CHAPTER 2: CLIMATE CHANGE

One of the most important challenges confronting Oregon's energy sector is curtailing the energy-related greenhouse gas emissions that contribute to climate change.

About 80 percent of GHG emissions in Oregon come from daily energy use, and current energy and climate policies in Oregon are not sufficient to meet statewide GHG reduction goals.

Read on for an overview of GHG mitigation options and opportunities across Oregon's energy sectors.

KEY TAKEAWAYS

- In recent years, Oregon has been able to **meet more of its growing population's energy needs** with low carbon resources that will help the state meet its climate and greenhouse gas reduction goals. Despite this, Oregon is not yet on a pathway to fully transition its energy systems to a deeply decarbonized, clean energy future.
- Climate scientists have identified a two degree (Celsius) threshold on global temperature rise, beyond which there are **significant and unprecedented risks to society and the environment**. Oregon's current greenhouse gas emissions trajectory is far above its fair share contribution to that global limit. In Oregon, projected climate effects to health, livelihoods, and ways of life are avoided or substantially reduced in a lower global emissions scenario vs. the world's current path.
- Further actions are necessary to complete Oregon's low carbon energy transition, and looking to the experiences of other states and jurisdictions provides a menu of some potential actions. Selecting appropriate further action will require policymakers to examine costs and benefits of action—including the **costs of climate change itself**—and to consider multiple perspectives and issues, such as social and intergenerational equity and environmental and health tradeoffs.
- Oregon has an opportunity to capitalize on advancements and falling costs of low carbon technologies, as well as the state's unique position in how energy is made and used in the state, to make a **deep decarbonization pathway** feasible across all sectors of the economy.
- **Early action** would allow Oregon to gain a first-mover competitive advantage in a global clean energy economy, increase its energy independence through development of local renewable energy resources, and realize the substantial health and environmental co-benefits of reduced pollution.

Introduction

One of the most important challenges confronting Oregon's energy sector is the need to curtail energy-related greenhouse gas (GHG) emissions that are contributing to climate change. About 80 percent of the state's GHG emissions come from the amount and type of energy Oregonians use every day,[1] and current energy and climate policies in Oregon are not sufficient to meet statewide GHG reduction goals. This chapter takes stock of where Oregon is in relation to its GHG goals and other climate commitments, describes the policies and GHG mitigation efforts underpinning the state's current emissions trajectory, and synthesizes the best available science on the implications of staying on Oregon's current "Business as Usual" GHG emissions pathway (current policies plus forecasts of energy demand) versus a pathway to "deep decarbonization" (transitioning to a future with very little reliance on fossil fuels for energy). The chapter presents an overview of current literature on strategies to reach deep decarbonization, with consideration of policy design issues including timing, costs and benefits, equity and environmental justice concerns, and environmental tradeoffs. The chapter concludes with recommendations for future statewide climate planning efforts.

Oregon's GHG Reduction Goals and Climate Commitments

Oregon has recognized climate change as a major policy issue for 30 years, when the Oregon Task Force on Global Warming was created in 1988. The task force concluded that, "Climate change from global warming is a serious threat," and that "Oregonians can insure themselves against some of the changes by taking prudent actions to slow the emission of greenhouse gases and by planning to adapt to changes."[2] More recently, Governor Kate Brown stated that "Climate change poses the greatest threat to Oregon's environment, economy, and our way of life. Future generations will judge us not on the facts of global climate change, but what we've done to tackle it."

In 2007, the Oregon Legislature (ORS 468A.200-250)[132] set statewide GHG emission reduction targets:

- **By 2010, Oregon will arrest the growth of GHG emissions and begin to reduce emissions;**
- **By 2020, Oregon will achieve GHG levels that are 10 percent below 1990 levels; and**
- **By 2050, Oregon will achieve GHG levels that are at least 75 percent below 1990 levels.**

These climate change mitigation goals were set based on what climate scientists considered at the time to be the level needed to have the best chance of avoiding the worst effects of climate change. This risk-avoidance approach to setting climate goals is now commonly associated with a threshold of a global average temperature increase of no more than two degrees Celsius[3]. Although two degrees Celsius, which equates to a 3.6 degree Fahrenheit temperature increase, is the goal most often used in climate mitigation policy discussions, many countries and individuals have concluded that a 1.5°C, or 2.7°F, upper bound limit has a higher probability of minimizing risks to human health and the environment.[4]

In practice, these temperature targets most commonly translate to goals to reduce GHG emissions 80 to 95 percent below 1990 levels.[5] Other baseline periods or slightly modified goals are sometimes seen. Therefore, while Oregon's 2050 goal is over a decade old, it is still generally consistent with contemporary thinking around GHG emission reduction goals.

These GHG reduction goals are the catalyst for what is being called "deep decarbonization." Though the climate community has not yet settled on one definitive definition of deep decarbonization, it generally refers to a future in which global society meets the goal of limiting temperature rise to below 2°C through transformation of energy systems to those that emit little or no GHGs. This means an almost complete transition away from use of non-renewable hydrocarbons (e.g., the primary components of fossil fuels and chemicals that are classified as high global warming potential gases), which is why clean energy technologies are often referred to as zero-carbon, low-carbon, or decarbonized.

Since the early 1990s, major international and U.S. scientific assessments have concluded that both climate change mitigation and adaptation efforts are necessary in response to climate change.[6] Climate adaptation is often thought of as actions "to prepare for and adjust to new conditions, thereby reducing harm or taking advantage of new opportunities" or simply to reduce society's vulnerability to climate change impacts.[7] Although Oregon does not currently have specific statewide climate adaptation goals, entities around the state have implemented a number of adaptation planning processes. Examples of individual project-level or sector-based plans include Oregon Department of Transportation's Climate Adaptation Strategy[8] and Oregon Health Authority's Oregon Climate and Resilience Plan.[9] In addition, a statewide adaptation framework was developed in 2010,[10] for which the Department of Land Conservation and Development (DLCD) is beginning an interagency process to update. See Chapter 5 for a more detailed discussion of climate adaptation and energy resilience.

Climate Action Partnerships

Oregon has become a signatory to a number of regional, national, and international coalitions to advance climate action. A number of these are related to the Paris Agreement, a global agreement by parties to the United Nations Framework Convention on Climate Change (UNFCCC) that formally went into effect on November 4, 2016. Countries that are party to the Paris Agreement agree to individual, country-specific efforts aimed at "holding the increase in global average temperature this century to well below 2 degrees Celsius and pursuing efforts to limit the temperature increase even further to 1.5 degrees Celsius above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change."[11] The Paris Agreement also commits signatories to "increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience."[11] Each country agreed to determine, plan, and regularly report its own GHG emissions reduction contribution, and many countries' climate plans also included their adaptation goals, priorities, actions, and needs. The United States' intended contribution was to reduce its emissions 26 to 28 percent below 2005 levels by 2025.[12]

In the months leading up to the negotiations of the Paris Agreement, Oregon signed on to the Subnational Global Climate Leadership Memorandum of Understanding, which has now evolved into the Under 2 Coalition, and the Compact of States and Regions. The Compact provides a way for states, provinces, and regions to measure, analyze, and report progress on GHG emission reductions, while the Under 2 Coalition encourages an ambitious emission reduction commitment.

Oregon joined the U.S. Climate Alliance in summer 2017, following President Donald Trump's decision to withdraw the United States' government from the Paris Agreement. The U.S. Climate Alliance is a bipartisan coalition of governors from 16 states and Puerto Rico. Each member commits to implement policies that advance the goals of the Paris Agreement and to track and report progress to the global community. Members also agree to accelerate new and existing policies to reduce GHG emissions and promote clean energy deployment at the state and federal level.

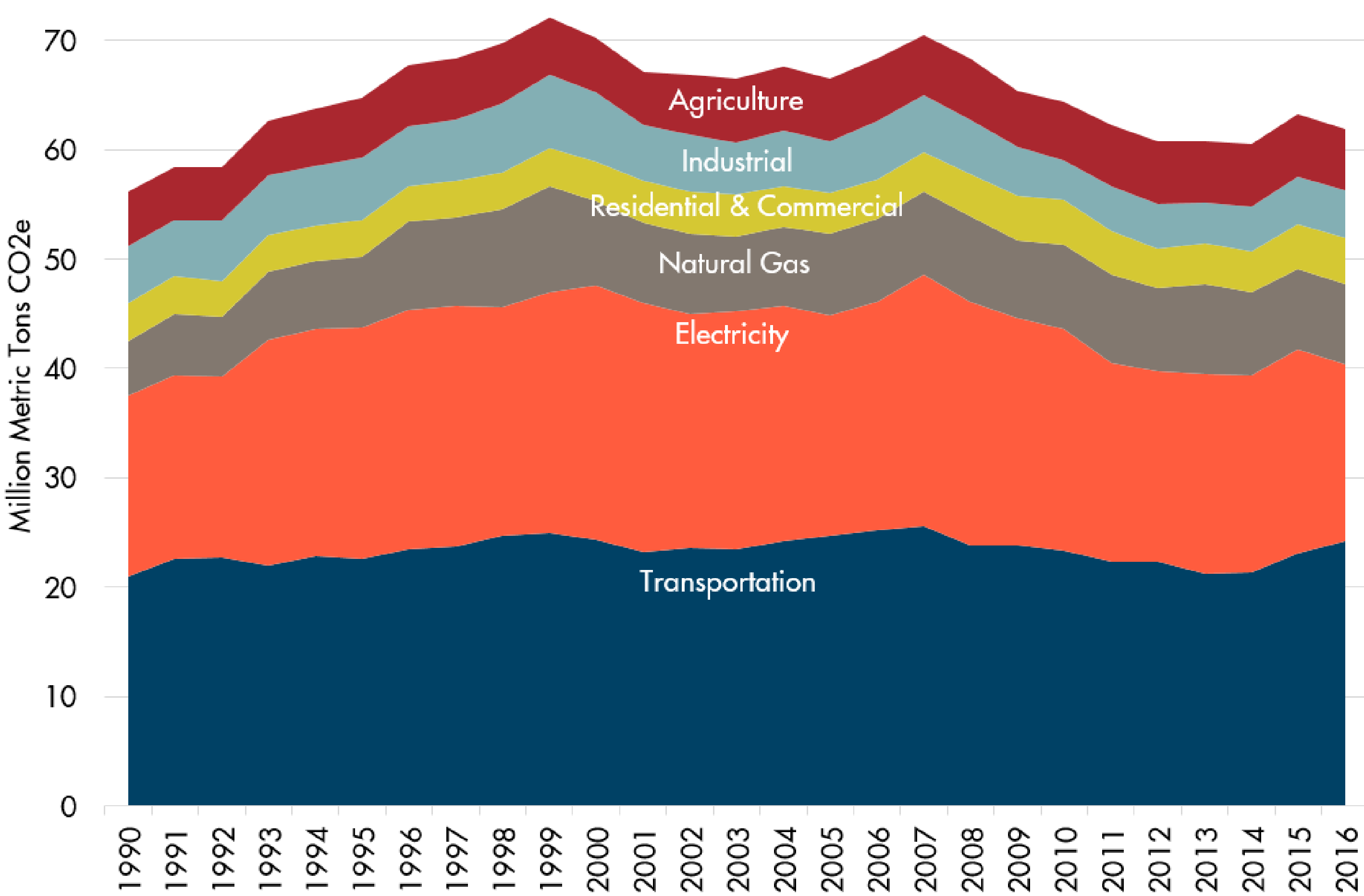
Oregon also signed America's Pledge, which brings together private and public sector leaders to ensure the United States remains a global leader in reducing GHG emissions and meets the country's ambitious climate goals under the Paris Agreement.

Oregon is a founding and long-standing member of the Pacific Coast Collaborative, a multi-state partnership between Oregon, California, Washington, and British Columbia that formally began in 2008. The PCC provides a forum for cooperative action, leadership, and information sharing, and is a common voice on issues in the Pacific North American region. Oregon has been engaged for many years on various PCC technical working groups to enhance a sustainable, low-carbon regional economy. In March 2018, the Governors and Premier reaffirmed their commitment to meaningful action on climate change, including how carbon pricing can effectively, efficiently, and fairly reduce GHG emissions. Their joint statement also noted that climate change disproportionately affects low-income and vulnerable populations, and discussed the importance of ensuring all climate policies provide support to these vulnerable groups.

GHG Reduction Goals: Oregon's Progress

Oregon's statewide sector-based GHG Inventory[1] provides GHG emissions going back to 1990 for four main sectors of economy—transportation, residential and commercial, industrial, and agriculture—and can also break out emissions associated with electricity and natural gas. For Oregon, this includes GHG emissions associated with electricity used in the state, regardless of where it is produced, but not emissions associated with electricity produced in Oregon but used out-of-state.

Figure 2.1: Sector-Based GHG Emissions with an Energy Lens: 1990-2016[1]



As seen in Figure 2.1, statewide sector-based GHG emissions peaked in 1999 and almost reached the same level in 2007, before they generally declined or stayed flat through 2013. Within the state's largest emitting sector, transportation, emissions were second highest in 1999, peaked in 2007, generally declined or stayed flat until notable increases each year in 2015 and 2016. Within the state's second largest emitting sector, electricity use, emissions peaked in 2000, were almost as high again in 2007, then generally declined or stayed flat with small increases in 2013 and 2015 followed by a notable decrease in 2016.

