

[iv] For more information, see the Oregon Department of Energy's *2022 Renewable Hydrogen Report* (Available November 15, 2022): https://tinyurl.com/ODOE-Studies

Electric Vehicle Chargers

Timeline

- **2008** — First publicly accessible level 2 electric vehicle charger installed in Oregon.[56]
- **2011** — First publicly accessible DC Fast Charger (level 3) electric vehicle charger installed in Oregon[56]
- **2012** — The West Coast Electric highway opens, providing CHAdeMO DC Fast Charging and level 2 charging with a frequency no more than 50 miles apart on major corridors in WA, OR, and later joined by CA.[57]
- **2021** — Daimler Trucks North America opens "Electric Island," the first heavy-duty vehicle charging station in Oregon.[58]
- **2022 - 2024** — Oregon and WA are updating 56 legacy West Coast Electric Highway chargers to offer both CCS and CHAdeMO fast charging capability.

EV Chargers in Oregon

Oregon has 917 public and proprietary EV charging locations or stations[56] with 2,177[56] charge ports. 1,705[56] are Level 2 chargers, while 472[56] are Level 3 DC Fast Chargers.

Chargers are the electric fueling infrastructure to support battery electric and plug-in hybrid electric vehicles. Currently, over 80 percent of charging is done at home, either through a standard outlet (Level I) or an installed Level II charger. At-home charging is more challenging at multi-unit dwellings — a recent study by nonprofit Forth found that only 5 percent of at-home charging occurs at multi-unit dwellings.[59] Additional public charging infrastructure is needed to support Oregonians living in those multi-unit dwellings and for those needing to travel and charge away from home. A study by the National Renewable Energy Laboratory estimates that 3.4 DC Fast Chargers and 40 Level 2 charging ports are needed for every 1,000 EVs.[60]

Trends and Potential

It is anticipated that EV charger availability will expand rapidly in the next five years. The Infrastructure Investment and Jobs Act passed by Congress in Fall 2021 includes $5 billion through the National EV Incentive program to support EV charging infrastructure along specific, high-travel corridors. The Oregon Department of Transportation will receive $52 million over five years to deploy DC fast chargers along Oregon's eleven electric Alternative Fuel Corridors.[v] The bill also includes billions of dollars across other programs that could provide funding for EV charging in private or public settings.[61] ODOT's Transportation Electrification Infrastructure and Needs Analysis – a statewide

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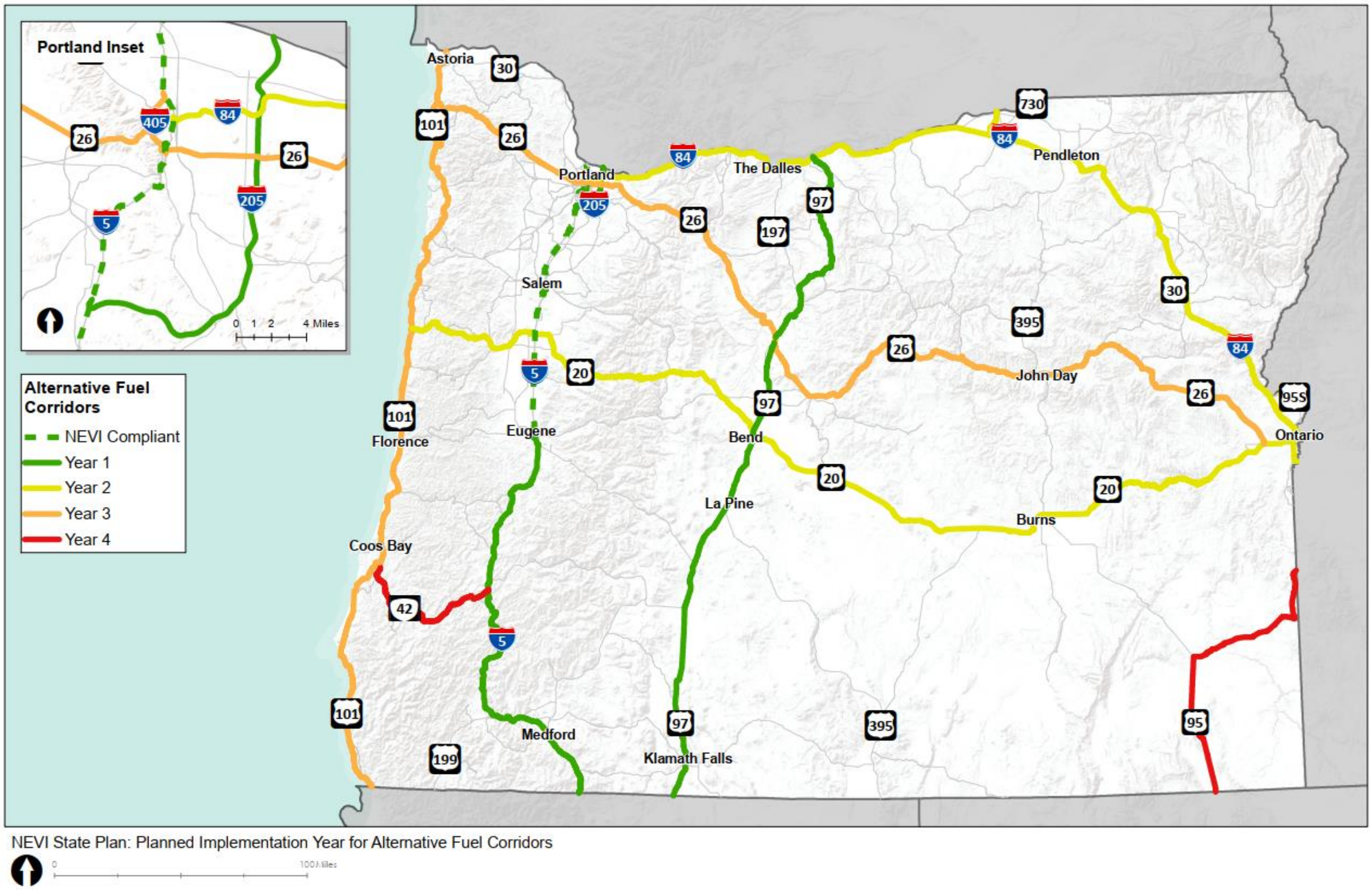
[v] As of 2022, Oregon has 11 electric Alteranative Fuel Corridors: I-5, I-84, I-82, I-405, I-205, US 101, US 97, US 20, US 26, US 95, and OR 42.

assessment published in 2021 of where chargers are most needed in Oregon – provides a strong foundation for optimizing charger deployment programs.

Figure 4: Oregon's Alternative Fuel Corridors (ODOT)



NEVI State Plan: Planned Implementation Year for Alternative Fuel Corridors

Charging done at home can often be completed overnight, and for many Oregonians, charging on a standard 110 V outlet is sufficient to meet most daily driving needs. For longer trips or for those who cannot charge at home, faster charging is necessary. The first wave of DC Fast Charger stations generally powered up to 50 kW. Today, the faster and more powerful 150 kW is becoming the standard and 350 kW are increasingly common. While older models of vehicles may only be able to charge at the 50 kW level,[vi] most new models today can accept up to 150 kW, and many auto manufacturers are competing to provide EVs that can charge at increasingly faster speeds using higher-powered chargers.

There are three types of connectors used on DC Fast Chargers: CCS, CHAdeMO, and Tesla. CCS chargers can charge most electric vehicles on the road today, while Tesla chargers can only be used for Tesla vehicles and CHAdeMO chargers can only be used with a small number of vehicle models. In recent years, North American and European vehicle manufacturers began coalescing around the CCS standard, so most vehicles available and on the road today accept this connector, with the exception of the popular Nissan LEAF. CHAdeMO chargers in the U.S. are rated only to 50 kW, and a new standard that would enable higher powered CHAdeMO chargers was released in 2020. CHAdeMO

[vi] Vehicles capable of only 50 kW charging can still charge at the higher-powered stations, as the chargers will recognize the capacity of the vehicle and provide the right amount of charge.

remains the primary standard in Japan, because it offers bidirectional charging – the ability to charge the battery as well as discharge the battery back to the grid.[62] In the U.S., CHAdeMO chargers will remain to support LEAFs and are required to be included for many publicly funded programs to support older generation electric vehicles.

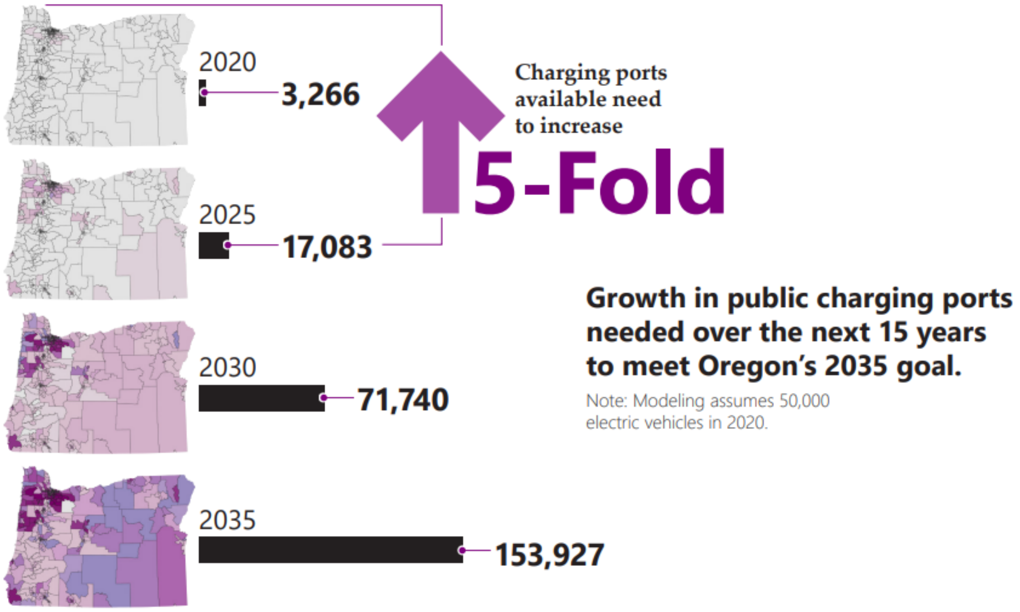
"Electric Island," a joint project by Portland General Electric and Daimler Trucks North America is a first-of-its-kind electric fueling station capable of charging everything from light-duty passenger vehicles to electric freight trucks.[62]

Oregon is also leading in the formative stages of medium- and heavy-duty vehicle charging infrastructure development. A joint project with Portland General Electric and Daimler Trucks North America developed a first-of-its-kind publicly available electric fueling station capable of charging everything from light-duty cars to electric freight trucks. Located on Swan Island in north Portland, the site can host up to 5 MW of charging infrastructure and is being used by PGE and Daimler to study how utilities and fleet owners can optimize charging for larger vehicles.[58 63]

Beyond Energy

Adoption of electric vehicles is a central pillar of Oregon's strategy to reduce greenhouse gas emissions in the transportation sector, and the rapid deployment of charging infrastructure is critical to accelerate EV adoption in the next five years. To support this, the Oregon Department of Transportation, supported by the Oregon Department of Energy, developed the Transportation Electrification Infrastructure Needs Analysis study in 2021 to study and identify charging gaps and needs across the state.[64] The study points out the magnitudes of growth in charging required to meet Oregon's EV adoption

Figure 5: Growth in Public Charging Ports Needed Over the Next 15 Years[64]



goals.[65] ODOT is also committing more than $100 million in funding over the next five years to support EV charging infrastructure deployment along key travel corridors and within Oregon communities, provided through a mix of state and federal funds.

Ensuring that EV charging infrastructure is equitable and accessible to all Oregonians (including all communities, income levels, housing types, and geographic locations) has become a guiding principle in infrastructure deployment. A UC Davis study on the Air Quality Impacts of Oregon's Proposed Clean Fuels Program Changes clearly signals that the health of Oregonians will benefit from the expansion of the carbon reducing program.[66] The study shows clear air quality improvement in the vicinity of major roadways and that disadvantaged communities, including lower-income and Black, Indigenous, and People of Color populations, are more likely to live near major roadways and be exposed to vehicle pollution.

Access to charging and the ability to pay for electric fuel through a home or business utility bill affect how much drivers pay to fuel their EV. For example, someone who can charge at home may save as much as 80 percent compared to a gasoline car, while relying on public charging could reduce this savings to approximately 50 percent.[vii] This varies depending on several factors, especially volatility in gasoline prices. EV drivers who rent or live in multi-family dwellings, or who otherwise cannot charge at home, may pay more for electric fuel that must be purchased at publicly available EV chargers.

Rural Oregonians have more limited charging resources than metropolitan areas. There can be more than 50 miles between publicly available chargers on some Oregon highways, which may limit the use of older EV models with shorter driving ranges. When charging is available, rural drivers may have to make an additional investment of time to charge the vehicle when they travel. This additional time could be further inflated if only slower Level 2 chargers are available. In some rural areas of Oregon there is insufficient electrical capacity to support DC fast chargers without costly upgrades to the distribution system. The "sunk costs" of time waiting for charging might outweigh the fuel cost savings for some drivers.

Rural Oregonians have more limited charging resources than metropolitan areas. There can be more than 50 miles between publicly available chargers on some Oregon highways.

Siting and installing a significant number of EV chargers offers increased jobs and economic benefits for Oregon. Professional electrical installers and ongoing operation and maintenance needs are necessary to support the charging infrastructure, and the siting of chargers can have economic benefits for nearby businesses, such as restaurants and hotels, which may see increased traffic from drivers using the chargers. The consumption of electric fuel also retains more of Oregon's transportation dollars in state, supporting local utilities and energy developers. The U.S. Energy Information Administration estimates that in 2020, Oregon spent about $5.7 billion on transportation energy, which is mostly paid to businesses out of state.[67]

EV chargers are largely composed of metals and alloys, including copper, stainless steel, carbon steel, aluminum, nickel, chrome, and titanium. These components are necessary to meet charger design and operational standards, as well as for parts like charging cables that must be replaced over time, due to

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[vii] Calculation assumptions: 25 MPG car, $4-$5 dollar/gal gas, Home charging at ¢11/kWh, Public charging at ¢30/kWh

expected wear and tear. The rapid deployment of EV chargers will rely on global supply chains for these metals and alloys, some of which are strained due to COVID-related supply chain challenges. Global adoption of EVs and chargers will create high demand for these resources in the next decade or more, with the market for these materials increasing by 34 percent by 2028.[68] Similar to raw materials for the batteries that fuel EVs, the extraction, refinement, and transport of these raw materials has the potential for negative social and environmental effects, and the economic effect of the rapid upswing in demand for these materials could create increases in costs for equipment suppliers and EV owners.[68]

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Energy Resource & Technology Review: Energy Efficient Building Technologies

Energy use in buildings across the residential and commercial sectors makes up 25 and 19 percent of Oregon's 2020 overall energy use respectively, and produces 35 percent of Oregon greenhouse gas emissions. While adoption of energy efficiency measures continues to rise in Oregon, there remains significant potential to further reduce building energy use in new and existing buildings with new or improved energy efficiency measures,[1] including construction techniques, efficient equipment and appliances, and equipment controls that reduce the monthly consumption of utility-provided energy. These measures also provide many non-energy benefits for both the building owner/operator and the community, such as: saving money, reducing energy burden,[i] reducing greenhouse gas emissions and other pollutants, increasing jobs, reducing demand for future infrastructure, enhancing distributed energy resources, increasing local reliability, and supporting a more resilient energy system (for more information on this topic see the *Beyond Energy Savings* Policy Brief).

In Oregon, there are many drivers of energy efficient technology adoption. In addition to the benefits above, for individual businesses and homeowners it can be a desire for energy savings (and financial savings) or other benefits like improved indoor air quality, comfort, support for a clean energy system, or progress toward corporate sustainability goals. Drivers at a regional or market-scale include policies and programs that promote energy efficiency, such as those that improve energy building codes and energy efficiency standards; provide utility incentives and finance energy efficiency measures; provide tax incentives; address appliance labeling efforts like ENERGY STAR; fund research and development; and enable market transformation for new products through programs developed by the Northwest Energy Efficiency Alliance.[1] [2]

Energy efficiency saves Pacific NW ratepayers over $4 billion and reduces GHG emissions by over 22 million MTCO2 each year.

The region has made impressive strides acquiring energy efficiency. The Northwest Power and Conservation Council estimates that the Pacific Northwest has, as of 2018, cumulatively saved over 7,200 average megawatts of energy – making the energy efficiency resource second only to hydroelectric power – and saves ratepayers over $4 billion per year and reduces GHG emissions by over 22 million MTCO2 per year.[3] Yet there remain numerous challenges to acquiring more energy efficiency. One challenge is access to capital for energy efficiency investments, especially in existing buildings where goals require replacement of functioning equipment. While incentives or tax credits can help with these investments, they are not applicable in all situations. The Northwest Power and Conservation Council's *2021 Power Plan* discusses additional challenges, including decreased investment in cost-effective energy efficiency and the recent drop in the cost-effectiveness threshold that energy efficiency must meet. Energy

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[i] Energy burden is the percentage of household income spent on energy and transportation costs, and anyone paying more than 6 percent of their household income on energy is considered energy burdened.

efficiency has long been the lowest cost resource for the region, but is now facing competition from low-cost renewable solar and wind resources.[3] Other challenges to adoption include limited availability of technologies, lack of consumer familiarity with efficiency products, and recent supply chain and shipping delays related to the COVID-19 pandemic.

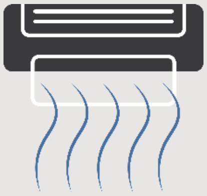
This Technology Review provides more information on energy efficient equipment, including heat pumps, water heaters, and smart devices and appliances.

Heat Pumps

Timeline

- **1834** — Refrigeration was a precursor to heat pumps, as Jacob Perkins filed the first patent in England for mechanical refrigeration to make ice. [7]
- **1855** — Peter Von Rittinger developed the first heat pump (heating only) at an Austrian Salt mine. A Swiss fuel shortage drove development for commercialization in the late 1930s and early 1940s).[7]
- **1968** — Mitsubishi releases a wall-mounted split-system room air conditioner, also called a ductless heat pump.[8]
- **1970s** — U.S. adoption of the technology starts to increase.[9]
- **2000s** — Widespread incentives became available for heat pumps, including the first tax credits in 2006-2007.[10] Local utility incentive programs and market transformation efforts focusing on promoting heat pumps picked up in the late 2010s and early 2020s.[11]
- **2022** – SB 1536 passed in Oregon establishing two statewide heat pump programs, one for incentives for homeowners and one rebate program for rental homes.
- **2022** – Federal Inflation Reduction Act created large scale investment in energy efficiency and clean energy including a tax credit and rebate program for residential heat pumps.

Heat Pumps in Oregon and the Northwest



In 2017, about **15 percent of single-family households in the Northwest used a heat pump** as the primary heating system (11.3 percent air source heat pump; 3.4 percent mini-split heat pump; and 0.7 percent geothermal (or ground source) heat pump).[4]

Research from Washington state showed an **increase in the number of households using electricity for heating** — from approximately 20 to 90 percent of surveyed respondents — indicating an increase in homes using electric technologies like heat pumps.[5]

Oregonians could **save about 50 percent on home heating costs** with a heat pump compared to electric resistance heat, like cadet or baseboard heaters.

Heat pumps move heat rather than create it. In heating mode, heat pumps collect heat from ambient outdoor temperatures, concentrate it, and transfer that heat inside the building — even on cold days. In cooling mode, heat pumps operate like regular air conditioners and refrigerators, moving heat from inside the building or refrigerator to outside. Heat pump technology is essentially the same as refrigeration technology, except that heat pumps have a reversing valve that allows operation in two directions for both heating and cooling.

What Makes a Heat Pump Efficient?

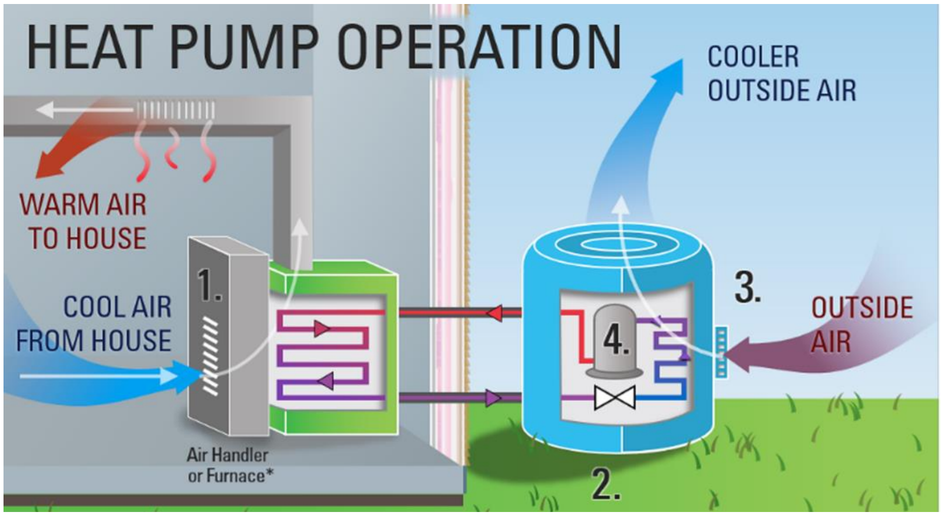
Heat pump efficiency is generally expressed using standard metrics, such as the Seasonal Energy Efficiency Ratio (SEER), Energy Efficiency Ratio (EER), Heating Season Performance Factor (HSPF), or Coefficient of Performance (COP). For these metrics, higher values indicate greater efficiency.

SEER or EER measures a heat pump's efficiency in cooling mode, and HSPF measures the heating mode efficiency. Heat pump incentive programs often require minimum SEER and HSPF ratings.

The Coefficient of Performance measures the overall efficiency of a heating or cooling technology. Measured in kilowatts, it is calculated as the amount of heating or cooling provided by the technology compared to the kilowatts of power consumed by the technology. A COP of 3 means that three units of beneficial energy (for heating or cooling purposes) are delivered for every one unit of electricity energy that is input into the system. Put another way, a COP of 3 would mean that equipment is 300 percent efficient.

To qualify as ENERGY STAR-rated, heat pump models need to have: a minimum 8.5 HSPF, a minimum 15 SEER, or a minimum 12.5 EER for air source split systems.[6]

Figure 1: Air Source Heat Pump Operation[12]

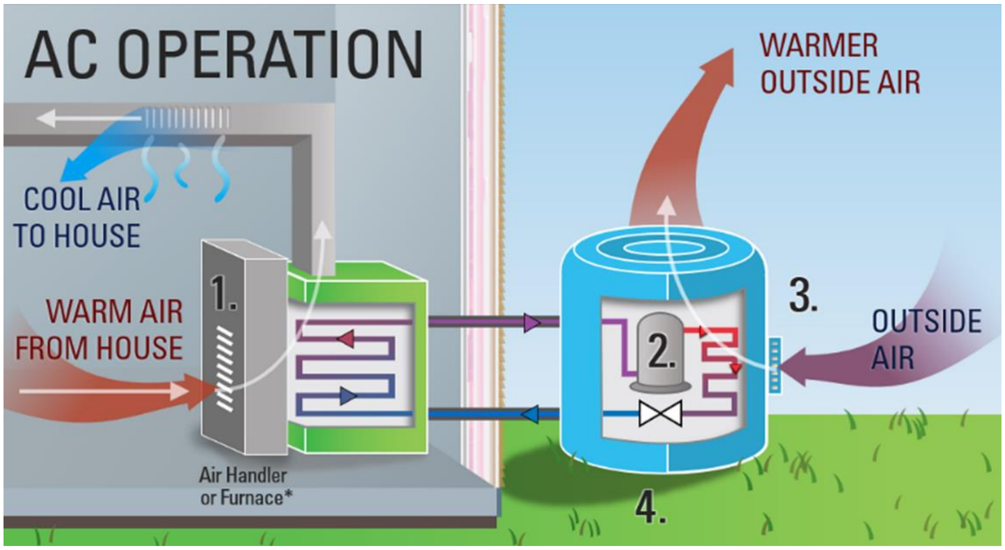


1. Cold air from inside the home is passed across the high-temperature, high-pressure gas refrigerant in the indoor coil, which transfers heat to the cold air. The refrigerant condenses to a liquid, and warm air is circulated through the home.

2. Warm liquid refrigerant is passed through an expansion valve, which relieves pressure. As the pressure is reduced, the temperature of the liquid is reduced, and the cold refrigerant passes through the outdoor coil.
3. Heat energy transfers from the outside air to the low-pressure, low-temperature, liquid refrigerant.
4. The low-temperature gas refrigerant goes through a compressor, which raises its temperature and pressure and passes it back to the indoor coil.

Ductless units operate similarly, except the fan is built into the indoor unit and blows warmed air directly into the room.

Figure 2: Air Conditioner Operation[12]



1. Warm air from inside the home is passed across a cool refrigerant coil, and the heat is absorbed by the liquid refrigerant, which evaporates into a low-temperature gas. The cooled air is ducted back through the house.
2. The low-temperature gas refrigerant goes through a compressor, which raises its temperature and pressure.
3. Hot, high-pressure refrigerant gas is passed through the outdoor coil. The refrigerant passes heat to the outdoor air and condenses to a high temperature liquid.
4. Warm liquid refrigerant is passed through an expansion valve, which relieves pressure. As the pressure is reduced, the temperature of the liquid is reduced. The low-temperature, low-pressure liquid refrigerant is then piped back into the house.

Ductless units operate similarly except the fan is built into the indoor unit and blows cool air directly into the room.

Types of Heat Pumps:

Air Source Heat Pumps

- Use electricity to operate a compressor to transfer heat between the air inside and outside of the building
- Most common type of heat pump system
- Often the least expensive heat pump option
- Can be ducted or ductless (some ductless versions are called mini-splits)

Ground Source Heat Pumps (sometimes referred to as geothermal heat pumps)

- Use the relatively constant underground temperature near the building instead of air for heat transfer
- Typically higher in capital costs to install
- More efficiently transfer heat than air source heat pumps
- Tend to have lower operating costs than air source heat pumps

Water Source Heat Pumps

- Use a pumped closed water loop from a nearby surface or groundwater source instead of air for heat transfer
- Typically higher in capital costs to install
- More efficiently transfers heat than air source heat pumps
- Tend to have lower operating costs than air source heat pumps

Gas-fired or Absorption Heat Pumps

- Use the combustion of natural gas or propane to generate the heat source for transfer to the building, rather than mechanical energy used in air source or compression heat pumps
- Absorption heat pumps are not reversible and do not create cooling or air conditioning
- More efficient than traditional gas furnaces
- Relatively new type of heat pump that is not yet commercially available

Trends and Potential

Currently, heat pump technology enhancements are focused on improving cold weather capabilities, efficiency, and suitability for retrofitting large commercial buildings in a cost-effective manner. In cold climates, traditional air source heat pumps tend to provide less heating capacity and operate at lower efficiency levels, but advances in the technology such as variable speed fans and two-speed compressors have greatly improved effectiveness and efficiency in cold environments. Heat pumps operate at a lower supply air temperature than traditional fuel-based heating systems; therefore, in large-scale installations replacing a central heating system with a heat pump often requires extensive updates. Heat pumps are being effectively deployed to save energy (and reduce GHG emissions) across the United States, from cold climates such as Alaska and Maine all the way to the hot and humid south.

Senate Bill 1536 (2022) requires ODOE to create a $10 million statewide Community Heat Pump Deployment Program that prioritizes assistance to: environmental justice communities, individuals who rely on bulk fuels (e.g., LPG, propane, coal, and wood) or electric resistance heating, or individuals who reside in a home or structure that does not have a functioning heating or cooling system. In addition, it requires ODOE to create a $15 million Oregon Rental Home Heat Pump Program, working through contractors installing heat pumps for owners of a rental home, manufactured home, or recreational vehicle that provides housing for low-income residents. ODOE expects to launch the program in 2023.

Incentives

Learn more about the Oregon Department of Energy's incentive programs and save:

www.oregon.gov/energy/Incentives

Beyond Energy

Contemporary heat pumps that operate solely on electricity are more efficient than electric resistance heat, and play an important role in achieving decarbonization goals. Depending on the proportion of renewable energy in the utility's electricity generation source, installing new heat pumps can reduce greenhouse gas emissions created from heating and cooling buildings. Heat pumps also have no site emissions; coupled with increasingly clean power grids, this can support better air quality for Oregonians especially when compared to other heat sources like wood and propane. However, heat pumps do often use hydrofluorocarbons as the medium to transfer heat; these gases have a high global warming potential (GWP), and the prevalence of their use may have wider environmental impacts. High-GWP refrigerants are being phased out through federal mandates, reducing their effect in the future. This phase-out will decrease the production and import of HFCs in the United States by 85 percent over the next 15 years (by 2036). In cases where heat pumps replace an existing inefficient heating system, the units add cooling without the need for additional pieces of equipment that will need maintenance. The savings from the winter months can help offset the cost of the added summer cooling.

OREGONLIVE
The Oregonian

Oregon's heat wave death toll grows to 116

Updated: Dec. 01, 2021, 12:18 p.m. | Published: Jul. 07, 2021, 12:42 p.m.

Salem Fire Department paramedics and employees of Falck Northwest ambulances respond to a heat exposure call during a heat wave, Saturday, June 26, 2021, in Salem, Oregon. Nathan Howard | AP Photo

Following the June 2021 Oregon heat dome event, which led to more than 100 heat-related deaths,[13] access to cooling has become an important topic to address when planning for Oregon's changing climate. The dual heating and cooling benefit that heat pumps provide can help people stay safe during extreme weather events. SB 1536 required ODOE to contract with the Energy Trust of Oregon to create a $2 million Community Cooling Spaces program for landlords to provide community cooling spaces for tenants. It also required ODOE to study the cooling and electrical needs of publicly supported housing, manufactured dwelling parks, and RV parks, focusing on: the prevalence of cooling facilities, the need for cooling facilities, the barriers to transitioning housing and parks to include cooling facilitates, and where possible, specific scenarios for properties in development or preservation to add cooling facilities.