For the data in Figure 2.1, GHG emissions associated with electricity and natural gas use in all sectors is aggregated and displayed separately. For the Industrial and Residential and Commercial sectors, electricity and natural gas use are the largest source of emissions. The remaining emissions for these sectors are primarily associated with petroleum combustion (e.g., fuel oil for heating), waste and wastewater, and industrial process manufacturing emissions (e.g., production of cement, paper products, ammonia, urea, etc.). For a detailed analysis of emissions sources within sectors, see DEQ's inventory.[1]

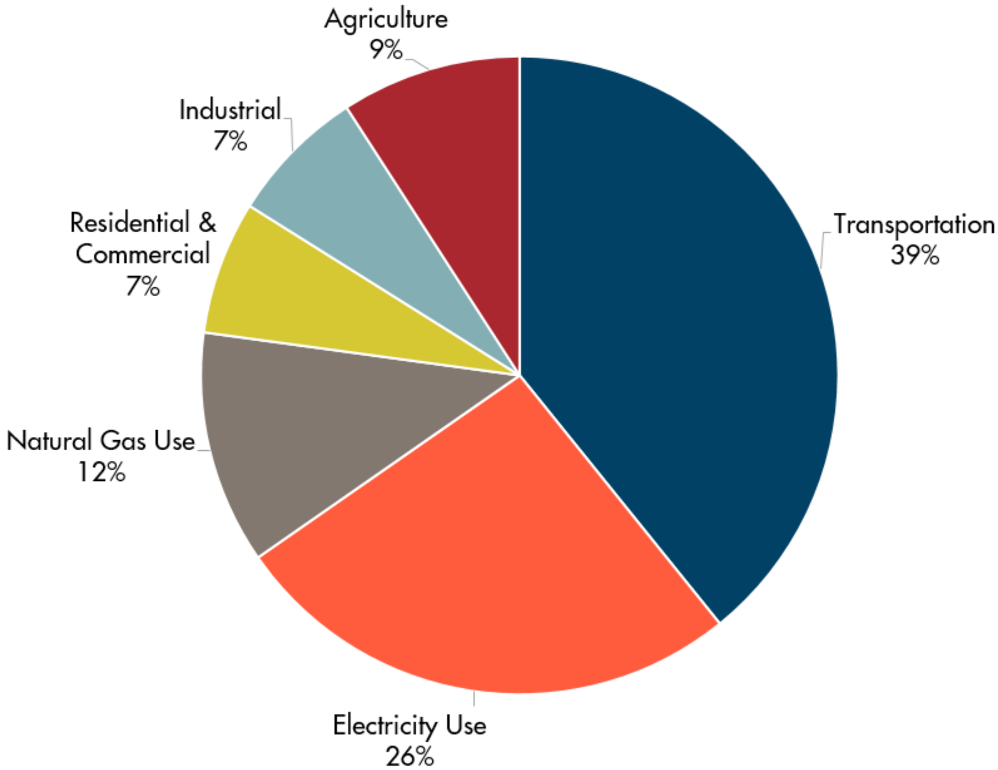
DEQ's sector-based inventory relies on data reported at the state level, following internationally-accepted GHG accounting protocols from the Intergovernmental Panel on Climate Change (IPCC).[14] It presents gross anthropogenic (human-caused) emissions, rather than lifecycle or net emissions inclusive of natural carbon sources and sinks, to facilitate data tracking and reporting on Oregon's statewide GHG emissions reduction targets. Consistent with this approach and with IPCC guidance, GHG emissions that are biogenic in origin—from biologically based materials rather than from fossil fuels—are not included in Oregon's sector-based inventory.* Biogenic emissions associated with wildfires and other biomass burning are therefore not included in Oregon's sector-based totals.

Given the normal time delay for data verification processes, the latest Oregon GHG Inventory contains verified data for 2015 and preliminary estimates for 2016 that use a small amount of 2015 proxy data. Inventory data for 2016 are unlikely to change substantially during the final verification process that relies on the latest federal GHG emissions data that have not yet been published by the U.S. Environmental Protection Agency.

Total statewide GHG emissions reflect the trends in the underlying sectors, increasing from 60 to 63 million metric tons of carbon dioxide equivalent (MTCO2e) between 2014 and 2015. The most recent 2016 estimates show Oregon's emissions at 62 million MTCO2e, with the breakdown by sector in Figure 2.2. Transportation emissions have grown as a share of Oregon's statewide GHG emissions total compared to emissions from electricity use. Specifically, transportation went from 35 percent of the statewide total in 2014 to 39 percent in 2016, while electricity use emissions decreased from 30 percent to 26 percent of the state's total emissions, and all other sectors stayed relatively constant over the same period. (For a deeper dive on the transportation sector see Chapter 4.) Almost half of transportation emissions are due to gasoline and diesel use by passenger cars and trucks, or about approximately 17 percent of emissions from all sources.[1]

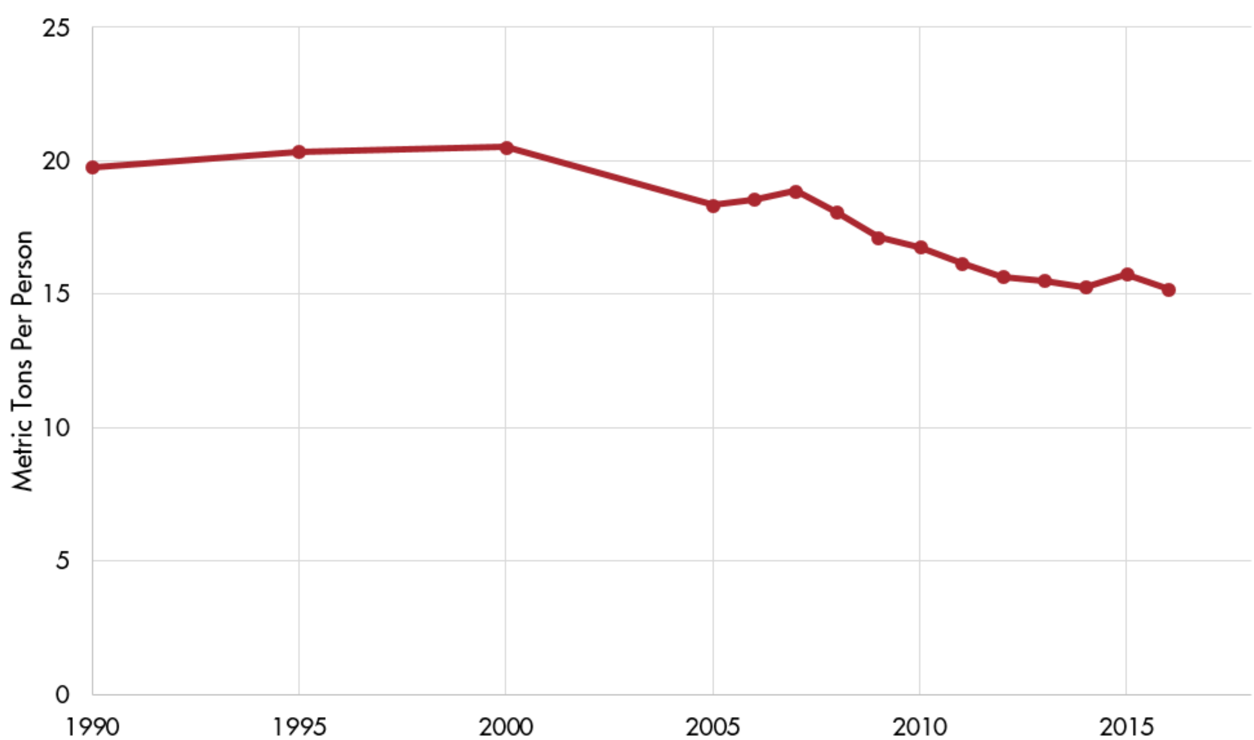
* Biogenic emissions are included in an accounting method known as net carbon flux, which considers the net effect of GHG emissions and carbon sequestration associated with land use, land use change, and forestry. Net carbon flux estimates are presented separately in the national emissions inventories submitted to the UNFCCC. Oregon Department of Forestry is currently conducting a process to estimate net carbon flux for the state's forests.[13]

Figure 2.2. Breakdown of Oregon GHG Emissions By Sector (2016)[1]



The state's GHG emissions trends can also be considered in the context of population growth within the state, which has increased 43 percent since 1990, and as of 2016 totaled 4.1 million people. Oregon's per capita GHG emissions peaked in 2000, a year after the peak in gross emissions, and then trended generally downward before ticking up again between 2014 and 2015, consistent with the total emissions trend.

Figure 2.3: Statewide Per Capita GHG Emissions[1,15]



For additional context, Oregon's sector-based GHG emissions total is roughly comparable in amount to the GHG emissions of some countries, such as those shown in Figure 2.4. Examples are shown from Western European countries with similar levels of GHG emissions as Oregon; however, these are rough comparisons for scale only, since their emissions totals are not completely comparable given differences in inventory method for GHG emissions from their respective electricity sectors.[16] Oregon uses a consumption approach (i.e., emissions from electricity used in Oregon regardless of where the electricity was produced), while country-level GHG inventory datasets use an electricity production approach. Given the normal time delay in compiling and certifying global emissions data, the most recent available 3-year averages are shown. When comparing per capita emissions (Fig. 2.5), these four example countries have lower emissions than Oregon, in some cases substantially lower, despite having larger populations (ranging from Ireland with about 4.7 million people to Portugal with about 10.5 million people).

Figure 2.4: Average Annual GHG Emissions (2012-14)[1,16]

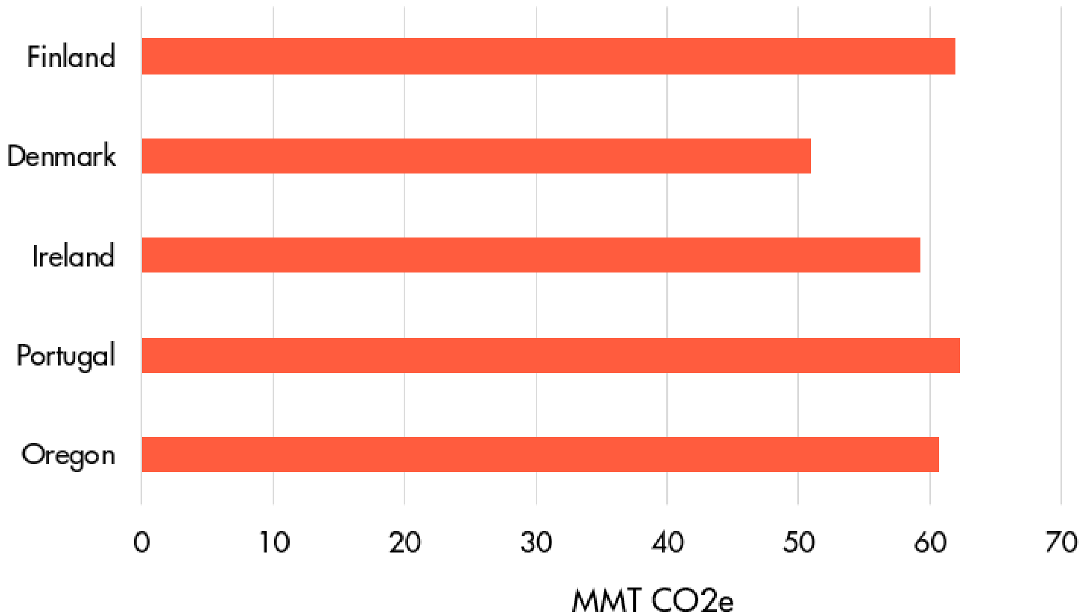
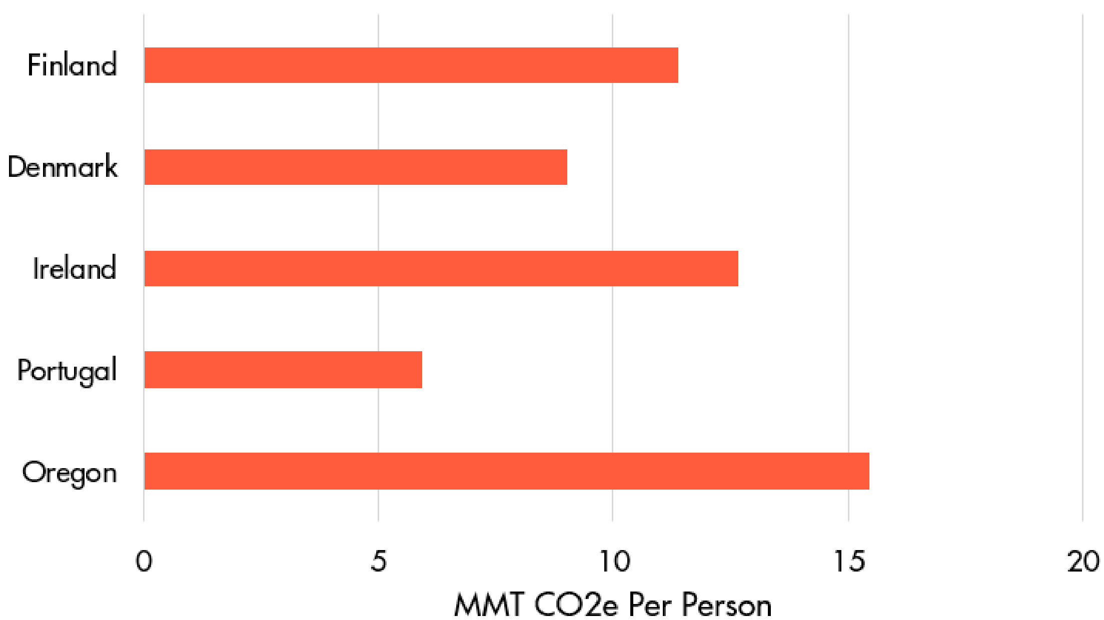


Figure 2.5: Average Annual GHG Emissions Per Capita (2012-14)[1,15,16,17]



Climate Policies

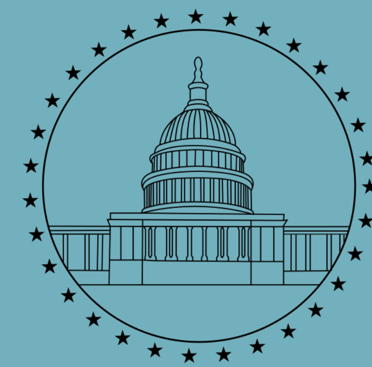
Policy, economic, and social factors have contributed to the state's ability to maintain relatively level GHG emissions while growing its population and economy. All of these factors together have contributed to where Oregon stands today in relation to its GHG emissions goals. Current policies together with known forecasts of energy efficiency and energy demand can be thought of as Oregon's "Business as Usual."

Policy factors include statutory mandates, regulations, and programs that affect or have the potential to affect Oregon's GHG emissions. Oregonians have a long tradition of being good stewards of the environment and climate, going back to the 1980s with some of the nation's most aggressive energy efficiency efforts (Chapter 6) and to 1997 with the passage of the first-in-the-nation carbon dioxide emission standard for large -scale fossil-fueled energy facilities sited in Oregon (ORS 469.503(2)).[133,134] Oregon's 2007 climate change statute (ORS 468A.200-250)[135] adopted GHG emission reduction goals and established the Oregon Global Warming Commission and the Oregon Climate Change Research Institute to advise on climate issues, but it did not create an implementation mandate or mechanism within executive branch agencies to plan for or carry out comprehensive climate mitigation or adaptation measures.

Starting in 2015, following the notable rise in emissions and increasing observations of climate impacts affecting the state[18], the Oregon Legislature and the Governor authorized a number of policies, standards, and programs aimed at or relevant to reducing GHG emissions from certain sectors. Some highlights of these efforts include the following, which are discussed in more detail in other chapters of this report:

- Governor Kate Brown's Executive Order 17-20 on energy efficiency in the built environment (Chapter 6).[136]
- An increased Renewable Portfolio Standard for the electricity sector (Chapter 3).
- The Clean Fuels Program, Zero Emission Vehicle requirements, and Governor Kate Brown's Executive Order 17-21 in the transportation sector (Chapter 4).[137]
- The provision in the Oregon Clean Electricity and Coal Transition Law (Chapter 28, Oregon Laws 2016) that eliminates imported coal-based electricity from Oregonians' rates by 2035.[138]

FEDERAL CLIMATE POLICIES



Federal policies and regulations began to explicitly target GHG emissions reductions in the 2007-16 timeframe, following the U.S. Supreme Court decision in *Massachusetts vs. EPA* in which the court held that GHGs are considered air pollutants subject to regulation under the Clean Air Act. The U.S. Environmental Protection Agency then issued the *Endangerment and Cause or Contribute Findings for Greenhouse Gases under section 202(a) of the Clean Air Act*. This formal determination that GHGs constitute a **threat to public health and welfare** paved the way for regulation of light-duty vehicle tailpipe emissions, which complemented action by the National Highway Transportation Safety Administration to tighten federal fuel efficiency standards.