Oregon is not only predicted to face record heat waves, but also record cold snaps and inclement winter weather. This increases the need to consider resilience in home heating systems. Depending on the type of heat pump and size, this could force older heat pump models to use electric resistance heating more often during extreme cold, increasing costs to the homeowner and demand on the electricity grid. Newer heat pump technology can operate more efficiently in colder temperatures without use of a secondary heating system. Heat pumps, when paired with a backup system such as on-site renewable generation with battery storage or a wood or natural gas fireplace, can also be part of a redundant system that provides flexible, efficient heating during normal operation and emergency backup during power outages.

Water Heaters

Timeline

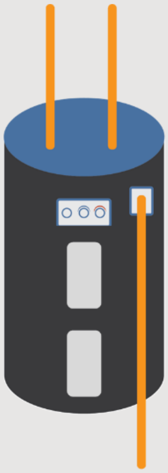
- **1890s** — Edwin Ruud designed automatic storage tank-type natural gas water heater, which were safer for use in homes.[17,18]
- **1889** – Edwin Ruud invented the electric water heater with automatic storage in Philadelphia.[19]
- **1897** — First natural gas-fueled, tankless hot water patented in Philadelphia by Edwin Ruud.[17]
- **1937** — Heat pump water heaters were first patented by G. Wilkes and F.M. Reed.[20] [21]

Energy-Saving Water Heaters[14]

Oregonians can see a **50 percent reduction in annual electricity use**, on average, for switching from an aging electric resistance water heater to an electric heat pump water heater.

Households can also see an **8 percent reduction in natural gas use** when swapping a standard water heater model to an ENERGY STAR-rated gas fired water heater. Savings are further increased by about 10 percent when swapping from a storage tank style to a direct vent tankless gas water heating unit.[14,15]

Oregonians could **save about $330** per year for a family of four when switching from an aging electric resistance storage water heater to a highly efficient heat pump water heater.



Water heaters are a standard appliance in all sectors. They provide hot water for the taps and showers in occupied residential and commercial spaces, and directly to processes and equipment in commercial and industrial applications. There are multiple types of water heater technologies that serve these markets. These common technologies include electric storage water heaters (which are available in both electric resistance and heat pump models), natural gas storage water heaters, and tankless (or instantaneous) water heaters (which are available in both natural gas and electric models). Solar thermal water heaters and propane-fueled water heaters also represent a small percentage of the overall market.

What Makes a Water Heater Efficient?

UEF is the Uniform Energy Factor, a measure of water heater overall efficiency determined using a USDOE test method. The higher the value, the more efficient the water heater. SUEF is the Solar Uniform Energy Factor, or the energy delivered by the total system divided by the electrical or gas energy put into the system. Again, the higher the value the more efficient the system.

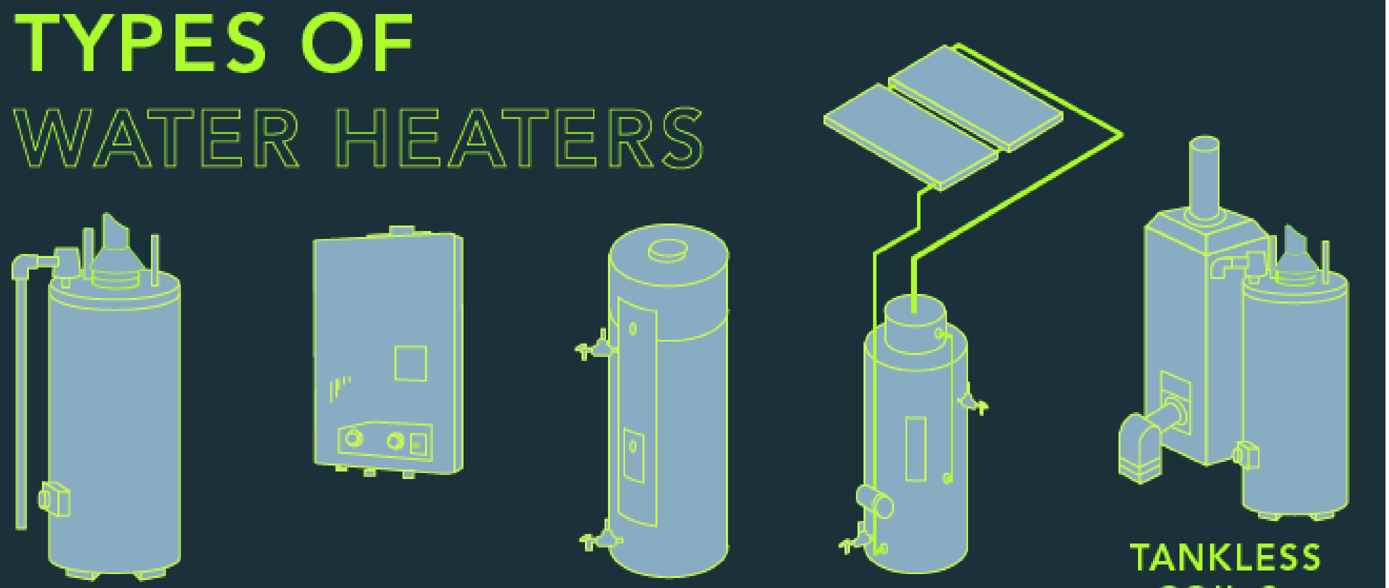
The Coefficient of Performance (COP) is 3.0 for heat pump water heaters, and about 1.0 for high efficiency storage water heaters (both gas and electric).

To qualify as an ENERGY STAR model, water heaters need to meet these factors:[16]

- Hybrid Heat Pump/Electric Storage water heaters
    - Integrated Heat Pump Water Heater UEF 3.3 min
    - Integrated Heat Pump Water Heater, 120 V UEF 2.2 min
    - Split System Heat Pump Water Heater UEF 2.2 min
- Gas Storage water heaters
    - < 55 gal UEF 0.64 min
    - > 55 gal UEF 0.78 min
- Gas instant water heaters EF 0.87 min
- Solar water heaters
    - SUEF 3.0 for those with electric backup
    - SUEF 1.8 for those with gas back up

Like many products and appliances, water heaters are available in varying levels of energy efficiency.

Figure 3: Types of Advanced or ENERGY STAR-Certified Water Heaters[22]



	STORAGE	TANKLESS	HEAT PUMP	SOLAR	TANKLESS COIL & INDIRECT
COST	$	$$	$$	$$$	$$
LIFE EXPECTANCY	10-15 years	20+ years	10-15 years	About 20 years	10-11 years
PRO	Lower purchase cost	Provides a constant supply of hot water, and is 8-34 percent more energy efficient than a storage water heater. Depending on the amount of hot water your home uses daily, you could save at least $100 a year.	2-3 times more energy efficient than a storage water heater and lower operating costs. Energy Star heat pump water heaters can save homeowners almost $300 a year on their electric bills	50 percent more efficient than gas or electric water heaters	Lower installation and maintenance costs
CON	Standby heat loss – energy can be wasted to keep the water in the tank heated to the set temperature.	Limited flow rate of hot water means simultaneous, multiple uses of hot water can stretch a tankless water heater to its limit, and some times the energy savings don't pay for the cost of purchase and installation.	Performance is dependent on the installation location, and heat pump water heaters exhaust cold air -- increasing the load on space conditioning appliances during heating months.	Solar water heaters may require a backup system for cloudy days and times of high demand.	Inefficient choice for many homes, especially for those in warmer climates.
SOLUTION	Look for an insulated tank to reduce heat losses and lower operating costs.	Install two or more tankless water heaters connected in parallel or separate ones for appliances that use a lot of hot water.	Switching the heat pump water heater to regular resistance mode will stop cold air exhaust but also reduce the appliance's efficiency.	Make sure you buy a solar water heating system that includes a storage water heater as part of the system package.	

High efficiency gas storage water heaters. These water heaters are similar to standard efficiency gas heaters, but offer increased insulation, more efficient burners, and other improvements to increase the overall energy efficiency. Models known as "condensing" gas water heaters include a secondary heat exchanger that recovers additional energy from the combustion exhaust stream and lead to increased energy efficiency.

Heat pump water heaters. These units operate using a similar cycle to typical refrigerators, air conditioners, or heat pumps. This technology captures heat from the surrounding area and transfers it to the water in the tank. High efficiency units, such as ENERGY STAR certified water heaters, can use 50 percent less electricity compared to standard electric resistance water heaters. Heat pump water heaters typically also include a traditional electric resistance heating element to enable the heater to operate in heat pump mode or as a standard electric water heater in the case the heat pump is not able to meet the demand for hot water. This increases flexibility and offers a balance between performance and energy efficiency.

Solar thermal water heaters. This type of heater offers a variety of technologies and configurations to provide hot water. The configurations all have a common aspect of using solar energy to heat the water through solar energy collectors and storage tanks. Solar thermal water heaters can operate in conjunction with standard water heater technology as a backup to provide consistent hot water to the end user.

Tankless (or instantaneous) water heaters. These can come in natural gas or electric models and operate using the same concept as typical water heaters, but they do not contain a storage tank. These models use a sensor to activate the heater when needed and heat the water as it flows through, meaning that they must heat the water much faster than a storage water heater to be able to supply sufficient hot water to meet user demand (such as a shower). By only heating water on demand, these units save energy by eliminating the heat loss from a storage tank during standby operation; not having a pilot light also reduces gas use. In addition, tankless water heaters have direct venting which reduces the risk of carbon monoxide poisoning and limits exposure to cold outdoor air from a constantly open-air vent. To serve a building with multiple simultaneous hot water uses (such as a home with a kitchen and multiple bathrooms), these units typically require increased electricity or natural gas supply infrastructure.

Trends and Potential

Building energy codes and appliance standards help to ensure that newly installed water heaters and hot water systems meet minimum efficiency standards.

In Oregon and nationally, building energy codes and appliance standards help to ensure that newly installed water heaters and hot water systems meet minimum efficiency standards. This work, combined with ENERGY STAR labeling and regional- and utility-run energy efficiency programs, helps incentivize, reduce costs, and drive adoption of leading water heater technology in Oregon and the region. In addition, building hot water storage tanks represent a potential avenue for thermal storage that, in combination with Oregon's new rule for demand response controls for water heaters, could reduce peak demand from building energy use and help offset future demand growth, and reduce reliance on fossil fuels for generation.

Most single-family homes in Oregon have a storage water heater (water heaters that have a water tank), which are typically fueled either by electricity or by natural gas (about 50/50 split). About 1 percent are fueled by propane. In the Pacific Northwest, approximately 2 percent of homes use an electric heat pump water heater as of 2017. Data and distribution of water heater types for the northwest can be seen in the following table from NEEA's Residential Building Stock Assessment.[4]

Figure 4: Distribution of Water Heaters in the Northwest by Detailed Type[4]

Detailed Type	Water Heaters		
	Percent	Error Bounds for the Analysis	Number of Homes in Sample
Instantaneous-Electric Resistance	0.8%	0.7%	6
Instantaneous-Fossil Fuel Condensing	3.0%	1.1%	31
Instantaneous-Fossil Fuel Non-Condensing	2.0%	1.1%	19
Storage-Electric Heat Pump (Packaged)	1.8%	0.9%	20
Storage-Electric Resistance	46.3%	3.1%	551
Storage-Fossil Fuel Condensing	4.1%	1.3%	38
Storage-Fossil Fuel Non-Condensing	41.3%	3.2%	390
Storage-Indirect Water Heater	0.5%	0.3%	10
Total	**100.0%**	**0.0%**	**1,048**

Smart Devices and Appliances

Timeline

- **1620** — Origin of the thermostat: Cornelius Drebbel invents an egg incubator with a mercury thermostat-based air and temperature control.[24]
- **1830** — Andrew Ure invents the modern-day application and what we currently refer to as a thermostat to keep boilers warm.[24]
- **1880** — Professor Warren Johnson invents first electrical thermostat to control room temperature in buildings.[24]
- **1906** — Mark Honeywell builds on previous patents and develops the first programmable thermostat.[24]
- **1962** — Imperial Chemical Industries invents Direct Digital Controls.[25] DDC controls would become more commercially available and popular in the 1970s and 1980s.
- **1975** — Smart home technology is invented, which uses radio frequency bursts onto existing electrical wiring to control appliances. [26]
- **2010** — Nest Learning Thermostats are introduced.[26]
- **2014** — Amazon Alexa is introduced and accelerates the trend toward connected home devices.[26]

Smart Devices in Oregon

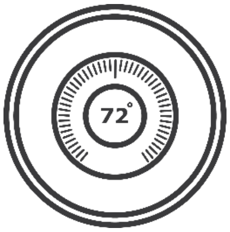
As of 2017, **10 percent of households in Oregon** use smart devices or appliances and the adoption rate continues to increase.[4]

Smart thermostats can save between 10 and 15 percent of heating and cooling costs when operated correctly, and offer more convenience compared with the level of effort required to achieve similar savings with a programmable thermostat.[23]

Smart devices and appliances cover a broad category of Wi-Fi enabled or otherwise connected devices that can be programmed to reduce energy use, collect information about energy use habits of building occupants, and receive and respond to signals from the owner, grid, or utility. This can range from a fully integrated automated building energy management system in a commercial building—where multiple appliances and pieces of equipment can be monitored and controlled by a central computer—down to a single smart appliance such as a refrigerator that sends a mobile alert. Smart devices and appliances are designed to use automation and connectivity to conveniently achieve energy savings while reducing the amount of time that building occupants need to actively engage in energy management practices. This combination of advanced technology and convenience are the main attractions of smart technology. These devices can also be part of utility demand reduction or demand response programs where participants voluntarily agree to have the utility control the device and turn it off or change settings to reduce peak loads and operate the system more cost-effectively, thereby helping to keep rates as low as possible.

Technology/Resource Overview (What is it and How Does it Work?)

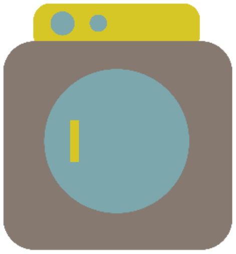
Smart Thermostats[23]



Smart thermostats are Wi-Fi enabled devices capable of connecting to a smartphone or similar device. They differ from programmable thermostats in that they are easily controlled remotely. Smart thermostats can be programmed to use a phone's location and Wi-Fi connection to track occupancy to change room temperature settings. These thermostats can use machine learning to predict when occupants will come home and can raise or lower temperature to ensure the home is comfortable upon arrival. In addition to energy savings, the benefit of this type of convenience for homeowners is saved time. Smart thermostats can also be connected and respond to grid and utility conditions to manage systemwide load, reduce outages, and minimize peak demand.

Smart Appliances[27]

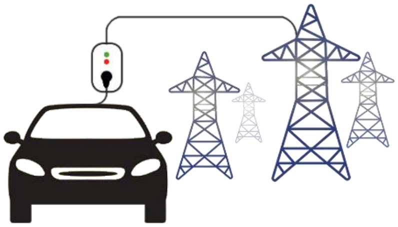
Smart Appliances don't have to be Wi-Fi enabled and controllable by a smartphone, but many are. Refrigerators, water heaters, heat pumps, furnaces, washers, dryers, and even tea kettles or coffee makers can come with this added level of control and connectivity. The primary components are integrated features that save energy and add convenience (and sometimes increase safety). An early example of this type of appliance are programmable coffee pots, where a timer can control when the coffee pot starts brewing coffee and how long afterward the warming plate turns off. Other features common in smart appliances are maintenance alerts and other monitoring features to help ensure the appliance is running at peak efficiency, and energy saving convenience features like programmable delays (for example allowing you to set your dryer cycle to begin at a certain time so laundry is ready to be folded when you arrive home from work, reducing the number of times you use the de-wrinkle cycle).



Another layer to smart appliances is grid connected devices that, when demand is high, can allow the utility provider to make minor adjustments to equipment settings to reduce peak demand, potentially in exchange for reduced rates or incentives. Adjustments are generally minimal and imperceptible to the occupant, and users always have the option to override if needed. These demand response programs can help utilities meet short duration peak electricity demand periods while delaying or removing the need for more expensive new generation assets.

Smart Electric Vehicle Chargers[28]

Electric vehicles (EVs) are expected to create load growth for electric utilities as adoption increases. Utilities can meet this anticipated growth through a variety of options, including smart EV chargers that can regulate when and how fast an EV charges. Wi-Fi enabled or programmable chargers allow a smart phone or timer to program EVs to charge at times when energy demand and/or costs are lower. Many utilities offer a lower EV-specific rate during off-peak hours, often overnight. A smart charger could be programmed to run during these hours or set to enable the utility to communicate with the charger to help balance EV fueling needs with grid demand. Like the demand response programs for appliances described above, smart EV chargers can enable utilities to control EV charging to help reduce peak loads. The ability to regulate charging is a critical component for utilities managing increasing numbers of EVs on their systems, and some Oregon utilities provide rebates to incentivize installation of smart charging infrastructure. Electric vehicles with smart charging technology also present a unique opportunity for small scale energy storage, when paired with bi-directional flow and grid integration. Excess electricity generation from on site or the grid can be directed to the chargers for storage in vehicle batteries, and if desired can be used to provide energy on site during peak demand or electric system outages.



To learn more about grid interactive smart chargers and utility planning for increased ZEV charging demand, see ODOE's *2021 Biennial Zero Emission Vehicle* report.

Controllable Lighting

Lighting controls come in various forms, the simplest being occupancy detectors that turn off lights in an area after a certain amount of time if no movement is sensed. Additional types of controls automatically dim lights by using daylight sensors to change the lighting based on how much natural light is coming through the windows in relation to a required minimum light level setting. Outdoor lighting can be controlled using motion detection and/or daylight sensors. More advanced lighting controls can include Wi-Fi connectivity and control in combination with the sensors listed above, which allow for the convenience of remote control while also using automated sensors to passively save energy. In Oregon, for new commercial construction and retrofits, energy codes include requirements for occupancy and scheduling controls.

Conclusion

Advances in energy efficiency have helped utilities manage regional demand and reliability for energy, improved energy bills and thus reduced energy burden for many Oregonians and contributed to progress toward state and local climate goals. There remains significant energy efficiency potential to continue to provide these benefits. Advanced technology adoption rates vary according to many factors, but costs and barriers can leave some groups behind. Incentives and market transformation efforts that focus on closing these gaps will help achieve regional and local goals.

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Energy Resource & Technology Review: Electricity Storage

Timeline

- **1800** – Allessandro Volta, Italian physicist, builds the first electrochemical battery. Named the voltaic pile, it is a stack of copper and zinc plates separated by brine-soaked paper disks that can produce a steady current over time.[1]
- **1838** – William Grove develops the first *fuel cell* — a device that converts the chemical energy of a fuel into electricity through a chemical reaction with an oxidizing agent.[1]
- **1907** – Pumped storage hydropower is first used at a facility near Schaffhausen, Switzerland.[2]
- **1923** – Hydrogen is first discussed as an energy storage medium in a paper by John Haldane titled: "Daedalus or Science and the Future."[3]
- **1930** – The Connecticut Electric and Power Company creates the first large-scale pumped-storage facility in the United States near New Milford, Connecticut. It pumps water from the Housatonic River to a large storage reservoir 70 meters above.[4]
- **1985** – The Bath County Pumped Storage Station begins operating and is described as the "largest battery in the world." It is located in Bath County, Virginia and it remained the largest pumped-storage power station in the world until 2021 when it was surpassed by the Fengning Pumped Storage Power Station in northern China.[5]
- **1987-1991** – Akira Yoshino, Japanese chemist, patents the first commercial lithium-ion battery. Four years later, Sony starts selling the world's first rechargeable lithium-ion batteries based on Yoshino's design.[6]
- **2013** – Portland General Electric opens a 5-megawatt energy storage facility in Salem, Oregon. The Salem Smart Power Center was an industry-first in its use of lithium-ion battery technology in a large, utility-scale application.[7]
- **2018** – Wheatridge Energy Facility is the first state-jurisdiction approved battery-storage facility in Oregon.
- **2021**- The U.S. Department of Energy invests $27 million dollars in battery storage technology. It aims to support domestic manufacturing of next-generation flow batteries and increase equitable energy storage access.[8]

Electricity Storage in Oregon

There are more than **600 small-scale battery storage systems in Oregon**. Together these systems provide more than **8 megawatt-hours of backup power** for Oregon homes and small businesses. Many larger systems, co-located with solar and wind facilities, are planned or under construction. Oregon's Energy Facility Siting Council has approved applications for more than **400 MW of battery storage**, and nearly 3,000 MW of storage is in the application process.

Most energy we use directly can be stored in some form, like gasoline tanks on vehicles and at gas stations, or in natural gas and propane storage tanks. Electricity is unique because it must be used as it is created. The *fuel* (e.g., water, coal, or natural gas) used to generate electricity can be stored in many circumstances and used at the necessary time, and in other cases the fuel (e.g., wind, sunshine) cannot be stored. To store electricity once it is created, it must be converted into some other form of energy. There are four different categories of storage mediums used to store energy from electricity: electrochemical, chemical, mechanical, and thermal. Each of these categories includes different technologies. For example, lithium-ion batteries are a form of electrochemical storage, and pumped hydropower is a form of mechanical storage.

There are trade-offs for each type of storage, including varying levels of energy conversion efficiency, energy capacity, discharge time, lifetime, and physical space requirements. Conversion efficiency refers to the overall measure of how much energy is lost throughout the input and output cycle — for all storage technologies there is necessarily more energy input than energy output. It requires energy to convert electricity into another form of energy, and all forms of potential energy are subject to natural processes that slowly reduce the amount of energy stored.[i] There are also energy losses that result from the physical conditions of the storage medium. For example, lithium-ion batteries can lose more of their stored energy in colder weather, and pumped hydropower can lose more stored energy on hot and windy days due to evaporation.

Each type of storage technology results in greenhouse gas emissions, including from the extraction and processing of source minerals, production of components, transportation of source materials, components, and final products. These greenhouse gas emissions are not provided in this technology review, but instead discussions of climate effects focus on emissions associated with the electrical energy that is stored in each of these technologies.

Common Energy Storage Measurement Terms

Storage capacity refers to the maximum amount of electrical energy that can be stored in a particular technology, expressed in megawatt-hours or kilowatt-hours. The maximum amount of electricity a technology can supply to the grid at any given moment is referred to as **power**, or in the case of batteries, the **power rating**, and is expressed in kilowatts or megawatts. The **discharge time** refers to how much time it would take for a storage technology to discharge electricity before it has spent all its stored energy. Discharge time may be constant for some types of technologies, such as flywheels, or it may be dynamic, such as batteries which can be discharged at varying rates.

For example, excluding inevitable energy losses, a 5-kWh capacity battery with a 1 kW power rating could discharge 1 kWh of electricity for five hours, or a battery with a power rating of 5 kW could discharge the same 5 kWh of electricity for one hour. For electric vehicles, the rate of charge and discharge for a battery is determined by the driver’s needs. Utility-scale batteries, however, are

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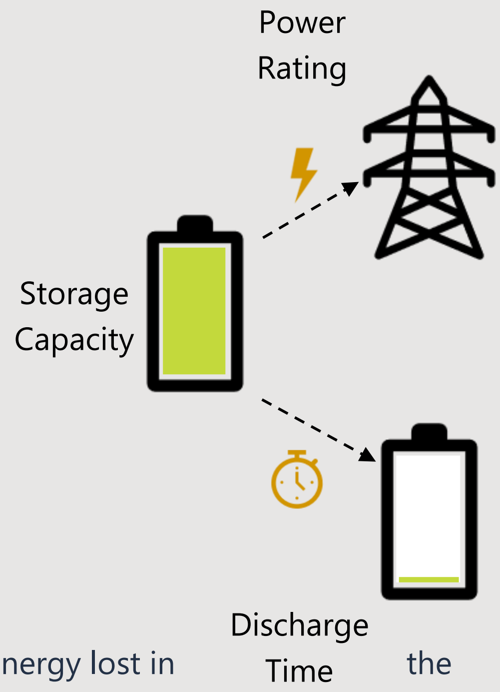
[i] The second law of thermodynamics states that as energy is transferred or transformed, more and more of it is wasted or lost.

often optimized to charge and discharge in a way that preserves the battery lifetime while also supporting grid services.[ii]

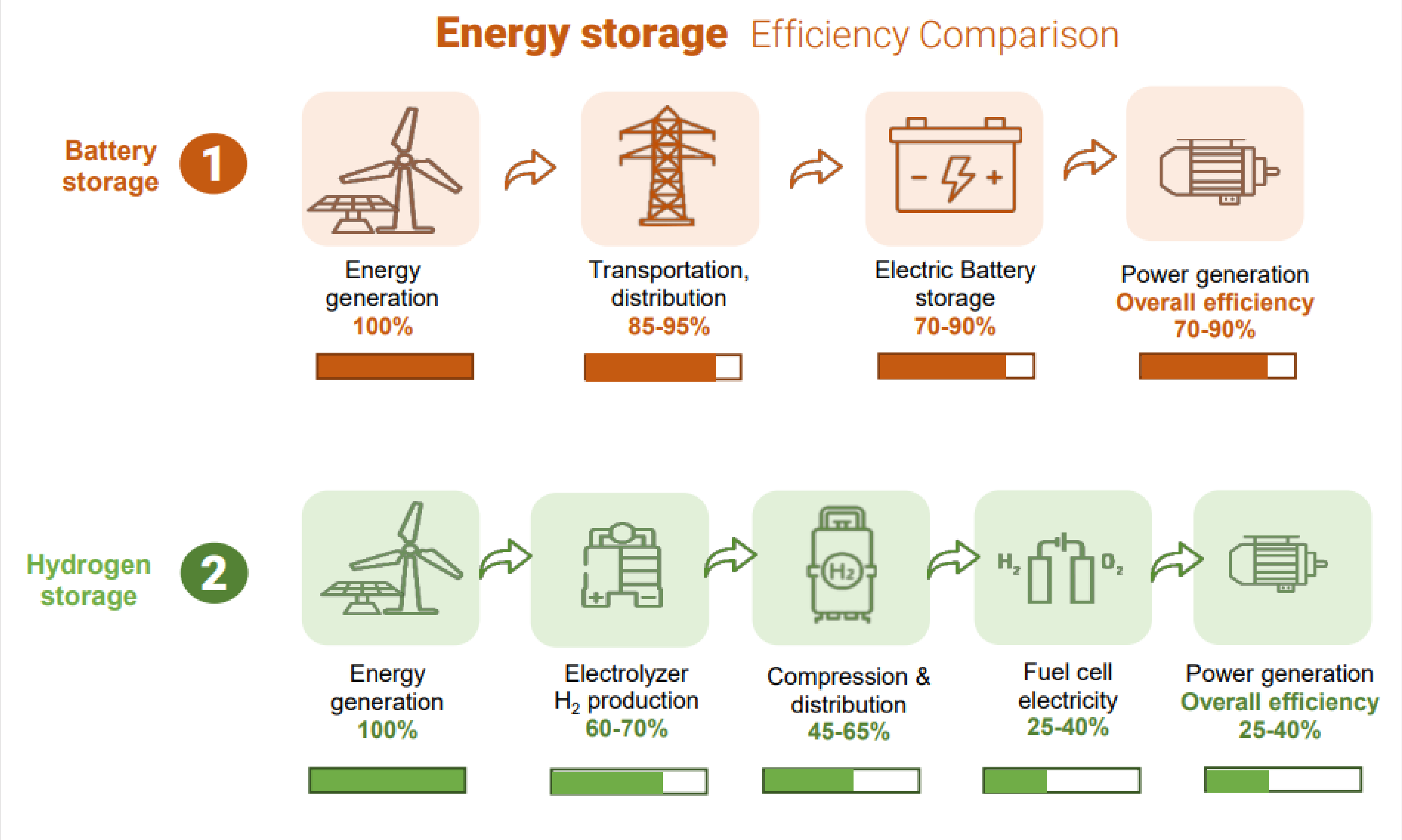
- **Storage Capacity or Energy Rating:** A measurement of the maximum volume of stored energy, in megawatt-hours (MWh) or kilowatt-hours (kWh), within a given storage technology.
- **Power or Power Rating:** A measurement of how much energy, in megawatts (MW) or kilowatts (kW), can flow out of a battery device and onto the power grid in a given instant.
- **Discharge Time or Duration (seconds to days):** A measurement of the energy-to-power ratio of the storage technology expressed as the amount of time that the technology can discharge at its maximum power rating until it has exhausted its energy supply.
- **Energy Density (watt-hour per liter):** The amount of energy stored in a given technology per unit volume.
- **Efficiency Rating (percent):** The amount of usable energy lost in the process of converting electricity to and from the storage technology.



The efficiency of a storage technology refers to how much energy is consumed or lost in the process to convert electricity to the storage medium and then convert it back into electricity. All electricity storage devices are net consumers of usable energy, meaning the amount of electricity delivered back to the grid will be less than the amount of electricity initially sent to the storage technology. Lithium-ion batteries are very efficient, returning about 85 to 98 percent of the energy they store back to the grid, whereas storing electricity by converting it to hydrogen requires large amounts of energy inputs and returns only about 25 to 45 percent of the electricity back to the grid.

[ii] Grid services are functions that help maintain a reliable electricity grid. They include maintaining the proper flow of electricity, addressing imbalances between supply and demand, and helping the system to recover after events like blackouts.

Figure 1: Efficiency Comparison of Different Storage Technologies[9]



Source: Company data, Goldman Sachs Global Investment Research.