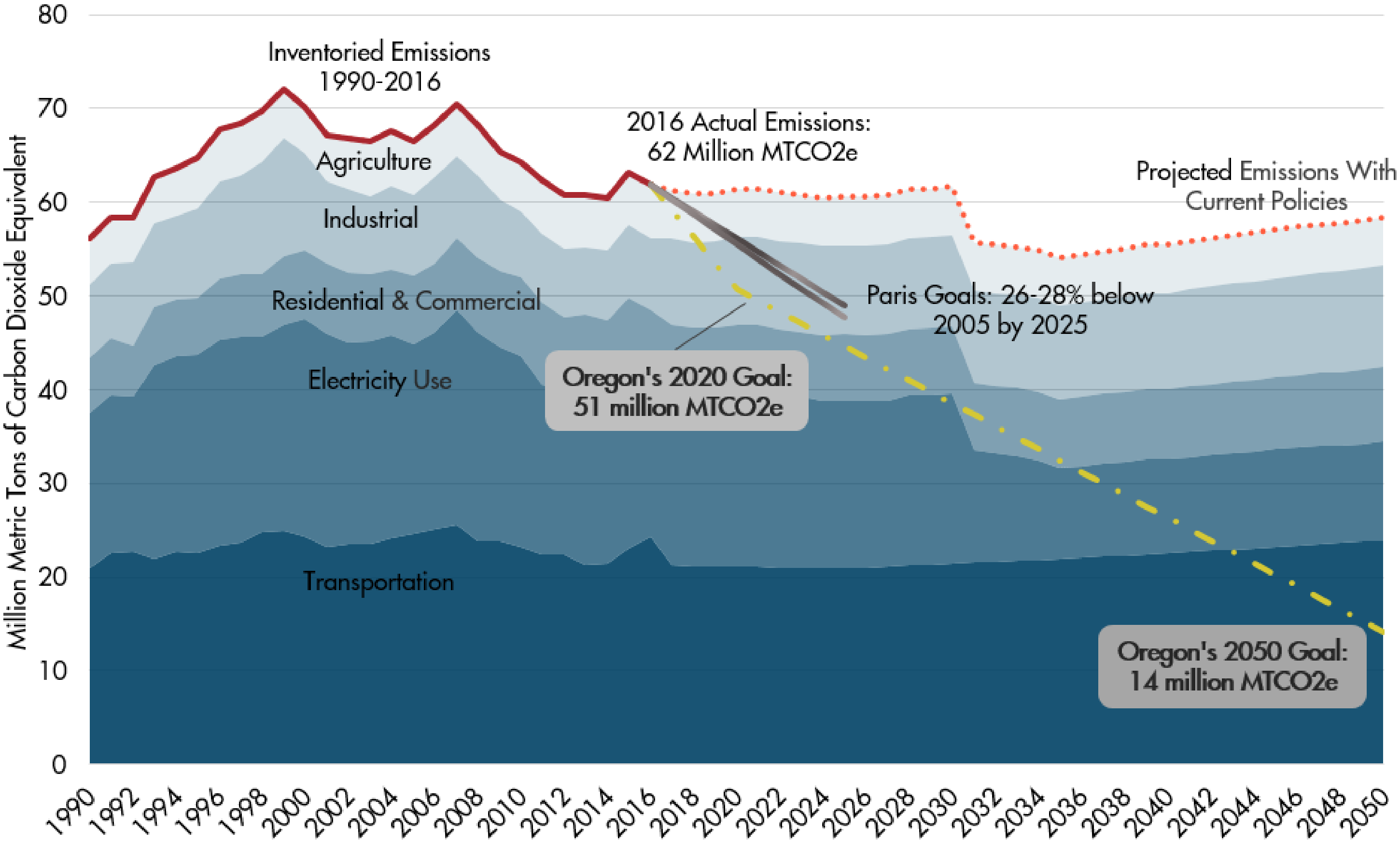
Additional regulation of GHG emissions followed, such as those for medium-and heavy-duty vehicles, stationary sources that require air pollution permits, power plants, oil and gas facilities, and landfills. Other federal climate actions were outlined in Second Biennial Report of the United States of America to the UNFCCC. In addition, on the legislative side, the U.S. House of Representatives passed the American Clean Energy Security Act in 2009,[139] which was the first bill approved by a chamber of the U.S. Congress to explicitly address GHG emissions that are causing climate change. The bill would have established a national emissions trading program, but did not become law.

Economic and social factors that have and continue to affect GHG emissions include the falling costs of renewable energy technology as described in Chapter 3, and changing consumer preferences for energy conservation, efficiency, and low carbon sources of energy, as described in Chapters 5 and 7. Additionally, the following section describes the efforts underway in other jurisdictions within the state, including Tribal, regional (metropolitan), and local (county and city) governments. All of these efforts together have contributed to where Oregon stands today in relation to its GHG emissions goals.

Business as Usual

The 2015 and 2017 reports from the Oregon Global Warming Commission[19] concluded that Oregon's Business as Usual will not be enough to meet the state's 2020 GHG reduction goal and does not put the state on a course to meet its 2050 goal. Meeting the 2020 goal would require reducing emissions by 11 million metric tons of carbon dioxide equivalent (MTCO2e) within the next two years, from 62 million MTCO2e (2016 preliminary total) to 51 million MTCO2e. The dotted line in Figure 2.6 shows the trajectory of Oregon's emissions under its Business As Usual. The yellow and dark gray lines represent the emissions levels needed to meet Oregon's statutory goals and the Paris agreement goals, respectively.

Figure 2.6: Oregon's Projected GHG Emissions vs. Goals[20]



Projected emissions are a forecast of Oregon's emissions assuming compliance with existing state policies like the Renewable Portfolio Standard and Clean Fuels program. Industrial, Residential, and Commercial sectors exclude emissions from electricity, because electricity use emissions is presented as its own sector. Because the United States' goals for the Paris agreement were expressed as a range to reduce its emissions 26 to 28 percent below 2005 levels by 2025, there are two emissions projections associated with that range.

Local, Regional, and Tribal Government Climate Action in Oregon

Climate action in Oregon consists of the cumulative efforts of Oregonians throughout the state to quantify and reduce their GHG emissions and to plan for the effects of climate change. While these types of actions are not formally aligned or coordinated with state-level actions, they contribute to GHG emissions trends that are tracked at the state level. Because GHGs accumulate over time and mix globally in Earth's atmosphere, any emissions (e.g., from an individual, community, company, country) contribute to the collective problem and affect others.[21] So individual actions, from reducing energy and fossil fuel use to choosing low-carbon products, are essential contributors to the state's ability to meet its climate goals.

This chapter focuses on institutional efforts to address climate change in ways that support collective action and enable individuals to make climate-friendly choices. City, county, and Tribal governments in Oregon are leaders in pursuing local climate initiatives for their communities. Academic institutions such as Lane Community College, Lewis and Clark College, Oregon Institute of Technology, Oregon State University, Portland Community College, Portland State University, and University of Oregon have publicly committed to various climate or carbon neutrality goals and actions.[22] Metropolitan planning organizations are pursuing local and regional solutions for GHG reductions in the transportation sector. Although these types of actions are not formally aligned or coordinated with state level actions, they contribute to GHG emissions trends that are tracked at the state level.

Cities and Counties

Table 2.1 provides a snapshot of which counties and larger cities (with populations over 20,000) in Oregon are taking actions that help achieve climate mitigation and adaptation as part of Climate Action Plans, Sustainability Plans, Clean Energy Plans, or other types of existing planning processes. This table's focus on larger cities should take nothing away from the important work being done in smaller cities and at the community or neighborhood level.

Given the diversity of the types of plans that local governments have chosen to pursue, it is not surprising that there is also a diverse set of climate mitigation goals that jurisdictions are aiming to achieve. Such goals are not always expressed quantitatively or for any specific timeframe, but even when they are, the goals are not always directly comparable. Some cities, for example, have set goals for internal operations within the government's direct control, while others have set goals for the community or population as a whole. Similarly, the scope of their GHG inventories can vary, with some quantifying only internal operational emissions and others accounting for community-wide emissions. The table places a check mark next to the general types of climate mitigation strategies that local governments have identified in their plans, but this is not necessarily inclusive of all their planned actions and does not indicate implementation status. Some recognized challenges for implementation of climate plans include funding, organizational capacity, and political/public support.

LIVING CULLY COMMUNITY ENERGY PLAN

Published in 2017, the Living Cully Community Energy Plan identifies a set of priority energy conservation and renewable energy generation pilot projects for the Cully neighborhood in Portland. Listen to ODOE's *Grounded* podcast for more information.

https://go.usa.gov/xP93d

Table 2.1 was compiled by ODOE from publicly available information. This list is continually evolving – additions and corrections to the entries are welcomed and can be made by contacting ODOE at askenergy@oregon.gov.

Table 2.1: Jurisdictions in Oregon Taking Climate Change Actions

✓ = complete
→ = in progress

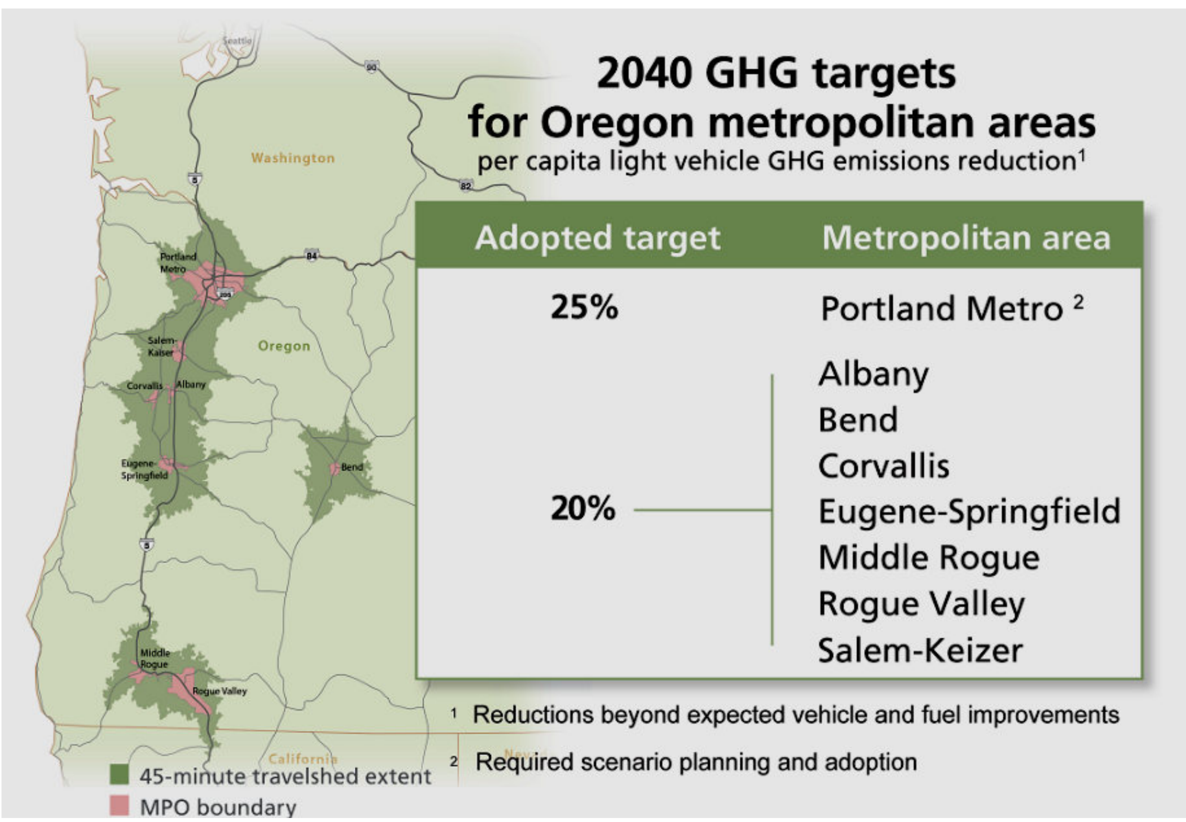
	GHG Inventory	GHG Mitigation Goal	Climate Adaptation Goal	Focus Areas for GHG Mitigation: Renewable Energy	Transportation & Land Use	Buildings	Materials Management	Carbon Sequestration
Ashland	✓	✓	✓	✓	✓	✓	✓	
Beaverton	✓	Carbon neutral by 2050; 1.5°C goal	→	✓	✓	✓	✓	
Bend	✓	✓	→	→	→	→	→	
Clackamas County	✓	80% reduction by 2050		✓	✓	✓	✓	
Corvallis	✓	✓	✓	✓	✓	✓	✓	
Eugene	✓	Carbon budget for city residents consistent with 350 ppm in atmosphere by 2100, requiring an annual average emission reduction of 7.6%		✓	✓	✓	✓	
Forest Grove					✓	✓	✓	
Gresham	✓	→					✓	
Hillsboro	✓	✓		✓	✓	✓		
Hood River County	✓	Replace 30%, 50%, and 80% of fossil fuel power with renewable energy by 2030, 2040, and 2050 compared to 2016	✓	✓	✓			
Lake Oswego	✓		→	✓	✓	✓	✓	
Milwaukie	✓	Carbon neutral by 2050	✓	✓	✓	✓	✓	✓
Portland and Multnomah County	✓	80% reduction from 1990 levels by 2050	✓	✓	✓	✓	✓	✓
Salem	→	✓			✓	✓		
Washington County	✓			✓	✓	✓	✓	

Metropolitan Planning Organizations

"Metropolitan areas" are designated by the federal government in urban areas with at least 50,000 residents. Each metropolitan area has a Metropolitan Planning Organization (MPO) that prepares a regional transportation plan that aims to guide investments and promote consistency among the various policy objectives of state, regional, and local jurisdictions, such as growth management, economic development, transportation system safety and accessibility, and environmental protection. Two out of every three Oregonians live within an MPO boundary[23], which includes Portland Metro, Salem-Keizer, Corvallis, Albany, Eugene-Springfield (Central Lane), Grants Pass (Middle Rogue), the Rogue Valley, and Bend. The majority of Oregon's transportation GHG emissions stem from gasoline and diesel use by light-duty vehicles (passenger cars and trucks), so in bills passed in 2009 and 2010, the Oregon State Legislature directed the Land Conservation and Development Commission to adopt rules that set targets for metropolitan areas for GHG emissions reductions from light-duty vehicles.[140,141]

Figure 2.7 shows the targets for each MPO, but only Portland Metro is required by the Department of Land Conservation and Development to implement a strategy to achieve its target. The figure also notes that these regional targets are separate from transportation GHG emissions reductions that would be expected from other federal and state policies that encourage cleaner vehicles and fuels. Chapter 4 discusses the role of vehicle efficiency standards, clean fuels policies, and other related programs in more detail.