Storage mediums also have limited lifetimes during which they can effectively store and release energy. The lifetime of the technology depends on different factors. Mechanical storage, such as pumped hydropower, tends to have longer lifetimes because limitations are based on mechanical and structural wear and tear, which generally can be maintained to last for a long time. Lithium-ion batteries are dependent on chemical processes that eventually degrade the chemistry of the battery terminals – much like rust accumulating on exposed metal – which diminish the capacity of the battery over time. Refurbishing batteries is generally not commercially available, so when batteries reach the end of their useful lifetimes for their original purpose, they are typically repurposed for another application.[10]

The physical space requirements, often referred to as energy density, can vary widely between different storage types. Electrochemical storage technologies tend to be very energy dense, which means more energy can be stored in relatively small spaces. Electrochemical storage devices like batteries are also scalable, meaning users can size the number of storage devices to meet specific storage needs. This modularity enables users to easily add to a site's total storage capacity. Other forms of storage, such as pumped hydropower, are less energy dense, requiring more space to store a similar amount of energy.

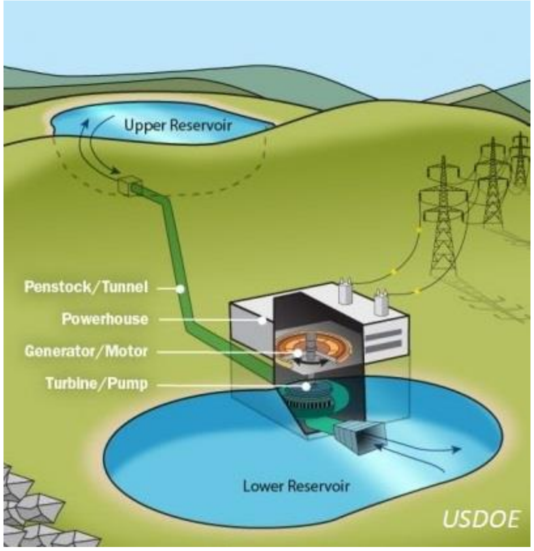
This technology review covers the four different types of storage forms, focusing largely on three specific technologies: pumped hydropower, battery storage, and hydrogen. These are the most common types of storage in the U.S., or in the case of hydrogen, have potential as a companion technology for renewable energy development.

Table 1: Comparison of Different Storage Technologies[1]

Storage Form	Storage Type	Power (MW)*	Discharge Time	Energy Density (Watt-hour /Liter)	Maximum Lifetime	Efficiency
Mechanical	Pumped Hydropower	100 - 1000	4 - 12 hours	0.2 - 2	30 - 60 years	70 - 85%
	Flywheels	0.001 - 1	10 – 20 milliseconds	20 - 80	20K - 100K cycles	70 - 95%
	Compressed Air	10 - 1000	2 – 30 hours	2 - 6	20 - 40 years	40 - 75%
Electro-chemical	Lithium-Ion Batteries	0.1 - 100	1 min - 12 hours	200 - 400	1000 - 10,000 cycles	85 - 98%
	Flow Cell Batteries	1 - 100	2 – 10 hours	20 - 70	12,000 - 14,000 cycles	60 - 85%
Chemical	Hydrogen	0.01 - 1	mins - weeks	600 (at 200 bar)	5 - 30 years	25 - 45%
Thermal	Molten Salt	1 - 150	hours	70 - 210	30 years	80 - 90%

** Power rating is based on typical storage devices today. Devices like batteries and physical mediums like hydrogen are easily scalable, meaning a particular site may have a much higher power rating.*

Mechanical Storage Technologies



Mechanical storage devices use kinetic or gravitational means to store energy. The most common form of mechanical electricity storage is pumped hydropower, which uses two bodies of water at different elevations to store potential energy[iii] in the water at the higher elevation. When electricity is needed, the water is allowed to flow downhill through an energy-generating turbine to the lower elevation reservoir. When electricity is plentiful (and often lower-cost), the water is pumped back up to the higher reservoir.[12]

There are other forms of mechanical energy storage, but they generally have limited applications. For example, flywheels convert electricity into stored potential energy by spinning a rotor that can release that energy to generate electricity. Flywheels are more amenable to high-power, low-energy storage needs, generally used to respond to

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[iii] Potential energy is the energy stored in a physical body relative to its surroundings. For example, water at higher elevations has potential energy that can be captured when it flows downhill, or a coiled spring has energy that is released when it is allowed to uncoil.

minor fluctuations in the electrical grid.[13] There are only four flywheel energy storage sites operating in the U.S., none of which contribute to Oregon's electric grid.[14]

Trends and Potential

In 2019, pumped hydropower accounted for 93 percent of all utility-scale energy storage in the U.S.[12] The U.S. currently has the second highest proposed capacity of new pumped storage hydropower projects in the world after China.[7] The Grand Coulee Dam in Washington State – the largest hydropower generator in the U.S. – has an associated pumped hydropower project that can supply as much as 314 MW of capacity when fully operated.[16] [17] In addition, projects in California, Colorado, and Arizona can also contribute to the electricity consumed in Oregon.[14]

There are no existing pumped hydropower systems in Oregon, but there are two proposed sites at different stages of permitting and development.

There are no existing pumped hydropower systems in Oregon, but there are two proposed sites at different stages of permitting and development.[18] The Swan Lake Energy Storage Project proposed in Klamath County received Federal Energy Regulatory Commission licensure in 2019, and is currently in the pre-construction phase.[19] As proposed, the project would have over 3,500 MWh of storage capacity.[20] A second, even larger, pumped hydropower facility has been proposed in Malheur County using Lake Owyhee as the lower reservoir. This project would link to the grid using the approved Boardman-to-Hemingway transmission line that will run within 10 miles of the proposed project substation.[21]

Development of pumped hydropower facilities involves extensive capital needs and complex permitting processes. These facilities generally have large capacities, from dozens to hundreds of megawatts, and require large land areas that necessitate environmental and cultural impact assessments. Like a conventional hydropower system, they can be highly flexible to meet changing power needs, such as balancing variable renewable energy resources like wind and solar. There are also high costs and permitting requirements if the owner/operator wants to expand the reservoir to provide additional storage capacity.[11]

Pacific Northwest Pumped Storage Hydropower Development Act[23]

Enacted as a part of the Infrastructure Investment and Jobs Act, signed by President Biden on November 15, 2021, a new law streamlines permitting processes for pumped storage projects. The bill assigns sole permitting authority to the Bureau of Reclamation for non-federal pumped storage development at federally owned reservoirs in the Pacific Northwest. Introduced by members of Congress from Washington State, the new law may encourage pumped storage development at some of the Federal Columbia River Power System dams in the region.

Beyond Energy

Pumped hydropower requires large areas of land to be converted to water reservoirs. This conversion of land can reduce biodiversity through impacts on existing freshwater habitats and land, including effects on fish species.[24] There is also an initial release of methane (a greenhouse gas) when reservoirs are first created due to the decomposition of organic material in the inundated areas. Pumped hydropower projects also require water. This is a concern in arid areas with limited water supply, and particularly where water to supplement the project comes from underground aquifers.[25] These effects are highly variable based on the surrounding landscape and biodiversity, and would require environmental analysis to effectively understand site-specific impacts.[26]

Any form of hydropower can affect lands and natural and cultural resources. In particular, tribal lands and sacred sites and resources have the potential to be damaged or destroyed. Many areas of Oregon have sites that are sacred to Tribes, including archaeological sites and areas where traditional foods and medicines are available and harvested. Previous inequitable policy decisions to flood sacred and productive tribal lands for hydropower use led to the submersion of important cultural resources, such as the Celilo Falls fishing community after the construction of The Dalles Dam.[27] Tribes have indicated that they must be included in discussions around projects like pumped hydropower to ensure their recommendations are incorporated into all project development and planning discussions and processes.[28]

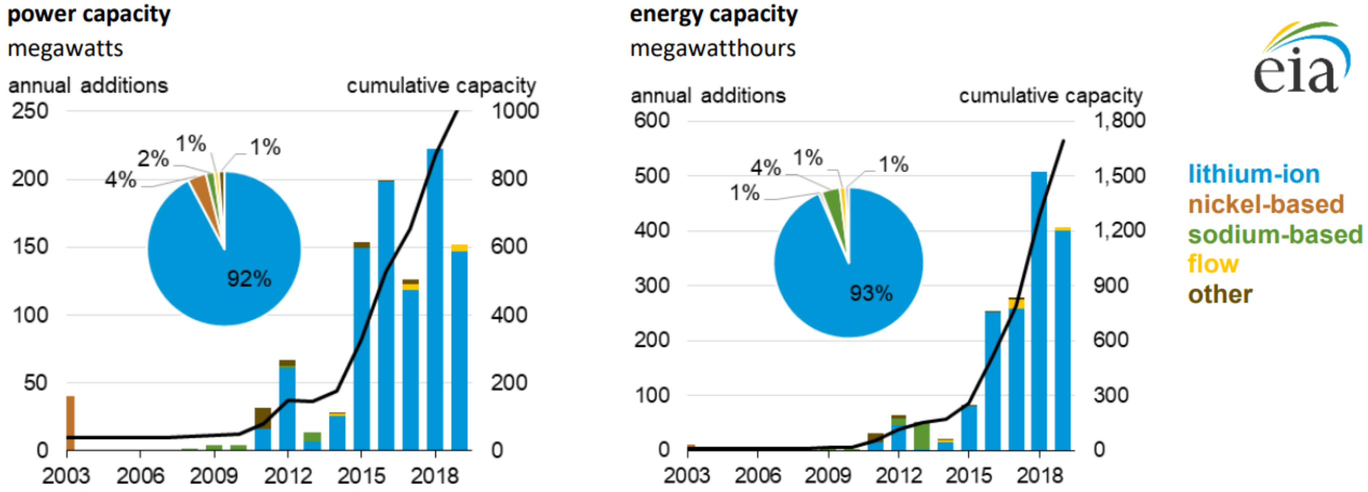
Tribes must be included in discussions around projects like pumped hydropower to ensure their recommendations are incorporated into all project development and planning discussions and processes.

Electrochemical Storage Devices

Electrochemical storage uses electricity to cause a chemical reaction that can be reversed later to generate electricity. The storage technologies for electrochemical reactions are called batteries. There are many types of batteries used for a wide variety of applications.[29] Lithium-ion batteries account for 98 percent of utility-scale battery use[30] and are the most commonly used in residential storage systems.[31] Compared to other battery types, lithium-ion are more energy dense, weigh less, are more energy efficient, perform better in higher temperatures, and maintain charge better when not in use.[29]

Other battery chemistries used by U.S. electric utilities include nickel, sodium, and lead acid. These chemistries have been used for a long time in the industry and accounted for about 6 percent of battery storage in 2019. These legacy storage batteries are often replaced with better-performing lithium-ion when upgrading facilities.[32] Redox flow batteries – a type of battery where the electricity-conducting fluid is contained in a separate tank until the battery is activated – are a relatively new technology that is largely used in pilot and demonstration type projects.[33]

Figure 2: Large-Scale Battery Storage Capacity by Chemistry (2003-2019)[32]



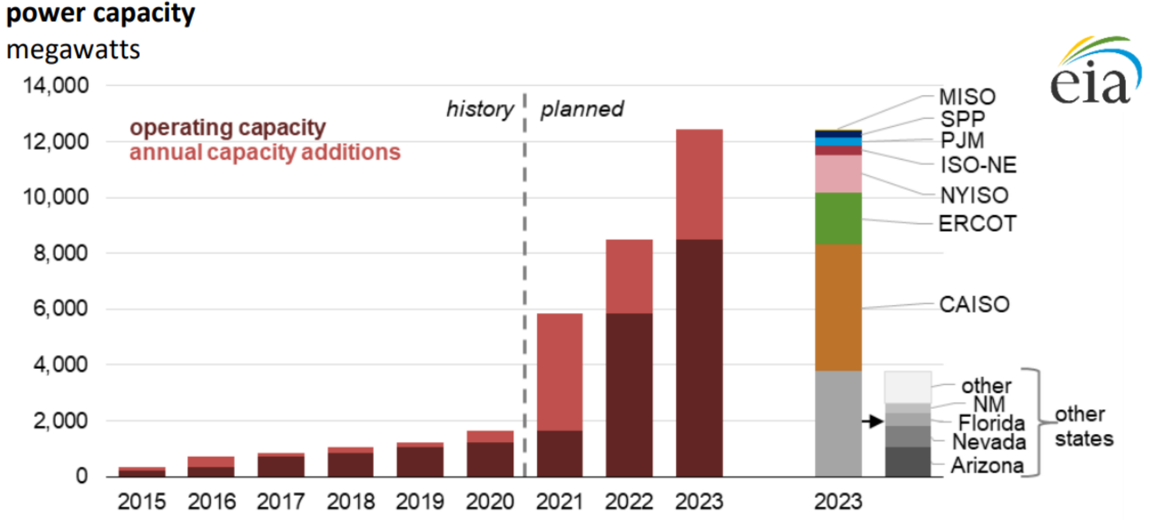
Source: U.S. Energy Information Administration, 2019 Form EIA-860, *Annual Electric Generator Report*

The ability to store electricity that can be dispatched at a later time can provide several different services to the grid. Batteries can support critical grid management functions on a second-by-second basis, shift supply to meet peak demand needs, enable better and more efficient use of variable renewable technologies, support more efficient and reliable transmission and distribution systems, and reduce energy costs by deferring large investments in infrastructure or taking advantage of minute-to-minute fluctuations in electricity generation costs.[34] Some battery types and configurations may be optimal for a specific function, but most utilities opt for lithium-ion batteries because they can meet all electric utility battery use case applications.[32]

Trends and Potential

Lithium-ion battery storage production is expected to continue its rapid increase in the next five years to meet demand for electric vehicles, consumer electronics, and increasingly for utility-scale and small-scale battery storage.[35] Lithium-ion battery costs have fallen 89 percent in the last decade, from over $1,200 per kWh in 2010 to $132 per kWh in 2021.[36] Global demand is expected to grow rapidly in the next decade, and lithium-ion batteries will likely dominate the storage market through 2025.

Figure 3: U.S. Large-Scale Battery Storage Cumulative Power Capacity, 2015-2023[37]



Source: U.S. Energy Information Administration, Dec 2020 Form EIA-860M, *Preliminary Monthly Electric Generator Inventory*

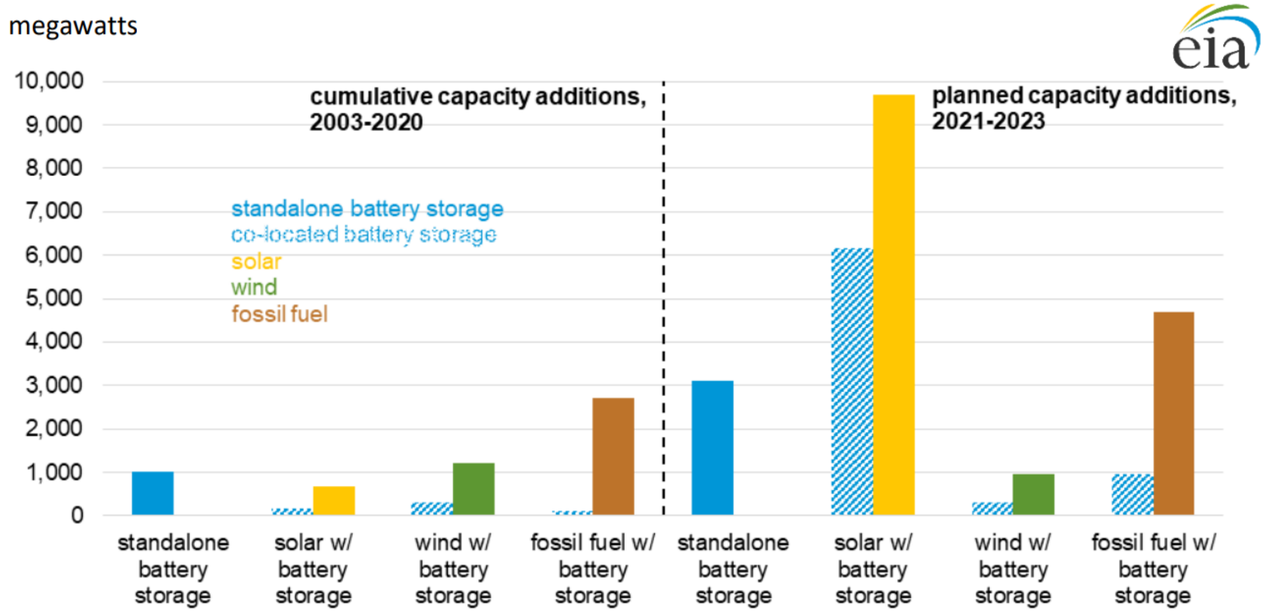
Utility-Scale Battery Storage

Lithium-ion battery use in the electricity sector is also expected to increase in the U.S. by more than 500 percent over the next five years, from 1,500 MW in 2020 to 7,800 MW by 2025.[38] In California alone, the California Independent System Operator anticipates more than 6,000 MW of battery storage will be online by 2024.[39] To date, most battery storage has been used to maintain second-to-second grid stability by charging and discharging in small amounts, and integrating solar and wind generation is expected to be one of the biggest drivers for utility-scale batteries in the years ahead.[40] They store energy at times when wind and solar are plentiful and electricity supply exceeds demand; the batteries then discharge their stored energy back to the grid as electricity when renewable generation resources are limited.

Batteries can also lower costs for utilities by reducing the need to purchase expensive electricity on the market when demand is high, or by deferring the need to build infrastructure to meet growing electricity demand. They can also address transmission line congestion by storing energy so it can be transmitted at times when there is more capacity, reducing the need for transmission expansions or upgrades. Batteries are especially useful to address daily electric load patterns, such as storing energy when solar production is high in the middle of the day and then supplying energy to the grid in the early evening when electricity demand is high and the solar resource is waning.[34]

Most utility-scale storage in the U.S. are standalone sites, which provide general grid support, but increasingly batteries are being sited with renewable energy facilities. This trend is driven by lower costs for battery production and incentives that require co-locating with renewable resources. By 2023 it is expected that 60 percent of batteries will be co-located with wind and solar projects, as shown in Figure 4.[41] In Oregon, Portland General Electric's Wheatridge Renewable Energy Facility is one of the first facilities in North America to site wind, solar, and battery storage at one site.[42]

Figure 4: U.S. Large-Scale Battery Storage Power Capacity Additions, Standalone and Co-Located[37]



Source: U.S. Energy Information Administration, Dec 2020 Form EIA-860M, *Preliminary Monthly Electric Generator Inventory*

Note: Solid yellow, green, and brown bars indicate generating total capacity of solar, wind, and fossil fuels that have battery storage on-site.

Inflation Reduction Act Support for Storage

In August 2022, the Biden Administration signed into law the Inflation Reduction Act, providing funding for programs and actions across multiple sectors, including clean energy development.[43] The IRA extends the Investment Tax Credit for renewable energy projects, including both standalone battery storage projects and renewable energy generation co-located storage systems. The tax credit starts at 6 percent of the project development cost but increases to 30 percent if certain labor practices are used in the development of the project, and can increase an additional 10 percent if the project meets domestic content requirements. It can be applied to battery, thermal, or hydrogen energy storage projects with at least 5 kWh nameplate capacity. The new law also allows for cash payment options in lieu of tax credits that can be used by tax-exempt organizations, including state and local governments, Tribes, and others.

Batteries can mitigate transmission and distribution line issues, such as congestion on segments with heavy usage or to manage voltage levels at the ends of long lines.[44] Electricity can be stored in batteries to be transmitted when the lines are less congested. That power would then be available when demand is high and without the need to transmit the electricity across congested lines. Similarly, batteries can store energy at the ends of long distribution lines, which can help to maintain grid.

Although lithium-ion batteries are the predominant battery chemistry used today, new battery chemistries have the potential to improve upon capabilities. Solid-state batteries are one of the most discussed and potentially market-altering new types of battery, which have the potential to become commercially available in the next few years.[45] Unlike the lithium-ion batteries in use today, which use liquid electrolytes, solid state batteries use electrolytes made of a solid material. This innovation could make batteries safer, more affordable, and improve overall battery performance, including faster charging times. Many solid-state chemistries have been demonstrated as viable, with businesses and U. S. Department of Energy laboratories working toward commercialization pathways.[46] Other types of batteries may be necessary for advancements in long-duration storage (see the Long-Duration Storage Energy 101).

Small-scale Battery Storage

The residential and commercial sectors in the U.S. account for about 41 percent each of total small-scale[iv] storage installations, with the industrial sector at about 14 percent.[v] The remaining 4 percent is directly connected to the grid, usually for utility-run small-scale storage. There were 402 MW of small-scale battery storage capacity in the U.S. in 2019. California accounted for 83 percent of that, largely due to state incentives that support small-scale storage installations and state requirements for 325 MW of customer-sited storage capacity to be installed by 2024.[47]

[iv] Small-scale battery storage systems are defined as those that have less than 1 MW of generating capacity.

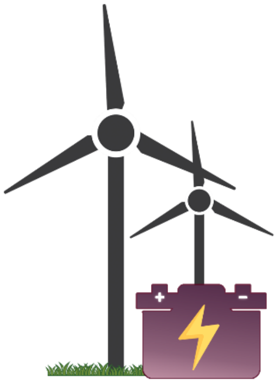
[v] This includes only small-scale storage reported to the U.S. Energy Information Administration. Small-scale storage that has been added on the customer side of the meter and not reported to the local utility may not be included.

There are more than 600 small-scale energy storage systems in Oregon totaling more than 8 MWh of energy storage. The adoption of small-scale storage is limited in the Pacific Northwest by high up-front costs coupled with low electricity costs. This makes them less cost-effective than in parts of the country where retail electricity prices are higher. Battery storage can be particularly economical for customers that have time of use electricity rates, where the retail cost for electricity varies at different hours of the day. The option to store low-cost electricity for use at times when costs are higher makes an energy storage investment pay for itself more quickly.

The Oregon Department of Energy runs the Oregon Solar + Storage Rebate Program, which issues rebates for solar electric systems and paired solar and storage systems for residential customers and low-income service providers. To date, the program supported the installation of more than 200 small-scale storage projects in Oregon homes. The 2022 passage of the federal Inflation Reduction Act will also provide tax credits for small-scale storage. See ODOE's *2020 Biennial Energy Report* for more information on residential-scale battery storage.

Beyond Energy

Batteries that supply electricity to the grid are not inherently zero-carbon but take on the emissions of the type of electricity used to charge them. In theory, this would mean that a battery charged with solar or wind power would have zero emissions, whereas a battery charged with electricity generated by natural gas would have the same amount of carbon as that natural gas source. In practice, the emissions profile associated with batteries is more complex, largely driven by when and where batteries are charging and discharging. At any given point in time, grid electricity is a mixture of both non-emitting and carbon-emitting resources, which contribute to the charging of the battery.



Batteries can be co-located directly with zero-emission generating resources, like wind or solar projects. The identification of the carbon emissions impact of this, however, is not straightforward and is not zero by default. For example, if a solar project could export energy to the grid and displace the use of carbon-emitting energy in real-time, then co-locating a battery to otherwise store that solar energy could result in more carbon emissions on the system than if the solar project had been allowed to discharge directly to the grid. In other circumstances, a co-located battery could enable using more solar output than would have otherwise occurred. In addition, batteries can also be used to optimize the operation of carbon-emitting resources, which would have the effect of reducing its overall emissions. For example, Portland General Electric added battery storage to their Port Westward natural gas plant, allowing that plant to operate more efficiently, reducing fuel use and emissions at the plant.[48]

Lithium-ion batteries are made of raw materials such as lithium, cobalt, nickel, and graphite.[49] These minerals are largely mined and refined in foreign countries. Domestic reserves of these and other minerals often constitute less than 5 percent of the total world capacity, as shown in the table below.

Table 2: Comparison of U.S. Mineral Reserves and Manufacturing Capacities vs. the World[50]

Element	U.S. Reserves (1,000 Metric Tons)	Percent of U.S. Reserves	World Reserves (1,000 Metric Tons)	Total Manufacturing Capacity w/ US. Reserves (GWh)*	Total Manufacturing Capacity w/ World Reserves (GWh)*
Lithium	750	3.6%	21,000	7,470	209,163
Cobalt	53	0.7%	7,100	703	94,164
Nickel	100	0.1%	94,000	167	156,510
Manganese	230,000	17.7%	1,300,000	3,271,693	18,492,176

**Reflects the estimated total capacity of batteries that could be produced with this element.*

Although new technologies are being developed to reduce dependence on certain minerals, the expected dominance of lithium-ion batteries in the near future means the U.S. is dependent on foreign nations for raw material supply unless new domestic mines are developed and begin production. In many countries where mining provides a large share of national revenue, the practices at the operations may have negative effects on local communities due to environmental damage, human rights abuse, and inadequate safety and health standards.[51] The USDOE has collaborated with the Federal Consortium for Advanced Batteries to develop a *National Blueprint for Lithium Batteries* for the next decade, which provides guidance on supporting the development of domestic resources, materials processing, battery manufacturing, and end-of-life recycling strategies.[30] The 2022 Inflation Reduction Act included incentives for the development of domestic resources and component manufacturing as well as requirements that a percentage of minerals come from North America or a country that has a free trade agreement with the U.S. The act provides an additional 10 percent investment tax credit for projects using 100 percent U.S. steel and iron, and a percentage of the total costs of the project from components that are mined, manufactured, or produced domestically. The percentage is set at 40 percent initially and increases every year beginning in 2025 to 55 percent by 2028.[43]

Potential Lithium Resources in Oregon

The Oregon Department of Geology and Mineral Industries approved three applications for HiTech Minerals to explore lithium deposits located in southern Malheur County near the Nevada border. HiTech's parent company, Jindalee, estimates that the site has over 10 million metric tons of lithium, or more than 13 times the total amount of current U.S. lithium reserves.[52]

The U.S. Department of Energy estimates that by 2031 there will be 2 million tons of end-of-life *electric vehicle* batteries alone. Recycling batteries can reduce reliance on foreign raw materials and component production, lower overall battery manufacturing costs, and reduce waste and waste disposal costs.[53] Currently, recycling batteries is expensive, largely driven by costs to appropriately handle and transport the batteries for recycling and disposal. The National Blueprint for Lithium

Batteries includes a goal to "enable U.S. end-of-life reuse and critical materials recycling at scale and a full competitive value chain in the United States," which calls for incentives for battery recycling and the development of federal policies to require the use of recycled material in battery cell manufacturing.[54]

The U.S. Department of Energy's ReCell Center conducts research and development on advanced battery recycling techniques and leads multiple programs to support more efficient and cost-effective battery recycling.[55]

Lithium-ion batteries have the potential to cause fires or explosions when they fail or are mishandled. When batteries malfunction or are damaged, the internal temperature of the battery rises. Rising temperatures inside the battery can lead to the release of toxic and explosive gases, which can cause fires. This can cause a cascading reaction as one cell in a battery explodes, damaging adjacent cells that subsequently also catch fire and potentially explode. Batteries that are stored and maintained properly are at low risk for failure, but battery owners can also reduce their risk by: regularly inspecting batteries for damage or failure, including fire suppression systems and explosion protection devices in the storage facility design, following National Fire Protection Association standards, and designing an emergency operations plan in coordination with the local fire department.[56]

Increased use of batteries can support jobs across many economic sectors, including mining, raw materials processing, manufacturing, and transportation of materials and goods. As the U.S. identifies and supports raw materials production and processing, as well as battery manufacturing and recycling opportunities, new economies will be created to support the increased demand for batteries. Some of the jobs will be driven by geographic availability of raw materials, while manufacturing and recycling may be driven by proximity to raw material streams, the availability of low-cost and renewable forms of electricity, or the availability of a trained workforce.

Chemical Storage Technologies

Chemical storage involves storing energy in chemicals that can be later used to generate electricity.[57] Natural gas, coal, and diesel fuel are examples of chemical energy storage until they are combusted to produce large amounts of energy. This energy was "stored" hundreds of millions of years ago from decaying plant matter that eventually formed these hydrocarbons. In addition to energy stored by the earth's natural processes, energy can be stored in chemicals made specifically for this purpose. One form of chemical energy storage today is creating hydrogen from natural gas or water – the resulting hydrogen can then be combusted to spin turbines or run through a fuel cell to generate electricity. Other technologies and processes can be used to store energy from electricity by creating ammonia, methanol, and methane.[57]

Hydrogen can be used to fuel combustion turbines that generate electricity, either blended with ammonia or natural gas or as pure hydrogen. In some parts of the industrial sector, such as steel mills, refineries, and petrochemical plants, hydrogen – a byproduct of these industrial applications – has been used for on-site electricity generation for more than 20 years.[58] Most existing natural gas turbines can run on low blends of hydrogen with minimal changes to the turbine, although upgrades to the plant are necessary to be able to store and blend the hydrogen.[59] To utilize higher blends of hydrogen, turbines must be retrofitted to account for physical differences between natural gas and hydrogen to ensure turbines are not damaged and can operate as effectively. Manufacturers are also developing turbines capable of using up to 100 percent hydrogen that could be installed at existing natural gas plants.

Trends and Potential

ODOE is not aware of any commercially operating sites in Oregon to create and store chemicals using electricity that can be used later to provide electricity back to the grid. Electrolyzers have existed for more than a century, but the practice of using these to store energy is not widely adopted today — though several projects are in development. The Advanced Clean Energy Storage hub is expected to go online in 2025 with an 840 MW turbine that will be capable of using renewable hydrogen stored in a salt cavern in Delta, Utah.[60] In Washington State, Douglas County Public Utility District held a ground-breaking ceremony on March 12, 2022, for a 5 MW hydrogen production facility that will help that utility provide more flexible electricity operations.[61] NW Natural filed an application at the Oregon Public Utility Commission for approval to build an electrolyzer project that would use electricity from the Eugene Water & Electric Board to generate clean hydrogen that will subsequently be mixed into the natural gas supplied to a small number of customers in the Eugene area. This project will help NW Natural confirm that its system standards, procedures, and equipment, along with downstream appliances, will be able to accommodate a 5 percent or higher blend of hydrogen.[62] The company is now testing hydrogen blends at its training facilities to assess the effect of blending hydrogen up to 20 percent in its distribution system.

NW Natural and the Eugene Water & Electric Board plan to partner on a project that will generate renewable hydrogen. The H2 will be mixed into the natural gas supplied to a small number of customers in the Eugene area.