Figure 2.7: State Targets Adopted for Metropolitan Area Passenger Vehicle GHG Emissions[24]



Three MPOs have conducted scenario-planning efforts to evaluate the GHG emission reduction potential associated with their regional plans, which generally focus on a combination of increased transit, transportation options, and compact, mixed-use development:

- Between 2011 and 2014, Metro conducted the Climate Smart Communities project to evaluate 144 scenarios. In December 2014, Metro adopted a preferred scenario that is expected to reduce GHG emissions by 29 percent per capita by 2035.
- Between 2012 and 2014, the Central Lane MPO and jurisdictions within the Eugene-Springfield area completed the Central Lane Scenario Planning project. In June 2015, Central Lane adopted a preferred scenario that is anticipated to meet its 20 percent per capita reduction target.
- In 2014, the Corvallis MPO took initial steps toward more detailed scenario planning by conducting a "strategic assessment" of its adopted plans.

Tribal Governments

The nine federally-recognized Tribes in Oregon are experiencing firsthand the threat that climate change poses to their traditional ways of life and are engaged in both climate mitigation and adaptation actions. All nine Tribes are members of the Affiliated Tribes of Northwest Indians, which has had an energy program since 1995 and more recently launched a climate change program (http://atnitribes.org/climatechange/). All of the Tribes also participate in the University of Oregon's Pacific Northwest Tribal Climate Change Network, which since 2009 has fostered "communication between tribes, agencies, and other entities about climate change policies, programs, and research needs pertaining to tribes and climate change."[25]

In December 2017, tribal members from Oregon participated in a ground-breaking regional Tribal & First Nations Climate Summit, jointly organized and hosted by ATNI and the PNW Tribal Climate Change Network, among others.[31] The Summit brought together more than 150 participants from Tribes and First Nations in the Pacific Northwest and Canada to learn from past work and chart courses for the future. The Summit indicated that areas of focus for the region's Tribes and First Nations include the role of traditional knowledges in addressing climate change, effects on cultural resources, climate resiliency and adaptation, and advancing policy.

Tribes in Oregon have been involved in various types of climate change-related work for many years. The summary below is not comprehensive; rather, it is meant to highlight the diversity of tribal climate actions that are occurring around the state.

SELECT TRIBAL CLIMATE MILESTONES

Wind turbine and solar array at the Tamástslikt Cultural Institute

The **Burns Paiute Tribe** is one of the four member tribes of the Upper Snake River Tribes Foundation that participated in a collaborative Climate Change Vulnerability Assessment in 2016, with technical assistance from Adaptation International, University of Washington, and Oregon State University. A profile of this effort is posted on the U.S. Climate Resilience Toolkit.[27]

The **Confederated Tribes of Coos, Lower Umpqua, and Siuslaw Indians** are incorporating climate change considerations into some of their natural resource planning, including their Wetlands Inventory and Assessment and their Terrestrial and Aquatic Invasive Species Management Plan.

The **Grand Ronde Tribe** joined the West Coast Electric Highway in 2013, installing a charging station at their Spirit Mountain Casino, and have installed solar PV panels on the Grand Ronde Tribal Housing Authority carport and at a low-income housing community for tribal elders. The Tribe received funding and technical assistance from the Energy Trust of Oregon and the U.S. Department of Energy.

The **Confederated Tribes of Siletz Indians** have implemented various clean energy projects through their Siletz Tribal Energy Program, focusing on weatherization and energy efficiency, conservation, renewable power, and solar for tribal buildings and homes. With funding and technical assistance from the Energy Trust of Oregon, the Tribe installed energy-efficient lighting and upgraded air handling equipment at their Chinook Winds casino.

The **Confederated Tribes of the Umatilla Indian Reservation** (CTUIR) is compiling climate vulnerabilities and impacts of particular concern to the Tribe through its climate change story map.[28] The Tamástslikt Cultural Institute, a nonprofit interpretive center on the reservation, has installed a wind turbine as part of its goal to become a net-zero building. The Tribe has also implemented a number of energy-efficient LED lighting and solar PV projects in keeping with the climate and renewable energy goals outlined in the CTUIR Comprehensive Plan and Energy Policy.

The **Confederated Tribes of Warm Springs** (CTWS) participated in a project with the Oregon Health Authority[29] to profile the health effects their tribal members are facing due to climate change. In addition, CTWS is the only Tribe in Oregon to have completed an Improved Forest Management project on a portion of its 650,000 acre reservation to generate carbon offset credits that can be sold into the Western Climate Initiative cap-and-trade market (see section X.X below for more on cap-and-trade and offsets). Revenue from these sales will support CTWS "tribal member services, economic development, and improved forest management, among other benefits."[30]

The **Cow Creek Band of Umpqua Tribe of Indians** is the only Tribe in Oregon with its own electric utility cooperative and the first in the Northwest that is both owned and operated by a tribe. The Umpqua Indian Utility Cooperative distributes electricity solely from Bonneville Power Administration, of which about 95 percent comes from zero-carbon emitting resources, mostly hydropower and a small amount of nuclear power.

The **Coquille Indian Tribe** is developing a climate adaptation plan to adapt to the challenges and threats to its land and natural resources, infrastructure and transportation systems, and in turn, the Tribe's culture, economy, health, and safety. In addition, the Tribe installed solar PV panels and a solar water heating system on the roof of its Community Center, and has implemented lighting and other efficiency upgrades in tribal buildings and residences.

The Klamath Tribes are involved in a number of Klamath Basin-wide climate projects spanning southern Oregon and northern California. A 2010 report, sponsored in part by the University of Oregon, assessed climate impacts and identified climate adaptation strategies relevant for Klamath Basin Tribes and local communities.[31] The Klamath Tribes participate in the Klamath Basin Tribal Food Security Project (administered by the University of California, Berkeley and the Karuk Tribe) to build capacity in identifying, monitoring, harvesting, managing, and preparing traditional foods, especially in the face of changing environmental conditions from climate change.[32]

Risks and Impacts Under High and Low Emissions Scenarios

Oregon's climate actions that are being or will be implemented in the near future — its Business as Usual pathway — put us on a trajectory that is far above the state goal to achieve our fair share contribution to the global level of GHG emissions that scientists have concluded is needed to have the best chance of avoiding the most severe projected impacts of climate change. This section summarizes key findings of research on the implications of a future in which local and global GHG emissions keep rising. The latest global climate models used by the scientific community to make future climate projections are based on a consistent set of future emissions pathways called representative concentration pathways (RCPs).[33] The higher global emissions pathway is known as RCP 8.5 — what many consider as a "worst-case" scenario of rising emissions, which is currently the path the world is on — while one of the most commonly studied lower emissions pathways is called RCP 4.5. The RCP 4.5 scenario represents efforts to reduce global GHG emissions such that they peak near mid-century then decline, and is often cited as the top end of the range of future scenarios that could potentially meet the UNFCCC goal of "stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.[11]"

Understanding the upper and lower bounds of expected changes is consistent with a risk management approach to climate change[34,35,36]; it enables us to understand what is at stake and what society stands to gain if the world moves from a high to a low emissions scenario. Oregonians strongly value the state's natural beauty, outdoor recreation opportunities, and clean air and water. Climate change is threatening these values, as well as the state's economy, environment, and way of life. Although risks are not limited to one area of the state, certain populations—including low-income communities, communities of color, and rural areas—are particularly vulnerable and less able to respond to and cope with climate change.

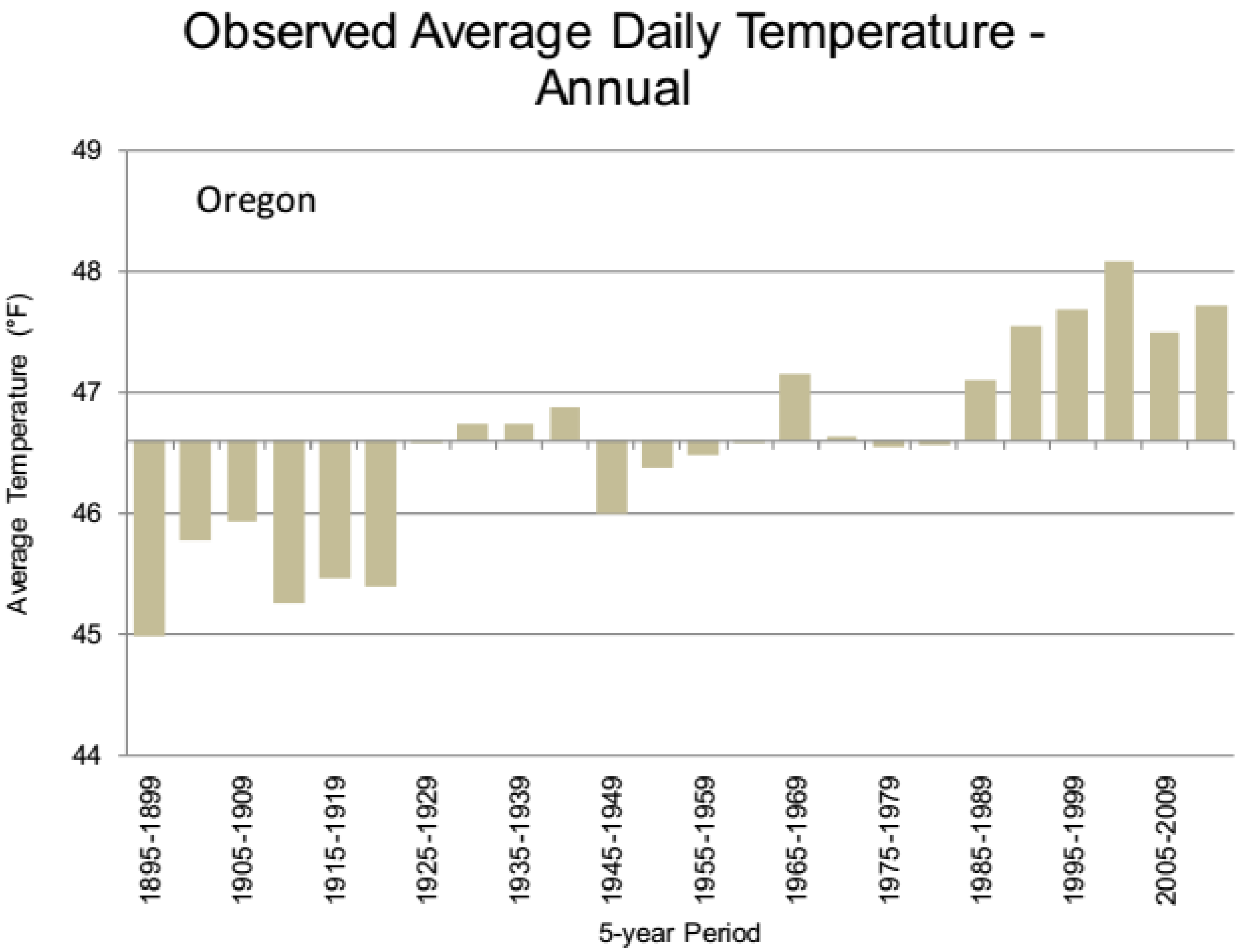
The following subsections provide a broad, high-level look at key trends and projected climate impacts affecting the United States and Oregon. This is for the purposes of comparing high-level risks under different global GHG mitigation futures; the studies and reports referenced in this section cover climate impacts in more comprehensive detail. See Chapter 5 for more background on climate vulnerability assessments used for the purposes of climate adaptation planning, which are designed to go into more detail on risks to the various sectors of Oregon's economy and society.

Warming and Extreme Heat in Oregon

Long-term increases in temperature due to anthropogenic GHGs have ripple effects throughout the Earth's climate system. The evidence base that global temperature is increasing comes not only from direct measurements of temperature itself, but also from changes such as altered regional precipitation and storm patterns, rising ocean heat content, and rising global sea level resulting from the thermal expansion of water and increased melting of land ice.[37] The most recent climate science volume of the U.S. National Climate Assessment, a federal scientific consensus report, concluded that the pace of change is more rapid compared to the pace of the natural variations in climate that have occurred throughout Earth's history, that there is no convincing evidence that natural cycles can explain the observed changes in climate, and that it is extremely likely (indicating a 95 to 100 percent probability of occurrence) that human influence has been the dominant cause of the observed warming since the mid-20th century.[37]

Since the beginning of the 20th century, temperatures in Oregon have risen approximately 2°F, and temperatures since the 1990s have been higher than any other historical period since records began in 1895.[38,39] Since the 1970s, warming in the Pacific Northwest been accelerating faster than over the last century.[39]

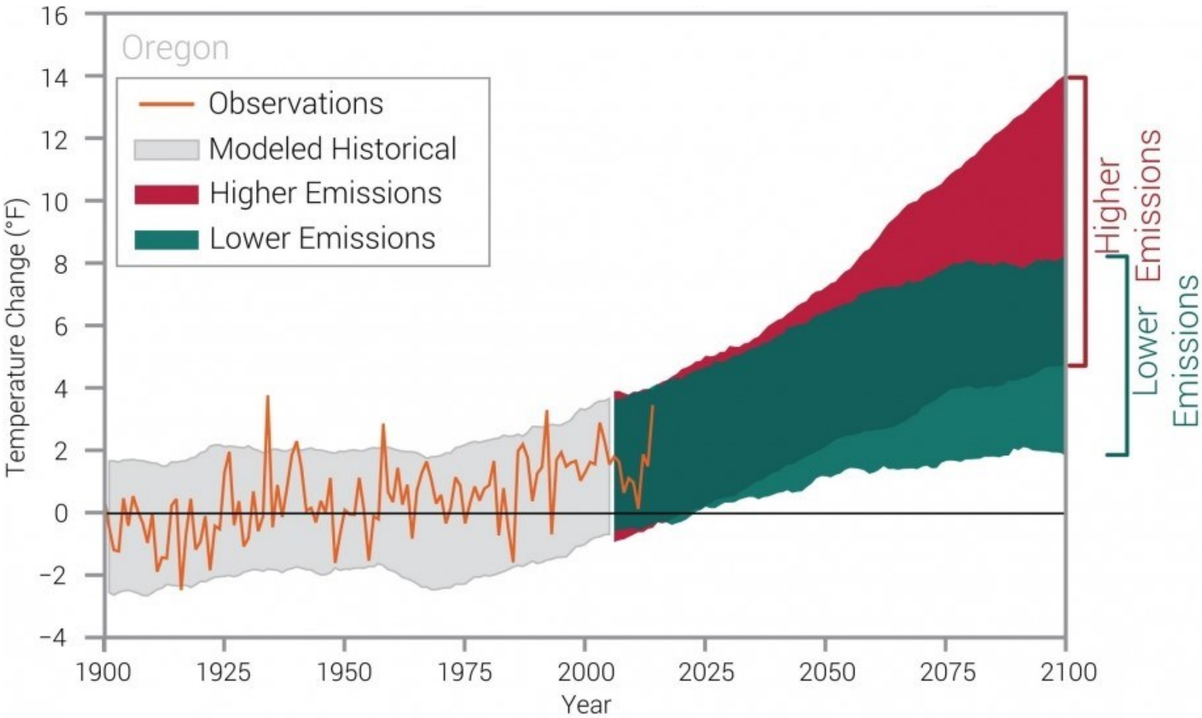
Figure 2.8: The Observed Average Daily Temperature for the Years 1895-2014, Averaged Over 5-year Periods.[38,35]



Under a higher global GHG emissions scenario (RCP 8.5, as shown in the red shaded area of Figure 2.9), historically unprecedented warming is projected for Oregon by the end of the century.[38] On average, Oregon can expect a 5.0°F increase (with a possible range from 2.9° to 6.9°F) by the 2050s and an 8.2°F increase (4.8° to 10.7°F) by the 2080s.[39] Even under a lower global GHG emissions scenario (RCP 4.5, as shown in the green shaded area), average annual temperatures are projected to most likely exceed historical record levels by 2050.[38] Oregon can expect an average increase of 3.6°F by the 2050s and 4.6°F by the 2080s.[39]

In either future scenario, warming temperatures will result in extreme heat events with increased frequency, duration, and intensity.[39] In the next few decades, recent record-setting years like Oregon's summer of 2015 may become common.[37,39] But overall risks associated with warming temperatures would be reduced on the lower emissions pathway because there is a greater possibility of staying only slightly warmer than historical records[39], which means closest to the gray shaded area in Figure 2.9.

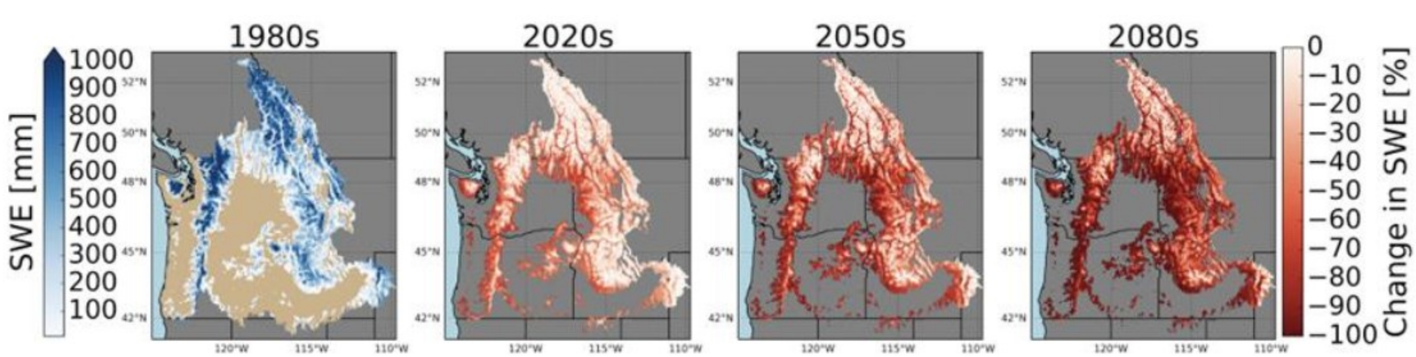
Figure 2.9: Observed and Projected Annual Average Temperature Change in Oregon (1895-2100).[38,35]



Water Resources in Oregon

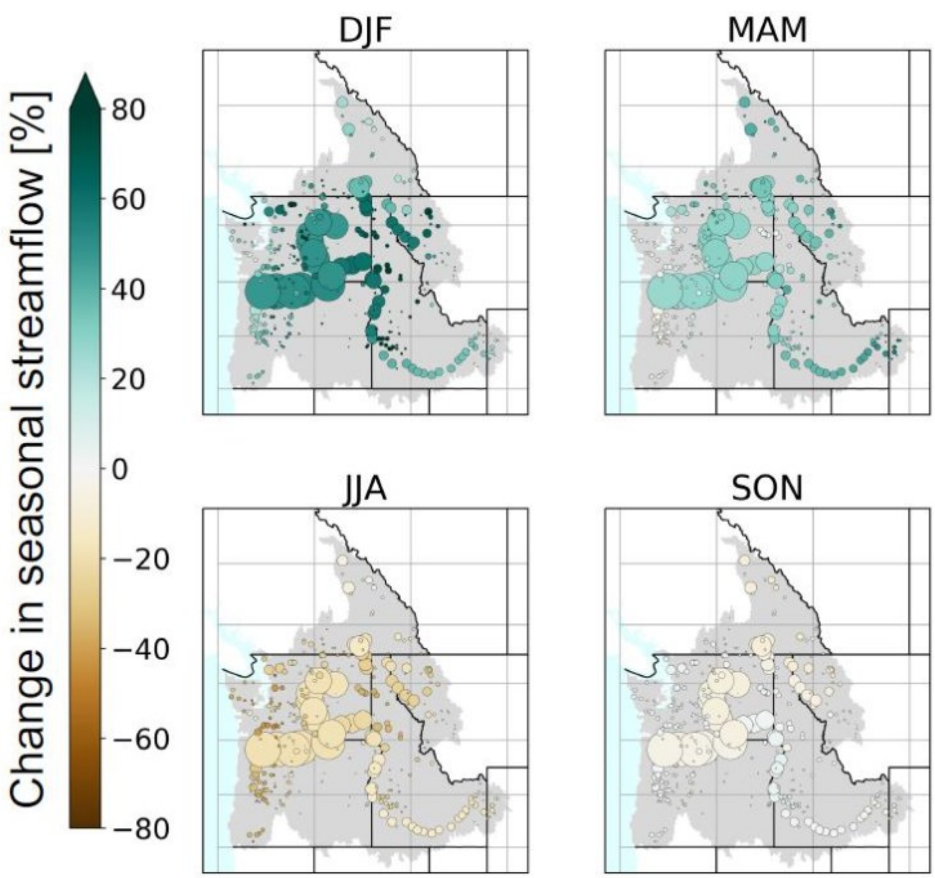
Climate change will affect water resources in Oregon and the Northwest, such as the amount and seasonal timing of water in rivers and streams, winter flood risk, and summer extreme low flows and drought risk.[39] A key indicator for these impacts is mountain snowpack, which is a natural source of water storage that has provided a vital supply during the summer dry season for irrigated agriculture and municipal and industrial water uses in Oregon and throughout the western U.S.[41] Oregon State University researchers track snowpack trends across the western U.S., and nearly all measurement stations in Oregon have documented snowpack declines[41], with an average 37 percent decrease from 1955 to 2015.[39] For every 1°F of future warming, the snow line—the average lowest elevation at which snow falls—increases by about 300 feet.[38] In the Cascade Range, mountain snowpack as measured in peak snow water equivalent is expected to decline 22 to 30 percent for every 1.8°F of temperature rise.[39] Therefore, a lower emissions pathway (RCP 4.5) would reduce risks associated with loss of snowpack because it would limit the likely range of temperature increase. Under a higher emissions scenario (RCP 8.5), snowpack in the Cascades is projected to decline by up to 81 to 90 percent, as shown in Figure 2.10.

Figure 2.10: Observed and Projected Columbia Basin Snow Water Equivalent (SWE)[42,43]



Wet season precipitation will increasingly fall as rain rather than snow as temperatures continue to rise, further reducing the accumulation of snowpack, particularly in low to mid elevations (about 3300 to 6600 feet).[39] As shown in Figure 2.11, this is projected to shift streamflow magnitude and timing in the Northwest toward higher winter runoff, lower summer and fall runoff, and an earlier peak runoff in the region from summer toward spring.[39,43,44] This means there will be less water available in Oregon's rivers and streams during the summer, and the frequency, intensity, and geographic extent of summer drought and extreme low stream flows is expected to increase.[39]

Figure 2.11: Projected Changes in Seasonal Streamflow in the Columbia River Basin by the 2030s[43]



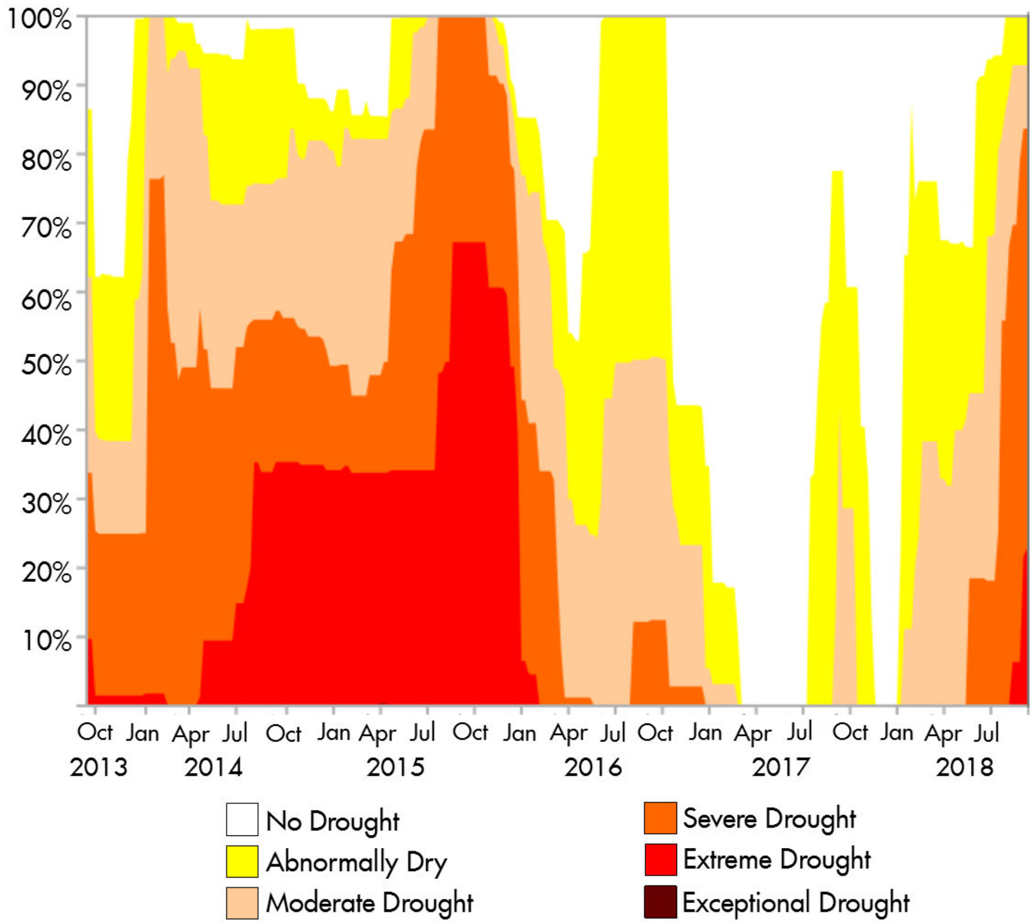
The figure shows percent change in annual water volume under a higher emissions scenario compared to a historical period of 1976-2005 (larger circles have larger annual volumes in the historical period). Darker green colors indicate larger projected runoff volumes in winter and spring, while browner colors in summer months indicate an expected decrease in available water.

Implications for Oregon's Economy and Natural Resources

Oregon's diverse natural resources support high quality native ecosystems and rare plant and animal species, are major contributors to the state economy, and sustain livelihoods for Oregonians across the state, particularly rural, coastal, and tribal communities. An overview is provided below of ways in which many of these resources are already experiencing effects of climate change and are projected to be affected by future changes.

The summer dry season is expected to become drier at the same time that rising temperatures and more frequent and intense extreme heat events increase evapotranspiration and soil dryness.[39] **Drought** reduces forage and water availability for livestock grazing, and warmer temperatures reduce beef and dairy production and may enable crop diseases, pests, and invasive weeds.[39] The severe lack of water for irrigation in 2015 led to damaged crops, reduced yields, and fewer crops being planted[45], with monetary losses estimated to be in the hundreds of million dollars.[38] Figure 2.12 shows that from 2013 to 2018, there were only short periods of a few months in 2017 where Oregon was not experiencing abnormal dryness or moderate drought.

Figure 2.12: Drought Intensities: Percent Area for Oregon[54]



More frequent large **wildfires**, an increase in the total area burned, and a longer fire season have been documented over the last several decades in the Western U.S.[39] Wildfire frequency and area burned are expected to continue increasing in the Pacific Northwest.[39] Droughts and heat waves contribute to greater fire severity; all are expected to increase in Oregon.[18] The 2015 drought conditions and lack of snowpack led to a historically severe wildfire season with more than 1.6 million acres burned across Oregon and Washington, resulting in more than $560 million in fire suppression costs.[39] As of October 2018, the Oregon Department of Forestry estimated gross costs of $101 million to fight wildfires in 2018, which will net to over $40 million after federal cost-sharing.[46]

Oregon's extensive **forest resources** are at risk from increasing temperatures, changing precipitation patterns, wildfire, pests (such as mountain pine beetle in Ponderosa pine) and disease (such as Swiss needle cast in Douglas fir trees), and extreme events such as droughts and floods.[39] These climate impacts are also expected to adversely affect the ability of the forest to provide ecosystem services, such as flood protection or water purification, and goods, such as species habitat or forest products.[18] **Winter flood risk** is expected to increase for many Oregon watersheds (particularly those classified as mixed rain-snow basins) due to slightly more average rainfall in the wet season and slightly more frequent or intense extreme rainfall events.[39]

Changes in **river and ocean temperature**, ocean acidification, and marine hypoxia have serious implications for Oregon commercial fisheries, particularly salmon, groundfish, and crab, as well as shellfish hatcheries:

- Summer water temperatures in streams and rivers in Oregon and throughout the Northwest are projected to rise due to the effects of reduced summer flows, along with higher air temperatures and the loss of the protective cooling effect of snowmelt runoff.[18,39]
- The world's oceans have absorbed about 93 percent of the excess heat caused by greenhouse gas warming since the mid-20th century.[37] For salmon, warmer ocean waters could alter their ranges and migration, and could cause thermal stress and increase susceptibility to disease and predation, and change their habitat structure and availability of food.[39]
- Surface ocean waters absorb part of the increasing CO2 in the atmosphere, which causes a variety of chemical changes in seawater termed ocean acidification. Acidification along the Pacific Northwest coast is increasing as a result of ocean upwelling that brings increasingly acidic deep ocean waters to the surface, and the rate of acidification is thought to be unparalleled in at least the past 66 million years.[37] Under the high emissions scenario (RCP8.5), the global average surface ocean acidity is projected to increase by 100 to 150 percent.[37]
- Over the last half century, major oxygen losses (hypoxia) have occurred in inland seas, estuaries, and in the coastal and open ocean.[37] Ocean oxygen levels are projected to decrease by as much as 3.5 percent under the higher scenario (RCP8.5) by 2100 relative to preindustrial levels.[37]

Additional effects on recreational and tribal fisheries are described later in this chapter.