There are many benefits associated with chemical storage, most notably the higher total energy capacity and longer lifetime than many other forms of storage.[57] Chemical storage systems can store energy for much longer periods of time – provided an appropriate containment vessel – than can electrochemical or thermal storage systems. However, powering the grid with non-petroleum derived chemicals costs more than simply combusting natural gas or coal because the infrastructure needed to safely create, store, transport, and handle the hydrogen – or other chemicals – is not yet fully developed.[63] Converting electricity to hydrogen, ammonia, or other chemicals to store the energy also has lower round-trip energy efficiencies (meaning it loses more energy as waste) than other forms of storage, which increases the plant size necessary to achieve equivalent storage capacity.[57]

Beyond Energy

Chemicals that store energy can have uses beyond electricity generation. Hydrogen and ammonia can be used as transportation fuels or in industrial applications, creating more potential revenue streams beyond energy storage.[57] For example, hydrogen sold as a transportation fuel can have a higher rate of return because it can benefit from revenues derived from participation in the federal Renewable Fuels Standard or Western states' low carbon fuels standards, such as the Oregon Department of Environmental Quality's Clean Fuels Program. For more on hydrogen, see the Hydrogen Energy Resource & Technology Review.

Storage of any chemical comes with safety risks. Combustible chemicals like hydrogen, methane, and methanol must be handled and stored correctly to avoid fires and explosions. Chemicals like ammonia[64] and methanol[65] can be harmful in large doses, requiring safe handling to avoid damaging the environment in case of accidental release. Without physical adjustments to the mechanical combustion mechanism on the turbine, hydrogen fuel has the potential to emit more oxides of nitrogen – an air pollutant that can lead to smog – than natural gas.[66] [67] Other forms of storage chemicals, such as methane and methanol, also have associated greenhouse gas emissions when burned, and potential emissions if leaks occur during transport.

Thermal Storage Technologies

Thermal energy storage uses surplus energy – excess electricity or waste heat – to store energy for later use by heating or cooling a medium (a solid, liquid or gas) that can be used at a later time.[68] This generally involves storing heat from solar radiation or industrial processes by heating water, which can be used later as the building's hot water supply or to help provide ambient heating. Waste heat from the cooling of buildings can also be captured and used for the same purpose, making more efficient use of the heating and cooling needs in a building or a collection of buildings connected via district heating. In addition to heating, excess electricity can be used to freeze water that provides cooling to the building.[69] Water is the most common storage medium, but solid mediums like rock can also be used.[70]

Concentrating solar-thermal power plant. Photo: U.S. Department of Energy

Concentrating solar-thermal power plants[vi] are the only form of utility-scale thermal energy storage in use in the U.S. These plants use a large array of reflectors (mirrors) to concentrate solar rays at a receiver that captures the thermal energy.[71] A molten salt tank that is capable of soaking up and retaining the heat can be added to this system to store some or all of the heat for later use.[72] Like other thermal generation plants, such as natural gas and coal, the captured heat is used to create steam to spin turbines. The heat stored in the

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[vi] Concentrating solar-thermal power plants, which use large mirrors to concentrate solar energy to heat up a substance, differ from photovoltaic solar, which collects photons of solar energy to generate electricity.

molten salt enables the plant to run the generator even after the sun goes down.[73] This effectively reduces the variability of solar-based energy production by enabling operators to choose when to dispatch electricity generated. Only direct sunlight can be effectively concentrated, so concentrating solar thermal plants work best in areas with high direct solar irradiance, such as the southwestern United States.[73] The only concentrating solar-thermal plants with thermal storage operating in the U.S. are in California and Arizona,[74] but thermal energy storage could be coupled with any heat-producing electricity generation unit, such as nuclear power.

Thermal Energy Storage and Nuclear Power

Nuclear electricity generators generally provide a steady supply of electricity to meet the constant and ongoing electrical power needs. However, nuclear technology does not have the ability to easily ramp up or down to meet changing demand needs for the grid. Pacific Northwest-based TerraPower received USDOE Advanced Reactor Demonstration Program funds to develop a new type of nuclear reactor with a molten salt thermal storage component.[75] The storage piece can boost the reactor's energy capacity from 350 MW to 500 MW for over five and half hours. The storage can also be used to boost and lower the electricity output, making it a more flexible generator than today's nuclear technology. TerraPower estimates that the new reactor and storage system will be commercially available at the end of the decade.

Trends and Potential

Utility-Scale Thermal Energy Storage

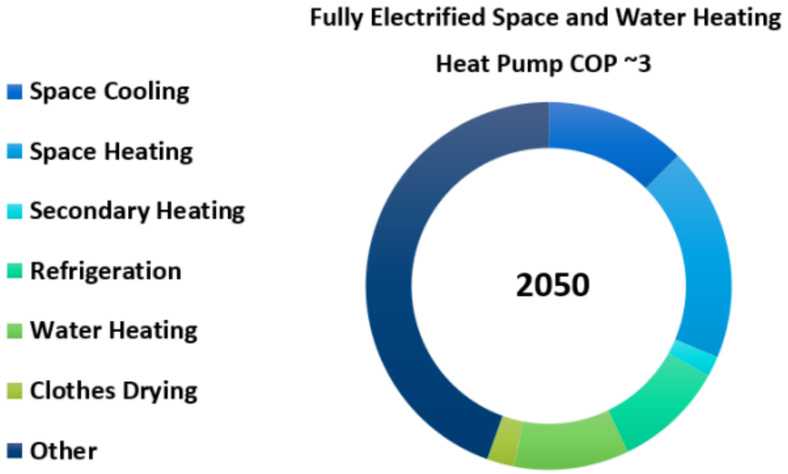
Concentrating solar-thermal generation accounts for 1.7 GW of electricity capacity in the U.S., and of that, only 360 MW has associated thermal storage capacity.[73] [74] No concentrating solar-thermal plants have been brought online since 2015, largely due to the dramatic cost reductions for solar PV and lithium-ion batteries that have made these solar-thermal plants look much less cost-effective by comparison. It may be possible, however, to add more thermal storage capacity to existing concentrating solar-thermal plants to increase the value of these existing facilities. In 2022, solar-thermal generation plants coupled with thermal storage are not cost competitive with other generation resources, such as natural gas, wind, and photovoltaic solar.[76]

Thermal energy storage deployment with concentrating solar generation plants increases the cost effectiveness of the solar plant because it enables the plant to provide electricity to the grid outside daylight hours. Although the total capacity of the plant is not changed by adding thermal energy storage, its capacity factor – the percentage of actual energy output compared to the maximum potential energy output – is increased.[73] This is particularly useful in the southwestern U.S., where electricity loads tend to ramp up in the evening at the same time the sun is setting and solar power generation is waning. The higher overall costs of this type of electricity generation have stalled further construction of concentrating solar thermal plants. However, the associated storage may have applications with other heat-generating resources.

Building-Scale Thermal Energy Storage Systems

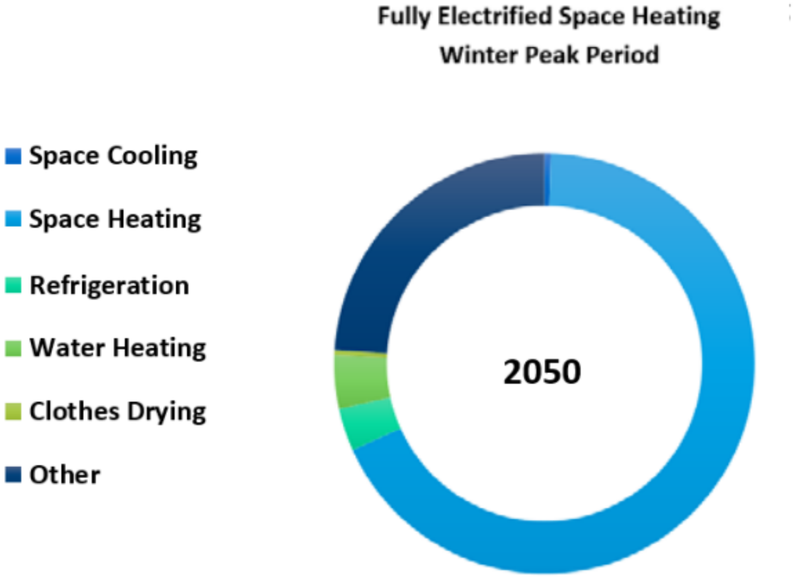
Thermal energy storage systems in buildings have the potential to help better manage building energy use, including reducing the building's peak energy load and providing grid reliability benefits.[77] The residential, commercial, and industrial sectors account for nearly 70 percent of all energy consumption in Oregon, much of which is spent to heat or cool a building or drive industrial processes. On average, heating and cooling loads account for 45 percent of annual electricity consumption in residential and commercial buildings, which is reflected in Figure 5. This percentage can increase when demand is higher due to heat waves and cold snaps. Building thermal energy loads are expected to grow by 2050, increasing to more than 50 percent of building electricity consumption and exceeding 75 percent during peak electricity demand times as shown in Figure 6.

Figure 5: Annual Electrical Energy Consumption in Residential and Commercial Buildings for Space and Water Heating[78]



Graphic modified from its original.

Figure 6: Peak Period Electrical Energy Consumption in Residential and Commercial Buildings for Space and Water Heating[78]



Graphic modified from its original.

Thermal energy storage is not adopted at the levels of lithium-ion electrochemical battery storage. For on-site storage in buildings, lithium-ion storage accounts for about 500 times more overall energy storage than thermal energy storage.[79] Thermal storage systems could operate in concert with battery storage systems to store energy and support heating and cooling activities at times when electricity is plentiful, while thermal energy storage technologies could further reduce the need for electricity to support heating and cooling.

Beyond Energy

Thermal energy storage options can help reduce greenhouse gas emissions from buildings. Buildings are overwhelmingly the largest consumer of electricity during peak loads.[78] Increasing storage capacity to shift building energy loads could reduce greenhouse gas emissions. Thermal energy storage could be a valuable tool for utilities to more effectively integrate and utilize variable renewable energy resources.

Building thermal energy storage has the potential to reduce energy costs. For example, ice storage systems can be set to operate overnight and provide cooling energy and lower energy use during the heat of the day during peak load periods. Other thermal storage, like water heaters, can supplement the electricity needed to create hot water, reducing the overall costs for the home or building owner. There is limited information on the costs of installation and operation for these technologies. In 2021, the U.S. Department of Energy hosted a workshop focused on priorities and pathways to the widespread deployment of thermal energy storage in buildings. A survey of those in attendance indicated that the main barriers to adoption are a lack of awareness of system costs, performance metrics, and value addition, followed by a lack of incentives.[80] More information is needed to fully understand the potential value of thermal energy storage systems for building owners and utilities.

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Energy Resource & Technology Review: Hydrogen

Timeline

- **1800** – English scientists, William Nicholson and Sir Anthony Carlisle, discover how to produce hydrogen and oxygen gases by applying an electric current to water. This process would later be known as "electrolysis."[1]
- **1807** – François Isaac de Rivaz constructs the first wheeled vehicle with an internal combustion engine in Switzerland. The engine is powered by a mixture of hydrogen and oxygen for fuel.
- **1923** – J.B.S. Haldane proposes a hydrogen-based renewable energy economy in a speech delivered at Cambridge University entitled: "Daedalus or Science and the Future."[2]
- **1956-1958** – The United States Air Force funds the development of a hydrogen-fueled reconnaissance aircraft. Although eventually cancelled, the project would lead directly to the first rocket engine powered by hydrogen.[3]
- **1959** – Francis T. Bacon, at Cambridge University, builds first practical hydrogen-air fuel cell. Named the "Bacon Cell", it is the fuel cell that would provide power to supply electricity to operate and power the Apollo missions.[4]
- **1970** – Electrochemist John Bockris coins the term "hydrogen economy" during a talk at the General Motors (GM) Technical Center in Warren, Michigan. It refers to the use of hydrogen to decarbonize "hard-to-abate" economic sectors such as cement and steel production, long-haul transportation, etc.
- **2021** – The United States Department of Energy launches its "Hydrogen Shot" through the Energy Earthshots Initiative. The goal of the project is to reduce the cost of clean hydrogen by 80 percent so that it costs $1 per kilogram by the end of the decade.

Hydrogen is the lightest element in the universe, and the most abundant. On Earth, it is found in the greatest quantities within water molecules, and is present as a gas in the atmosphere only in tiny amounts – less than 1 part per million by volume. It does not exist freely in nature and must be extracted from other sources like water and fossil fuels.[5] It is considered to be an energy carrier, not an energy source, in part because energy is required to separate, or extract, hydrogen from these sources.[6] The most common pathway to produce hydrogen today uses steam to separate the hydrogen from methane in natural gas (known as steam methane reformation, or SMR).[7] Hydrogen created from fossil fuels like natural gas is responsible for about 700 million metric tons of CO2 emissions per year globally — roughly equivalent to the total annual greenhouse gas emissions of the United Kingdom and Indonesia combined.[8]

Lower-carbon and zero-carbon hydrogen – often referred to as clean hydrogen – can be produced through several pathways, including electrolysis of water with renewable electricity or natural gas/renewable natural gas coupled with carbon capture and sequestration technology, among others. Renewable hydrogen is produced using renewable feedstocks. There's no single definition for renewable hydrogen – some limit its use to only electrolysis using renewable electricity while others may include biogenic pathways that use biomass or microorganisms.

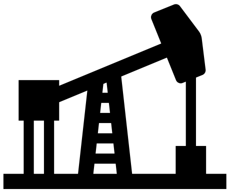
The industry describes hydrogen based on its carbon intensity, such as *clean* or *low carbon*.

Hydrogen is sometimes described using different colors to denote the feedstock used to produce it: "gray" for fossil fuel-based feedstock, "green" for renewable sources like solar or wind, and "blue" for fossil fuel-based feedstocks using carbon capture and sequestration technologies.[9] While the color label can give some idea of the environmental impact associated with the production of hydrogen, it does not provide quantitative specifics on the associated greenhouse gas emissions. For this reason, the industry is quickly moving to instead describe hydrogen based on its carbon intensity with terms like "clean" or "low carbon."

Assessing hydrogen *strictly* according to carbon intensity describes only the associated carbon content, and some environmental advocates have indicated a distinction should continue to be made between renewable and non-renewable hydrogen because using fossil fuel feedstock would support continued reliance on these fuels and slow down decarbonization efforts. Others counter that the road to full decarbonization is expensive and hydrogen produced from fossil fuels with carbon capture and sequestration is a critical intermediate step to building a hydrogen economy that will move closer toward zero emissions over time.[i]

Hydrogen Use

Hydrogen is used predominantly in industrial applications, such as petroleum refining, production of steel and other metals, food processing, and chemical production.[10] It is the primary feedstock for the production of ammonia, about 80 percent of which is used to manufacture fertilizers.[11] Oil refining accounts for about 33 percent of total global demand for hydrogen, where it is used in the refining processes to reduce the sulfur content of petroleum fuels and to transform heavier, low-quality crude oil into lighter, higher-value petroleum products.[12] The refinement process generates some hydrogen, which is typically captured on site to be used in the sulfur removal and other refinement steps. On average, about a third of the hydrogen used by refineries comes from this on-site hydrogen byproduct. The remaining hydrogen is provided by hydrogen production facilities, usually owned and operated by the refinery, and from suppliers.[13] Commercial supplies of hydrogen are also mostly produced from natural gas.[14]



In addition to its current uses, hydrogen is increasingly considered as an option to reduce greenhouse gas emissions in sectors where the option to electrify is either too costly or not technologically feasible. Potential new end uses of hydrogen include as fuel for medium- and heavy-duty transportation, rail, and aviation; long-duration energy storage; or as a substitute for natural gas combustion in high-heat industrial processes, among others.