Human Health Threats

In 2014, the Oregon Health Authority published the state's first climate and health risk assessment[47] that identified key climate-related health hazards in the state, including extreme heat events, wildfires, floods, and changes in infectious and waterborne disease trends. There is potential for climate change to have a positive influence on some health outcomes in Oregon, such as longer summer seasons that could lead to an increase in outdoor recreation. But on the whole, the rate of change and the evidence to date indicate current and growing adverse health impacts from climate change in the Pacific Northwest and Oregon[18,39,47]:

- Warming temperatures, changes in precipitation, and more extreme weather are projected to increase populations of disease-carrying vectors like mosquitoes with West Nile Virus and of the types of bacteria and toxic algae that contaminate shellfish and recreational waters for activities like swimming and boating.[48]
- Air quality is expected to worsen under future climate change and increased incidences of ozone-related illnesses and premature death are projected nationally under a higher emissions scenario.[48] Fine particulate matter emissions from wildfires are projected to increase by at least 160 percent by mid-century in the western U.S. under a higher emissions scenario.[49]

- The projected increase in flooding related to extreme rainfall (combined with sea level rise at the coast) threaten infrastructure like roads, hospitals, and drinking and wastewater treatment plants that are essential to safeguarding physical safety and human health.[48]
- Indigenous peoples are uniquely vulnerable to mental health impacts associated with climate change, which can include increased rates of mood and anxiety disorders, strong emotional responses, and loss of connections to homeland and social networks.[48] Community health is tied to sacred places and natural resources like water and salmon that have strong cultural, religious, and spiritual significance to many Indigenous peoples, and that are being adversely affected by climate change.[82]

SALEM DRINKING WATER CRISIS

As greenhouse gas emissions continue to drive global climate change, Oregon will experience negative environmental and economic effects – from increased heating and cooling costs to smoke from wildfires to compromised water sources. In 2018, samples from the City of Salem's drinking water supply, Detroit Reservoir, showed evidence of harmful cyanotoxins from an algal bloom. Salem residents were under a water quality advisory for weeks, during which older adults, children, and people with weakened immune systems could not drink the tap water. Algal blooms thrive in warm waters, which means as water temperatures increase from climate change or drought-reduced water levels, communities are likely to experience more frequent algal blooms, Tufts University environmental engineering professor Steve Chapra told Oregon Public Broadcasting in June.[52] In Salem, the City government implemented a new treatment process: adding powdered activated carbon to the water if and when cyanotoxins are detected. The estimated cost to update the infrastructure for the treatment solution was about $2.6 million. To add carbon to the water supply for one week costs the City over $150,000.[53]

Oregon Ways of Life and Heritage Resources at Risk

Oregon's coast is home to iconic landmarks and landscapes that are a significant piece of Oregonians' heritage, as shown by the landmark 1967 legislation known as "The Beach Bill"[142] that guarantees free unrestricted public access to all the state's beaches.[51] Along significant portions of Oregon's coast, sea levels are expected to rise about 1 to 4 feet by the end of the century.[39] Nearly a fifth of all housing in the state is located in vulnerable coastline counties, and property damages have been estimated to reach $33 million by 2040.[54] Global average sea level has risen by about 7–8 inches since 1900, with almost half (about 3 inches) of that rise occurring since 1993.[37] Human-caused climate change has made a substantial contribution to this rise since 1900, contributing to a rate of rise that is greater than during any preceding century in at least 2,800 years.[37] Locally, sea level change can be very different from the global average rate change due to geographic differences in natural geologic processes known as subsidence (land sinking) or uplift (land rising). Coastal storms and storm surge can combine with sea level rise to exacerbate coastal erosion and inundation hazards.

Outdoor recreational opportunities in Oregon span all seasons and include fishing, hunting and wildlife viewing, swimming, boating, hiking, and skiing. Oregon's outdoor recreation industry is estimated to support $12.8 billion in consumer spending, $955 million in local and state tax revenue, $4 billion in wages and salaries, and 141,000 jobs.[54] Sixty-eight percent of Oregon residents participate in outdoor recreation, with fish and wildlife-based recreation in Oregon valued at around $2.5 billion annually.[54]

Ski resorts are expected to be negatively affected by reductions in snowfall and snowpack that would result in later resort opening dates and earlier closing dates, a greater reliance on snowmaking during shorter viable time periods, and increased costs to skiers.[18] Declining snowpack and warmer summers increase the risk of stream temperatures that are lethal to fish (generally greater than 68°F, although this varies among populations).[55] The overall effect of climate and hydrologic change on salmon during all life cycle stages is likely to be negative and reduce salmon populations in the Pacific Northwest, especially given existing stressors and natural variability that act as additional stressors to fish populations.[39]

EFFECTS OF CLIMATE CHANGE ON FIRST FOODS

Tribal Salmon Bake.
Photo: Oregon State University.

Of paramount importance are "first foods," the traditional plant and animal species used for physical and spiritual sustenance over generations, to the Indigenous peoples across the United States. Beyond the nutrition they provide, first foods are central to traditional community practices, sacred ceremonies, physical and mental health, and subsistence and commercial economic activities.[50] In Oregon, these foods are gathered, harvested, and hunted in a variety of ecosystems that are projected to be affected by climate change.[56] This includes urban ecosystems, such as the city of Portland, which is home to the ninth largest urban Native American population in the country, including an estimated 58,000 or more people from more than 380 tribal nations.[57] The summary table[50,58,59,60] below highlights climate vulnerabilities of a number of first foods in Oregon, but is not comprehensive. Effects on fish and shellfish species of concern have been well-studied and documented, while more studies are needed on climate effects on berry, root, and game species.

Types of First Foods in Oregon	Habitat Vulnerability to Climate Change
Fish, including salmon, steelhead, lamprey	Ocean and rivers (anadromous species spend time in both) affected by rising water temperatures and ocean acidification
Shellfish, including several types of clam (Gaper clam, Nuttall's Cockle, butter clam, razor clam)	Nearshore and coastal habitats affected by sea level rise, rising water temperatures, and ocean acidification.
Berries, including huckleberries and chokeberries	Potential drought, wildfire, invasive species, flooding effects on: subalpine slopes, forests, bogs, and lake basins; and low- and mid-elevation, typically riparian zones.
Roots, including Wapato, Camas, Couse or Kowsh (also known as biscuitroot)	Potential drought, wildfire, invasive species, flooding effects on: marshes and wetlands; prairies and grasslands; and open, rocky slopes and meadows.
Game, including elk and deer	Potential stress related to wildfire, drought, pests, and disease effects on forests

Climate Risks Not Distributed Evenly

Certain populations face more exposures to hazards, have fewer resources to recover from climate change-related impacts, and are affected by existing environmental and health disparities.[47,48] In this way, climate change is likely to exacerbate current social, economic, environmental burdens on certain individuals and communities.[48,44] Those that depend upon natural resources and ecosystems, particularly tribal communities, are among the first to experience the impacts of climate change (Bennett et al. 2014; Norton-Smith et al. 2016). Multiple studies of regional climate impacts have found that Oregon's tribes are uniquely affected by climate change threats to their traditional culture and lifeways, sovereignty, health, and subsistence and commercial economies.[18,39]

The table below identifies many of the vulnerable populations in Oregon; however, these are not mutually exclusive categories, and there is often overlap. For example, older adults—those aged 65 years and older—comprise about 14 percent of Oregon's total population, but have greater representation in rural areas of the state.[47] Such uneven risks associated with certain geographic and demographic factors are some of the reasons why climate mitigation and adaptation policies are often discussed in terms of equity and environmental justice. For more information, see subsections on equity below and in Chapter 5.

Contributing Factors to Vulnerability	Populations Identified in the Oregon Climate and Health Profile Report[47]
Demographic factors and social determinants of health	• People with existing illness • People with disabilities • Older adults • Mothers, infants and children • Low-income communities • Indigenous peoples (e.g., American Indian or Alaska Native) • Immigrants, refugees, and linguistically isolated • Communities of color
Geographic and housing characteristics	• Urban heat islands • Wildland-urban interface • Agricultural communities • Coastal communities • People reliant on private water systems • People living in residences located on steep slopes
Occupation	• Wildland firefighters • Outdoor workers • Growers, ranchers and farmworkers • First responders and health care workers • People who work in agricultural communities

Exploring Deep Decarbonization Pathways for Oregon

2016 GHG Emissions
OREGON TOTAL
61.87 million metric tons

There are different strategies available to the State of Oregon to reduce GHG emissions to a level consistent with a deep decarbonization scenario. Because deep decarbonization requires accelerating large-scale changes to energy systems, there is broad consensus across the climate policy community that both cross-sector mitigation policies, such as economy-wide market-based programs, and sector-specific actions are needed. [12,61,62,63,67]

Sector-specific strategies are sometimes described as complementary to economy-wide climate policies because although they can deliver significant emissions reductions in individual sectors, they inherently cannot account for shifts in emissions between sectors.

The following subsections introduce economy-wide and sector-specific strategies that could serve as options to help Oregon meet its climate goals. These categories of potential strategies are broad, and there is no one set of off-the-shelf, prescribed actions for deep decarbonization. Strategies will likely need to be modified as technology continues to progress and circumstances change. Periodic statewide deep decarbonization analyses and strategic planning can help evaluate and prioritize cost-effective actions to pursue that also have the greatest certainty to achieve the necessary emissions reductions.[61,62,63]

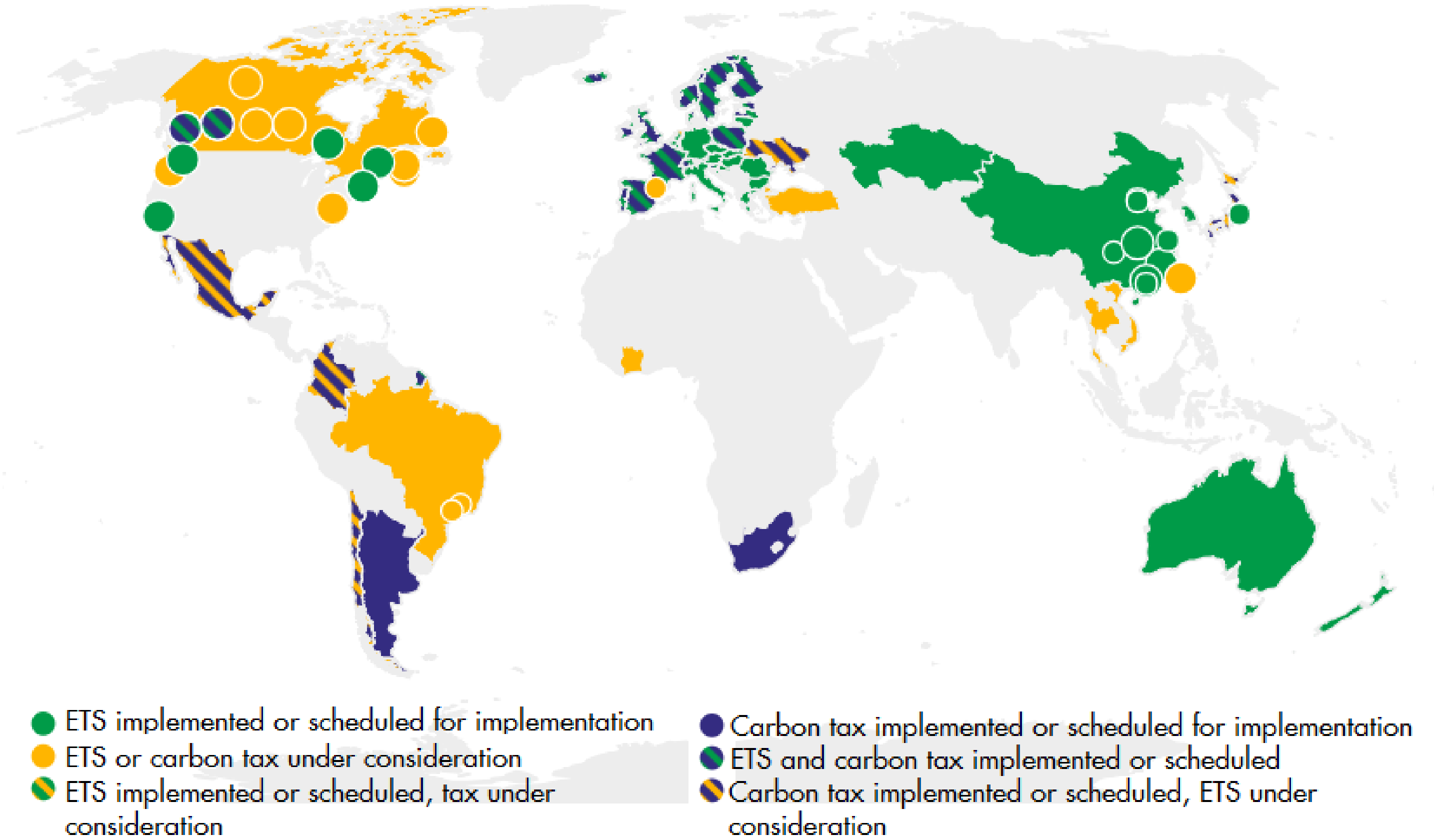
Economy-Wide Climate Policies

Two common focus areas for subnational jurisdictions with regard to economy-wide climate policies include carbon pricing and beneficial electrification.[12,64,65] These two policy approaches are introduced below.

Carbon Pricing to Reduce GHG Emissions

National and subnational governments around the world are increasingly turning to market-based carbon pricing policies to reduce GHG emissions (Figure 2.13). The two primary systems of carbon pricing—a carbon tax or a cap-and-trade system (also known as an ETS or Emissions Trading System)—are policy mechanisms that hold emitters of pollution financially accountable for the environmental and health costs of their pollution, thus creating an economic incentive to pollute less. These policies can also include the collection of revenue that is further invested in GHG reduction or transition strategies. Cap and trade as a policy mechanism rose to prominence in the U.S. with the Acid Rain Program established by the Clean Air Act Amendments of 1990. Based on the success of that program in achieving sulfur dioxide emissions reductions at comparatively lower cost than traditional environmental regulation, the mechanism began to be considered to reduce GHGs in the late 1990s.[102]

Figure 2.13: Global Map of Carbon Pricing Initiatives[68]



In World Bank's map (Figure 2.13), note that although Washington State has a green circle, in March 2018 a court invalidated parts of the state's Clean Air Rule, which would have required large GHG emitters to cap and reduce their emissions. The state has appealed that ruling to the Washington State Supreme Court.

The European Union was the first jurisdiction in the world to create an ETS for GHGs, which began trading in 2005. In the U.S., a group of northeast and mid-Atlantic states* developed a regional cap-and-trade program addressing carbon dioxide emissions from power plants. This program, called RGGI, or the Regional Greenhouse Gas Initiative, began trading in 2009. From 2009-12, western states including Oregon participated in a coordinated process to negotiate the framework for a linked cap-and-trade system known as the Western Climate Initiative, or WCI. California and the province of Quebec formally agreed to establish the WCI and began linked trading in 2013. With RGGI and WCI, roughly a quarter of the U.S. population lives in an area with a cap and trade program. As of 2018, 51 carbon pricing initiatives have been implemented or are scheduled for implementation globally. This consists of 25 emissions trading programs, mostly located in subnational jurisdictions, and 26 carbon taxes primarily implemented on a national level.[70]

* Existing participants include Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont; New Jersey and Virginia are currently in process to join.

STUDYING CAP-AND-TRADE IN OREGON

At the request of the Oregon Legislature (SB 5701 (2016)[69]), the Oregon Department of Environmental Quality wrote "Considerations for Designing a Cap-and-Trade Program in Oregon,"[20] which is excerpted below to explain the major features of this type of carbon pricing program in relation to a carbon tax:

How does a cap-and-trade program work?

A cap-and-trade program establishes an overall limit (the cap) on GHG emissions from certain sources of pollution, such as electricity providers, industrial facilities, and fossil fuel suppliers. Permits or "allowances" are issued by the state to regulated entities. Each allowance permits a business to emit or supply fuel that emits one ton of emissions. For example, if a program has a cap of 50 million tons of pollution in a given year, the state would issue 50 million allowances in that year. These allowances can be bought and sold on the market (the trade). Companies covered by the program must acquire allowances to match their emissions. As the cap declines over time, the entities covered by the program must make collective cuts in emissions. However, because of the formation of a marketplace for allowances, emission reductions won't be uniform across the covered entities but instead will occur where reductions are cheapest. Entities that can most cheaply reduce their emissions will do so, while others will pay to acquire sufficient allowances. This should reduce emissions where it is cheapest to do so, while spurring innovation to develop new methods for greater reductions.

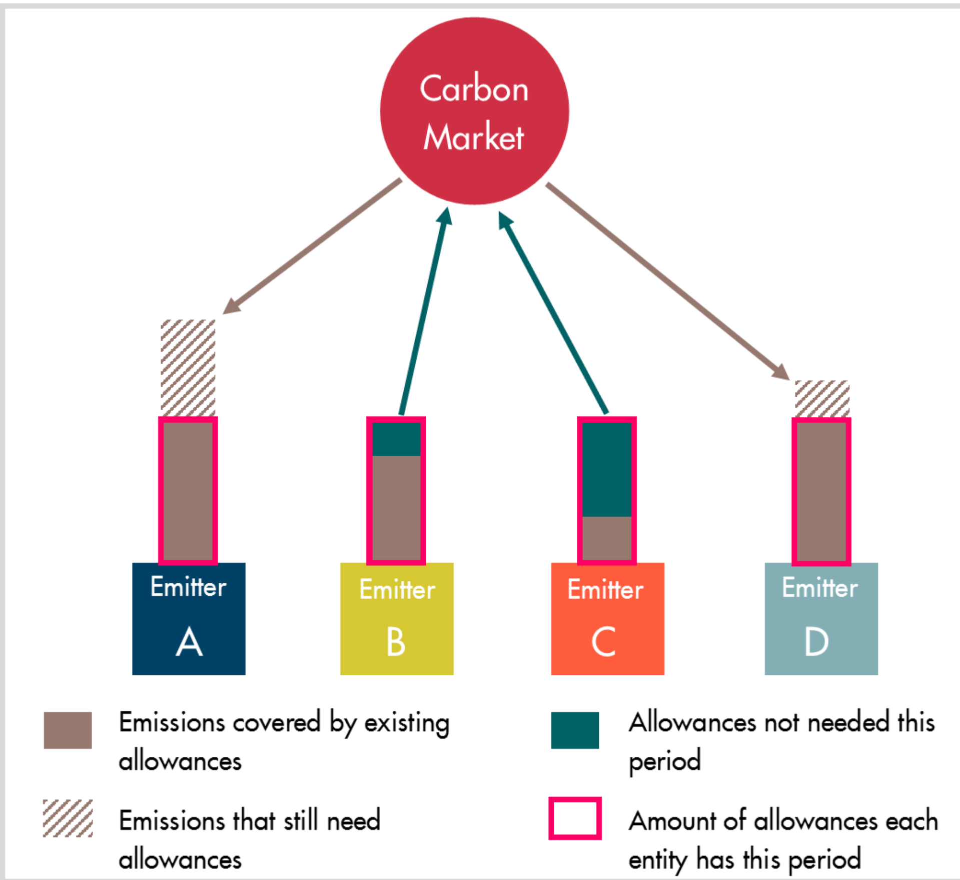
How does cap-and-trade differ from a carbon tax?

Both cap-and-trade and a carbon tax establish a price on GHG emissions. Cap-and-trade specifies a certain amount of emissions reduction and allows the price to pollute to adjust based on market demand, while a carbon tax does not prescribe an amount of emissions to be reduced but specifies a price to emit GHGs. Cap-and-trade sets a firm limit on emissions, providing certainty that pollution will be reduced to the level of the cap. This program does not establish a specific price on GHG pollution, letting the marketplace determine this based on the supply of allowances and the demand from regulated entities to pollute. In contrast, a carbon tax does not require specific emission reductions, but does set the price to emit GHGs. The flexibility offered by cap-and-trade provides some benefits compared to a carbon tax. In addition to providing certainty on emission reductions, cap-and-trade offers the state tools to better directly mitigate impacts to specific businesses and should produce emission reductions at a lower overall cost.

In designing a cap-and-trade program, policymakers can choose the sectors, sources, and types of emissions to be covered by the cap. Generally these markets function more effectively and efficiently when the cap is broad because that provides more options to find the most cost effective emission reductions. A multi-sector program also benefits from fewer perverse incentives for fuel switching to unregulated sectors without actually reducing emissions.[20] Figure 2.14 shows a hypothetical example of Emitters A through D that represent entities covered by a cap on GHG emissions across multiple sectors of the economy. This is a simplified depiction; actual details of the mechanics of a cap-and-trade program would depend on how that specific program is structured. The economy-wide emissions limit creates a budget of overall emissions allowances for a given compliance period. These allowances act like permits that each allow one metric ton of GHG emissions. Regulated entities are required to turn in an amount of allowances—or, depending on how the program is structured, a combination of allowances and offset credits (defined below)—that matches their emissions each compliance period.

In this example, the cap-and-trade program has been in operation for a few years. Emitters A through D have existing accounts with an equal number of allowances (shown as pink rectangles) that could have come from various sources—for example, free allocation from the state or purchases made in previous compliance periods that were held, or banked, for present use.

Figure 2.14: Simplified Illustration of Regulated Entities During One Compliance Period



Emitters B and C have more allowances than they need to cover their emissions this compliance period. This could be due to, for example, successful past investments in various GHG mitigation strategies. Emitters B and C now have an economic opportunity to sell their extra emissions allowances (shown as teal rectangles) in the carbon market or possibly keep them for use in future compliance periods depending on how the program is structured.

Emitters A and D will need to get additional allowances to cover the amount of emissions that exceeds their existing amount of allowances (shown as gray striped rectangles). They can go into the carbon market to purchase allowances either in a state-run auction or in the private secondary market (such as purchasing directly from Emitters B or C). In future compliance periods, Emitters A and D could also invest in strategies to reduce the GHG emissions for which they are responsible, such as reducing energy use or increasing operational efficiency—in other words, producing the same amount of product for less energy input. This would not only help reduce or avoid their need to purchase additional allowances for compliance, but would also help them save money on energy bills.

Policymakers designing a cap-and-trade program can choose to incorporate opportunities to count emissions reductions from sectors not covered by the cap in order to introduce an additional source of compliance options, called offset credits. This can help to reduce the compliance costs of the program by providing additional flexibility, though the approved use of offset credits is typically limited to a small percentage of the economy-wide emissions limit for a given compliance period. The DEQ report further explains that:[20]

Offset credits represent emission reductions from sources not covered by the cap. These credits can be incorporated into a cap-and-trade program and used like allowances. An offset is generally equivalent to an allowance; both permit the emission of one ton of carbon dioxide equivalent from an emission source covered by the cap. Offset credits also offer an opportunity to spread the incentive for emission reductions to sources not directly covered by the cap-and-trade program. For example, methane from agricultural sources may not be feasibly covered by the cap, yet offset credits awarded to dairy digesters could nonetheless allow the program to encourage reductions from these sources.

In Figure 2.14, Emitter B has more allowances that it needs this compliance period (illustrated by the blue rectangle) due to successful past investments in various GHG mitigation strategies. Emitter B now has an economic opportunity to sell the emissions allowances it does not need in the carbon market or possibly keep them for use in future compliance periods depending on how the program is structured. The buying and selling of emissions allowances during each compliance period occurs either in a state-run auction or directly between market participants like Emitters A through D. These market transactions determine the price of any given emission allowance, or what is often simply referred to as the carbon price. As with any traded commodity, the carbon price fluctuates with market signals and what entities are willing to pay. When regulated entities buy allowances from the state, that revenue can be used for any purposes identified by the policy-makers. Examples may include research and development programs, tax reductions, or grant programs that fund sector-specific mitigation strategies or projects in specific geographic locations or to benefit specific types of populations—for example, tribes, low-income and historically underserved communities, or those on the frontlines of climate change.

Compared to non-market based environmental programs, carbon pricing polices like cap and trade programs have demonstrated that they achieve desired environmental outcomes at an overall lower cost to society [72,73] At the same time, there are a number of important policy design considerations discussed later in this chapter, related to ensuring that costs of a program do not disproportionately harm certain populations and that the benefits of programs are equitably distributed.

Beneficial Electrification

Electrification as an economy-wide decarbonization strategy refers to transitioning end uses that have historically used fossil fuels (e.g., natural gas, propane, heating oil, gasoline) to electricity. End uses could include space heating, water heating, public transportation, personal vehicles, industrial equipment and machinery; electrification examples in individual sectors are also discussed throughout the sectoral decarbonization section below. This approach is about taking advantage of the emissions efficiency—the emissions per unit of energy output—inherent in many electric end uses, enabling consumers to produce less pollution per vehicle mile traveled or gallon of water heated, for example, with technologies that are becoming even more emissions efficient as the electric grid decarbonizes.

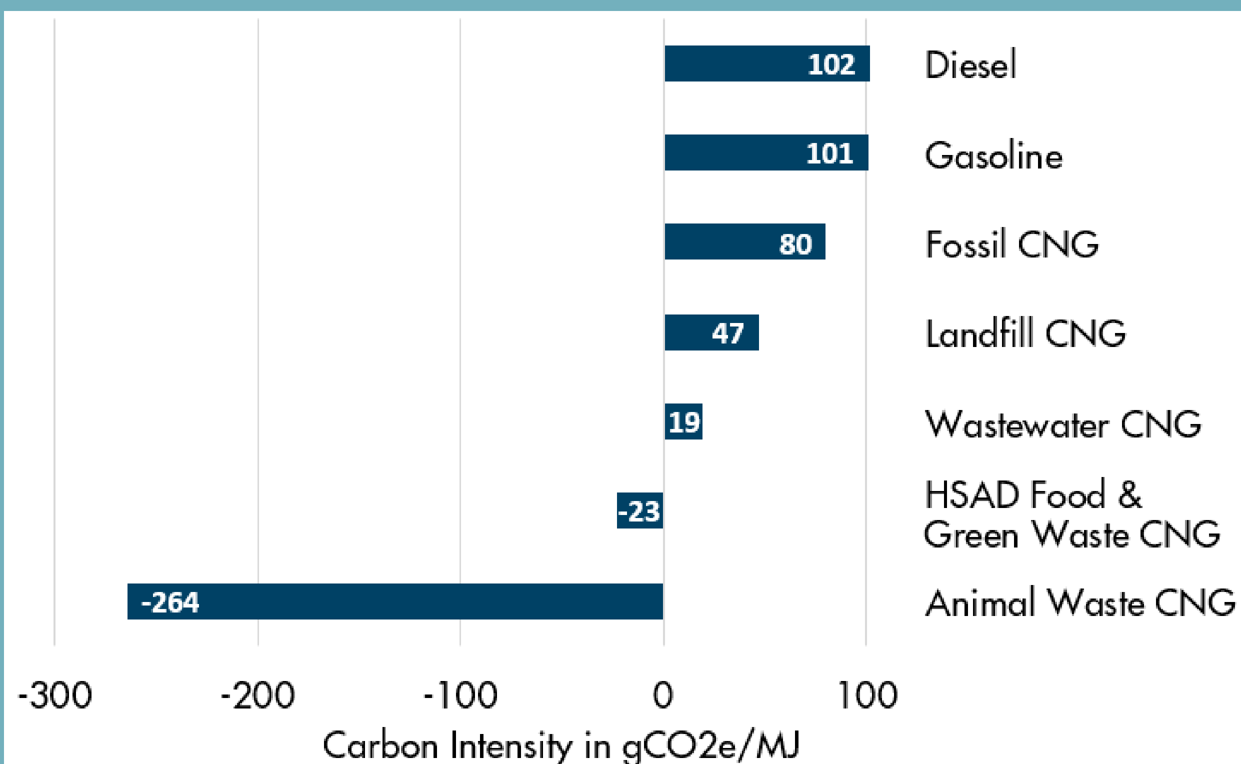
Multiple studies find that policies to promote economy-wide electrification should be designed to achieve multiple benefits, such as reducing greenhouse gas and other air pollutant emissions, enhancing energy security, increasing energy efficiency, saving consumers money, and enabling better grid management—hence the terms “beneficial” or “strategic” electrification are often used.[74,75,76,77] The Regulatory Assistance Project states that, “For electrification to be considered beneficial, it must meet one or more of the following conditions, without adversely affecting the other two: (1) Saves consumers money over the long run; (2) Enables better grid management; and (3) Reduces negative environmental impacts.”[77]

CARBON MARKET OFFSETS

The California Cap-and-Trade Program[78] issues offset credits for projects that meet certain qualifications and follow specific protocols. Currently there are approved project types in the areas of agriculture, forestry, methane capture from mines, and destruction of ozone depleting substances. Offset projects can be promising alternatives to polluters who do not wish to or cannot afford to lower their emissions. In Oregon, several opportunities exist for offset projects in the realm of renewable natural gas (RNG).

RNG can be produced through anaerobic digestion of municipal food waste, animal manures, municipal sewage sludge, and generated naturally from landfills. It can also be produced through thermal gasification of woody wastes, such as commercial timber harvest slash, as well as agricultural residuals such as wheat straw or corn stover. These are called *production pathways*, and they vary in their carbon intensity – the amount of carbon emitted over the entire lifespan of the fuel. Figure 2.15 shows the carbon intensities of different transportation fuels and shows that several RNG-based fuels emit less carbon over their lifetime than traditional transportation fuels such as gasoline and diesel.

Figure 2.15: Carbon Intensity of California Air Resources Board Low Carbon Fuel Standard Program-Approved RNG Pathways[79]



Sectoral Strategies That Support Deep Decarbonization

This overview is drawn from recent publications of climate researchers, government and non-governmental reports, and Oregon state agency climate documents to find areas of alignment on deep decarbonization options for Oregon's largest categories of GHG emitters: the electricity and natural gas inputs into sectoral activities, residential and commercial buildings, transportation, and industrial activities. This compilation is not exhaustive, should not be considered an "action plan," and does not reflect any particular state agency or state government policy priorities; rather, it is meant to summarize relevant findings from published studies on effective paths forward for deep decarbonization in individual sectors. These strategies rely heavily on using today's commercially available technologies and scaling up proven policies within individual sectors, often taking advantage of existing policy mechanisms and tools available to the state. In some instances, newer or near-commercial technologies feature in certain sectoral strategies, so the timing of when these could be feasibly implemented as part of a decarbonization strategy will depend on how quickly they become widely commercially available.