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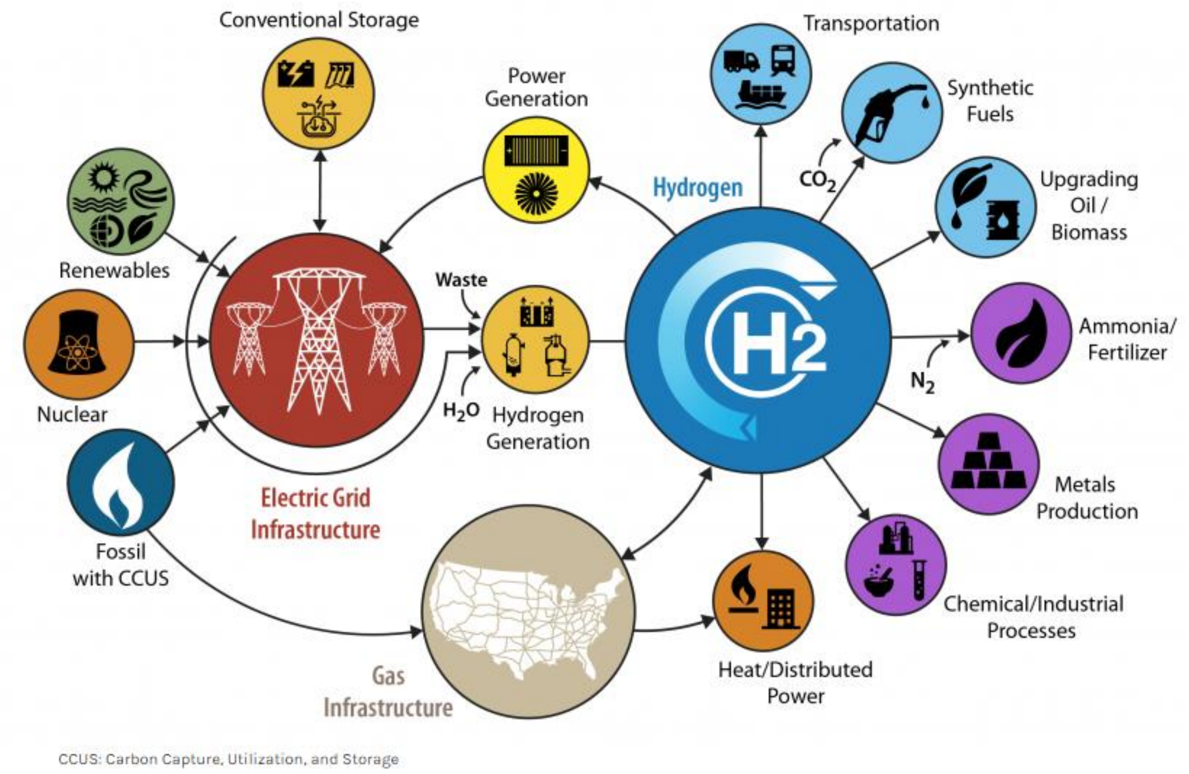
[i] For more information, see the Oregon Department of Energy's *2022 Renewable Hydrogen Report* (Available November 15, 2022): https://tinyurl.com/ODOE-Studies

Figure 1: Hydrogen Uses[37]



Hydrogen can be used to power fuel cell electric vehicles, which convert the hydrogen to electricity that powers the vehicle (see the Clean and Efficient Vehicles Technology Review for more). Hydrogen offers several advantages compared with battery powered vehicles, including faster refueling times, longer ranges, less sensitivity to cold temperatures, and the ability to maximize payload for heavy-duty trucks because of its lightweight and high energy density. Most of the hydrogen fueling stations in the U.S. are in California, which has provided state investments and support to establish hydrogen fueling infrastructure.[15] This initial support has driven FCEV adoption and increased the demand for and development of more hydrogen fueling stations.[16]

Hydrogen could be used to power turbines that generate electricity; however, there are no existing all-hydrogen electricity generators operating in the U.S. It can also be mixed into the natural gas pipeline at volumes of up to about 20 percent, based on information from projects in Europe and pilot projects in the U.S. The physical properties of hydrogen differ from natural gas, which is the limiting factor in how much hydrogen can be blended into existing natural gas infrastructure.[17] In particular, hydrogen can corrode and embrittle some metals, meaning infrastructure such as pipelines, pumps, plumbing, and appliances may need to be upgraded or replaced to carry or combust high concentrations of hydrogen. These effects are minimized when hydrogen is blended with natural gas at lower concentrations.

Trends and Potential

Hydrogen use is expected to grow through 2030, largely due to increasing demand for methanol and ammonia to support agricultural needs, iron and steel production, and crude oil refinement.[18] Beyond 2030, hydrogen demand will remain high, but continued growth will depend on global policy choices and strategies to decarbonize industrial and transportation end uses. Demand for hydrogen could continue to rise over the next several decades if policies and programs are instituted that heavily support the uptake of hydrogen-fueled vehicles.

Clean hydrogen production is also anticipated to increase in the next decade, but the rate of growth is dependent on the cost to produce clean hydrogen compared to natural gas steam reformation. The infrastructure and equipment to generate hydrogen from natural gas are largely in place today, whereas producing clean hydrogen would require capital investments to build electrolyzers. Policy supports for this development, such as the production tax credit included in the Inflation Reduction Act, are necessary for clean hydrogen to be cost competitive.[19] Goldman Sachs forecasts that renewable hydrogen could reach cost parity with hydrogen from fossil fuels as soon as 2025 in some regions.[20]

U.S. Department of Energy Hydrogen Shot – The “1 - 1 - 1 Goal”[21]

Hydrogen Shot is a program that seeks to reduce the cost of clean hydrogen by 80 percent to $1/kilogram in 1 decade. Currently clean hydrogen costs about $5/kilogram, and reducing costs by 80 percent would open up new end-use markets for this fuel. If achieved this could revolutionize hard-to-decarbonize industries like steel manufacturing, ammonia production, heavy-duty freight, and long-term energy storage. Hydrogen Shot was launched on June 7, 2021 and is the first US DOE Energy Earthshot program to address the most challenging barriers to reducing greenhouse gas emissions.

Crude Oil Refining

Hydrogen is a key resource for the oil refineries that provide gasoline, diesel, and other fossil fuels to Oregon. Although global oil demand is likely peaking today, the demand for lower sulfur and lighter distillate crude oil products – which require hydrogen as a feedstock – is expected to rise through 2030. Even as many vehicles are converted to zero emission options, there are some vehicle types that will be more challenging to decarbonize, including many long-distance shipping vehicles, such as freight trucks, airplanes, ships, and trains. These transportation vehicles will need other options to address emissions, including using lower sulfur, higher-distillate fuels that require hydrogen for refinement.[22] In addition, the most likely zero emission options for these vehicles are fuel cell electric vehicles or synthetic biofuels, which both require hydrogen.

Transportation Fuel

A zero-emission hydrogen fuel cell bus refuels in Irvine, CA.
Photo: NREL (CC BY-NC-ND 2.0)

Fuel cell electric vehicles may be the first widely adopted commercial use of hydrogen as a transportation fuel in Oregon. The vehicles are available in other countries and in California, but are not sold in Oregon because there are no publicly available hydrogen fueling stations to support them. If hydrogen fueling infrastructure becomes available, adoption of fuel cell electric vehicles could ramp up rapidly, leading to increased market demand for more hydrogen fuel. Support for adoption is largely driven by decarbonization benefits, and would therefore require the development of renewable hydrogen resources.[23] Since 2000, about 40 percent of publicly supported hydrogen-generating electrolyzer projects around the globe were built to support vehicle fleets. While FCEVs are not as widely adopted as other types of electric vehicles, several countries have deployment targets for these vehicles and the fueling infrastructure needed to support them.[24]

Hydrogen is also a potential precursor for the production of synthetic hydrocarbons, often referred to as biofuels.[25] It is used in the processing of biomass feedstocks to create renewable diesel, a fuel that is available and used in Oregon as a substitute for petroleum-based diesel.[26] There is growing interest in using hydrogen to create other fuels like ammonia, synthetic methane, and other synthetic fuels as lower carbon substitutes for existing fuels like diesel, natural gas, and aviation fuels. Synthetic fuel production is very nascent, and consequently has high production costs. Producing hydrogen using electrolysis is an energy intensive process – the amount of energy needed is more than half the amount of energy that is being stored. More research and technological advancements are needed to make biofuel production from renewable hydrogen a cost-effective energy resource.

Electricity

Electrolyzers can serve as flexible loads to help manage increasing amounts of renewable energy generation on Oregon’s electric grid. Hydrogen can serve as a long-duration energy storage medium, converting electricity to hydrogen that stores the energy for later use. Using hydrogen to store electrical energy when it is plentiful and provide it back to the grid when it is limited can help balance electricity supply with demand. It is also particularly useful for longer-term seasonal electricity generation needs. For example, the Pacific Northwest generally has ample supply of hydropower in the spring months, when energy demand tends to be lower, but less supply in late summer when cooling energy demands tend to be higher. Hydrogen could play a future role in supporting Oregon’s goal to achieve a 100 percent clean electric grid by 2040 by helping balance renewable energy supply and demand (learn more in the Electricity Storage Technology Review).

Hydrogen could play a future role in supporting Oregon’s goal to achieve a 100 percent clean electric grid by 2040 by helping balance renewable energy supply and demand.

Demand for clean hydrogen may increase as Oregon and other western states work to add more clean energy resources. Electrolyzers operate most cost effectively when the price of the electricity used to power the process is very low. The Pacific Northwest currently has limited circumstances when surplus carbon-free electricity is available, mostly during the spring season when wind may be curtailed.[27] However, as Oregon's largest electric utilities work to meet the state's 100 percent clean electricity goal by 2040, hydrogen could be an increasingly cost-effective option to help manage higher quantities of renewable resources supplying the grid.

Direct Use Fuel

Using hydrogen as a blended fuel to supplement the natural gas system is another area of potential growth, but it comes with challenges. The impetus for doing this would be to reduce greenhouse gas emissions in the natural gas sector. Because hydrogen is less dense than natural gas and requires increased pressure to move it through pipelines, adding 20 percent hydrogen by volume (the assumed maximum safe limit for blending) only results in a 6 to 7 percent reduction of GHG emissions. For this reason, blending renewable or low-carbon hydrogen into a natural gas pipeline may not be a cost-effective end-use for hydrogen if greenhouse gas emission reductions are the primary goal.

Energy Resilience

Hydrogen can support energy resilience, especially near clean electricity generation resources, where excess electricity could be used to create hydrogen that can be stored on site. In the case of events where traditional energy supplies are limited, stored hydrogen could provide a valuable energy resource for nearby communities. The hydrogen can also support a more reliable grid, as a method to store energy when demand is low and provide energy when demand is high. For example, there is interest in siting electrolyzers in coastal communities that could be used to create hydrogen from offshore wind resources[ii] to help balance grid needs and provide more energy resilience to those communities.

Beyond Energy

Hydrogen production today accounts for 700 million metric tons of CO2 per year, roughly 10 percent of total greenhouse gas emissions in the U.S. in 2020.[28] [29] Hydrogen combustion itself does not generate greenhouse gas emissions, but most hydrogen is produced from natural gas and coal, which creates about 10 metric tons of CO2 per 1 metric ton of hydrogen produced. There are existing technologies that can capture up to 90 percent of the emissions, but use of these technologies increases overall costs – adding about 50 percent for capital investments and 10 percent to power plant fuel costs[30] (for more information on carbon capture and storage, see the *2020 Biennial Energy Report*). Another option to reduce emissions is to generate renewable hydrogen.

[ii] Read more on renewable hydrogen and offshore wind in the Oregon Department of Energy's *2022 Floating Offshore Wind Study*: https://tinyurl.com/ODOE-Studies

Hydrogen could be generated using any form of electricity, but for it to be renewable it must use renewable electricity sources like solar and wind.

Hydrogen could be generated using any form of electricity, but for it to be renewable it must use renewable electricity sources like solar and wind. Without CCS, fossil-generated electricity, such as natural gas and coal, would have similar emissions as hydrogen produced as a byproduct of refining these fuels. The Infrastructure Investment and Jobs Act passed in November 2021, requires the Secretary of Energy, in consultation with the Environmental Protection Agency, to develop an initial standard for the carbon intensity of clean hydrogen production.[31] It initially defines clean hydrogen to mean hydrogen produced with a carbon intensity equal or less than 2 kg of carbon dioxide equivalent produced at the site of production per kilogram of hydrogen produced. The USDOE considers a number of feedstocks that could be eligible to produce hydrogen within that carbon intensity, including renewable electricity, electricity or thermal energy from nuclear reactors, and fossil fuel inputs coupled with carbon capture and storage.[32]

The electrolysis process to generate renewable hydrogen requires large amounts of water. Water consumption would double if all existing hydrogen generation resources (mainly created from natural gas) were converted to electrolysis generators.[33] Areas where water availability is limited may not be ideal locations for this type of hydrogen generation. There is interest in potentially siting renewable hydrogen electrolyzers near offshore wind installations, where seawater is readily available. The water would need to be desalinated to avoid corrosive damage to the equipment. The desalination process itself does take energy, but it is a minimal amount compared to the electricity output ultimately gained from the hydrogen produced.

Hydrogen presents health and safety considerations, as it is a combustible fuel. Hydrogen is non-toxic, but like other combustible fuels, handling and storage are important to reduce the potential for fires or explosions.[34] Hydrogen molecules are very small, which allows them to more easily seep through seals and linings, particularly through infrastructure designed for other gases. Special equipment is required to properly store and transport high concentrations. Because it is small and light, hydrogen disperses quickly in an open environment meaning the risk of ignition or explosions could be less than natural gas or gasoline vapors. However, like all volatile gases, the physical environments and conditions of hydrogen use must be tested and understood to fully characterize safety protocols for all anticipated commercial applications. [35]

Safety standards are critical for any industry to grow smoothly and efficiently, and such standards already exist across the current hydrogen production and delivery pathway. In addition, safety protocols are in use for hydrogen users.[36] As the industry grows more standards will be needed to ensure public safety. Organizations such as the Center for Hydrogen Safety and the Compressed Gas Association work to develop, update and promote these standards globally. Currently, the general public has limited interaction with hydrogen fuel, but this interaction will grow in the future as the industry expands. Public interactions with hydrogen fuel are most likely to occur at fueling stations for hydrogen fuel cell vehicles. Deliberate and clear communication about safety measures for hydrogen fueling stations and other new hydrogen end uses is essential to address safety concerns and ensure the safe handling and use of this fuel.

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