OREGON GLOBAL WARMING COMMISSION

In its 2015 Biennial Report to the Legislature, the Oregon Global Warming Commission analyzed a suite of GHG reduction options (called the "wedge" analysis), drawing on previous economic studies of Oregon-specific marginal abatement costs and macroeconomic modeling of carbon pricing. The Commission first identified sets of cost-effective individual measures for Oregon's largest sectors and then estimated the amount of reasonably achievable GHG emissions reductions. They found that an economy-wide carbon price filled in an important "wedge" of cost-effective emission reductions that could not be achieved with sector-based actions alone. In fact, the Commission's interim emissions reduction goal for 2035 could only be met with both the economy-wide policy and sector-specific actions.

2016 GHG Emissions
ELECTRICITY — 26%
16.17 million metric tons

Electricity

Electricity comprised 26 percent of Oregon's GHG emissions in 2016, down from 30 percent in 2015.[1] See section above on "Beneficial Electrification" for more discussion of the role of decarbonized electricity as an economy-wide decarbonization strategy. As an individual sector, scenarios of deep decarbonization consistently find that the electricity sector needs to quickly transition to nearly entirely GHG-free resources by 2050. Main features of this strategy are described briefly below.

Matching and Exceeding Past Growth in Renewable Energy and Energy Efficiency.

PGE commissioned a deep decarbonization study of its service area to inform its integrated resource planning efforts and statewide carbon policy discussions.[82] PGE's findings are consistent with other research results for Washington State,[82] the U.S.,[62,67] and other countries that identify three key features of a deeply decarbonized energy system:

1. **Electricity supply decarbonization.** Decarbonizing electricity generation is a key component of every study of cost-effective GHG mitigation.[61] Electricity suppliers in the Northwest have a relative advantage over other parts of the United States given the large amount of existing hydropower in the region. In both the PGE and Washington state decarbonization studies, by 2050 most new generation comes from renewables like wind and solar and about 90 percent or more of the overall electricity generation mix is GHG emissions-free, primarily from onshore wind, solar, hydro and geothermal resources. PGE's gas-fired resource fleet shifts from being a baseload energy resource to mostly a capacity and balancing resource.[82]

   Electricity supply decarbonization will also require new capabilities to efficiently integrate variable renewable resources into the electric grid. In both the PGE and Washington state studies, new sources of flexibility like energy storage solutions and flexible loads become widespread and complement traditional sources of flexibility, such as hydro and thermal resources. See related strategies below in *Natural Gas, Buildings*, and *Transportation*, as well as Chapter 3.

2. **Improved energy efficiency across sectors**. Energy efficiency is the first "go-to" resource today when evaluating resource need, and this remains true under deep decarbonization scenarios: "Energy efficiency is widely considered the first option to pursue in a low carbon portfolio…"[62] Most clean energy end-use technologies are designed to have low or zero GHG emissions and to maximize energy efficiency as much as possible, which means providing more desired services per unit of energy consumed. For example, electric vehicles are significantly more efficient that conventional internal combustion engine vehicles, consuming up to four times less energy per mile than conventional vehicles (see Chapter 4 for more information on EVs). As these technologies are adopted throughout the economy, multiple decarbonization studies forecast reductions in both primary and final energy consumption even as population and GDP grows. In PGE's study, overall energy demand in their service territory decreases 25 to 33 percent compared to a baseline case by 2050[83], which is on par with U.S.-wide studies that estimate an approximately 20 to 30 percent decrease compared to a baseline scenario by 2050.[62,67] These reductions are driven by efficiency gains across sectors, particularly in the transportation sector due to the deployment of EVs, and do not depend on reducing energy service demand such as for driving, home heating and cooling, etc. See related strategies below in *Buildings* and *Industrial*.

3. **Increased electrification as a share of total energy consumption**. As described above, U.S. decarbonization studies project reduced overall energy consumption in 2050 resulting from efficiency gains across sectors, particularly transportation. The third key feature of a deeply decarbonized energy system is through the total energy demand pie is expected to be smaller, electricity's share of the pie is expected to be larger given that most deep decarbonization scenarios call for significant and rapid deployment of clean technologies that run on electricity. So consumption of decarbonized electricity increases although total energy consumption decreases. PGE's study found that in order to support decarbonization strategies across the Oregon economy, particularly the transportation sector, it would need to access more zero-carbon electricity resources (either through additional generation that it owns and operates, or through contracts or market purchases) than ever before.[83] In the U.S., electricity generation is projected to increase 60 to 113 percent between 2005 and 2050 due to increased electricity usage in transportation, buildings, and industry[67] (see related strategies later in this chapter).

PGE'S PATH TO DECARBONIZATION

Oregon has an aggressive goal to reduce greenhouse gas emissions in our state by 2050. Local communities are taking action too: Multnomah County and the City of Portland have pledged to make the switch to 100 percent renewable electricity by 2035, and 100 percent renewable energy by 2050.

Portland General Electric emitted 6.4 million metric tons of carbon dioxide equivalent in 2016[84], and has committed to reducing its GHG emissions by more than 80 percent by 2050, consistent with its proportionate share of the state's economy-wide GHG reduction goal. To understand the complexities of reaching this goal and assisting the state and communities to reach their own GHG reduction and clean energy goals, PGE commissioned a deep decarbonization study of its service area.[83] The study identifies three pathways to reaching an 80 percent economy-wide reduction goal in its service territory. To reach the 80 percent economy-wide GHG reduction goal, the study found all energy services in PGE's service area would need to reduce carbon dioxide emissions to 4.3 MMT by 2050.

PGE's study and analysis found that deep decarbonization of the energy economy is possible, with multiple pathways to achieve it. Each pathway has three common elements or pillars that are essential to achieving decarbonization goals:

1. **Continuation/Increase in Deploying Energy Efficiency**
2. **Generating Electricity with Very Low to Zero Carbon Emissions**
3. **Substituting Fossil Fuel Use with Electricity**

Changing the energy system to achieve deep decarbonization will be challenging, and will require major changes to how all forms of energy are produced and supplied. While 2050 is over 30 years away, planning must start today. Key to successful economy-wide decarbonization will be investing in technologies that enable a balance of electricity supply and demand, developing more flexible energy resources, such as storage and demand response programs, and making a pronounced shift in the transportation sector to low- and no-emission vehicles.

As the system adjusts to take a path to deep decarbonization, it must also meet changing needs in Oregon, including a growing population, electrification of vehicles, and other home and business devices that are likely to increase electricity demand.

"PGE is committed to helping Oregon achieve a clean energy future by reducing our greenhouse gas emissions by more than 80 percent by 2050. By using clean, affordable, reliable and safe electricity to power our lives – especially in the transportation sector – we can help reduce the threat of climate change, improve air and water quality, and create a more sustainable way of life for all Oregonians."

— Maria Pope
PGE President & CEO

2016 GHG Emissions
NATURAL GAS — 12%
7.32 million metric tons

Natural Gas

Direct use of natural gas (i.e., not for electricity generation) was 12 percent of Oregon's GHG emissions in both 2015 and 2016.[1] Although it is a less GHG emissions-intensive fuel than coal, natural gas is primarily comprised of the greenhouse gas methane, which is a stronger climate warming agent pound-for-pound than carbon dioxide and is a precursor to ozone that itself is a GHG. But methane does not last as long in the atmosphere as CO2 (about a decade vs. about a century) and is not emitted in as large a quantity as CO2. Burning methane/natural gas for uses such as heating or cooking releases carbon dioxide, whereas methane can be directly released into the atmosphere through leaks or venting in natural gas production and distribution systems. Despite this, a number of studies find roles for "decarbonized" natural gas (defined below) in future scenarios of deep decarbonization.[62,81,85]

Decarbonizing Pipeline Gas While Also Reducing Waste in Other Sectors

A study of scenarios for California found that using the state's existing natural gas distribution network to deliver decarbonized gas could complement a low-carbon electrification strategy and still allow California to achieve its 2050 GHG reduction goal.[85] Deep decarbonization scenarios also rely on significant levels of energy efficiency to reduce GHG emissions in the sectors where natural gas is used[85]; see related strategies below in the *Buildings* and *Industrial* sections. Decarbonized gas can also be looked to in cases where it may be difficult to fully transition to electricity, either for technical, cost, or customer acceptance reasons. These include: "(1) certain industrial end uses, such as process heating, (2) heavy duty vehicles, and (3) certain residential and commercial end uses, such as cooking, and existing space and water heating."[85]

Decarbonized natural gas refers to natural gas produced through alternative processes — such as those described below — to reduce or offset its climate effects compared to traditional fossil natural gas:

1. **Renewable natural gas.** RNG as a decarbonization strategy replaces some percentage of the methane in the pipeline that comes from fossil sources with methane from biogenic (resulting from living organisms or biological processes) sources. There are two main processes to create RNG:

    - **Anaerobic digestion:** Digesters allow for "waste-to-energy" projects that have multiple benefits of creating an economically useful product while also reducing waste and emissions. This technology is being used currently in Oregon: NW Natural is partnering with the City of Portland to produce RNG from the city's Columbia Boulevard Wastewater Treatment Plant for pipeline injection as well as a natural gas vehicle fueling station[87], and Eugene-Springfield's Metropolitan Wastewater Management Commission is developing an RNG pipeline injection project. There are a wide variety of other RNG sources, including landfills, dairies, and programs that divert food waste.

    - **Thermal gasification of biomass:** This thermochemical process converts biomass fuels into synthesis gas, or syngas, which is made up primarily of carbon monoxide and hydrogen. Syngas can be converted to methane with additional processing. Woody biomass or corn stover are typical feedstocks, but recently the use of municipal solid waste has been proposed. Several thermal gasification technologies are available, with variations using different temperatures and feedstock heating approaches. High temperature approaches produce syngas while medium temperature approaches make "producer" gas, which has a slightly different chemical make-up but can also be converted to methane with additional processing.[88] There are currently no commercial-scale thermal gasification plants in the United States that take the conversion process from biomass all the way to methane. The existing plants produce syngas, which is burned and used to generate heat and electricity. There are significant research efforts underway to bring down the cost of the conversion of syngas to methane.

2. **Power-to-gas (P2G).** This technology uses electrolysis to convert electricity to hydrogen gas, which can then be converted to methane (termed synthetic natural gas), directly injected as hydrogen into the existing natural gas grid, or directly used as a transportation fuel in hydrogen fuel cell vehicles. P2G can be a decarbonization strategy if the electricity it uses as a "feedstock" comes from excess renewable electricity generated by wind, PV, hydropower, or other zero-carbon sources.[85] This technology is being piloted at several locations in Europe and the United States, but not yet in Oregon. Studies have identified beneficial roles for P2G technology in providing a balancing resource for the integration of variable renewable electricity generation, helping to address issues related to renewable curtailment by producing synthetic natural gas or hydrogen when renewable electricity supply exceeds net demand.[62,81] Additionally, P2G could provide a valuable source of low or carbon-free inter-seasonal storage, allowing excess renewable energy in the spring and summer to be used during peak demand in the cold winter months when less renewable output is available.[86]

In July 2017, the Oregon Legislature passed Senate Bill 334,[143] which directed ODOE to conduct a statewide survey of resources that could be used to develop and utilize biogas and RNG. This inventory quantifies the opportunity to take persistent, long-term waste streams and convert these waste streams into useful energy. Municipal waste streams like household refuse, wastewater, waste food, and agricultural waste streams like manure all generate methane as they break down in the environment. Redirecting these waste streams into controlled processes for optimization, capture, and utilization of the methane can be economically, socially, and environmentally beneficial to Oregon. Redirecting this fuel source into the transportation fuels sector, and eventually into the stationary fuels sector, can result in increased economic opportunity, energy security, and resilience for both rural and urban communities in Oregon. The results of the inventory indicate that there is potential for a substantial amount of RNG to be produced in Oregon from a variety of biogas production pathways. The gross potential for RNG production when using anaerobic digestion technology is around 10 billion cubic feet of methane per year. This is about 4 percent of Oregon's total yearly use, which includes gas used for electricity production, or 7.5 percent if comparing only to direct use of natural gas where RNG is expected to be used. At a future point, once technical obstacles are overcome, thermal gasification technology could produce up to 40 billion cubic feet per year — about 17 percent of the state's total annual natural gas use or 29 percent of annual direct use. The full report is available on ODOE's website.[89]

The Oregon Global Warming Commission's "wedge" analysis in its 2015 Biennial Report to the Legislature also examined biogenic waste streams.[19] Their report identified the following as some of the most cost-effective strategies for addressing these sources of GHG emissions:

- **Development of dairy anaerobic digestion and methane utilization projects.**
- **Increasing co-digestion of dairy manure and food processing waste, which provides a carbon neutral energy source for producing electricity or thermal energy.**
- **Increasing biogas energy production from municipal solid waste and at wastewater treatment plants.**
- **Installing landfill gas collection and destruction systems at landfills where they do not already exist.**
- **Preventing edible food waste to reduce the amount of biogenic waste entering landfills.**

2016 GHG Emissions
RESIDENTIAL/COMMERCIAL
7%
4.18 million metric tons

Buildings

The residential and commercial sectors, when including electricity and natural gas use, comprise 34 and 32 percent of Oregon's GHG emissions in 2015 and 2016, respectively.[1] When electricity and natural gas use are accounted for separately, residential and commercial GHG emissions drop to 7 percent and stem primarily from petroleum combustion (e.g., fuel oil for heating) and emissions from waste and wastewater originating from these sectors. This indicates a substantial potential for residential and commercial buildings and systems to reduce energy use and switch to low-carbon energy sources in order to reduce GHG emissions; some of the main approaches are summarized below.

Benchmarking and Transparency: Understanding and Communicating Building Performance

A cornerstone of reducing GHG emissions in this sector is understanding, measuring, and communicating information on building performance. While energy management has been voluntarily undertaken for decades, there has been a recent and significant rise in government laws and programs to drive standardized and centralized reporting. Mandatory benchmarking and reporting programs are available in over two dozen cities and several states.[90] For example, the City of Portland has mandatory commercial and residential reporting programs, completed on an annual basis or at time-of-listing, respectively. Once measured, building and home owners can compare their energy performance – with low-performing buildings being identified as likely having the highest potential for improvement.

These reporting programs have also quickly become the most available and reliable data source to understand energy use and the associated emissions of these buildings. The City of Portland found that the lowest-performing buildings use two to four times as much energy per square foot as the most efficient buildings.[91]

Retrofit Existing Buildings at Key Trigger Points

To reach major emission reductions in the residential and commercial sectors, the existing building stock needs to be addressed. The most well-established and cost-effective strategy for reducing emissions from buildings continues to come from improving the energy efficiency of buildings. In general, the most effective retrofitting that also reduces GHG emissions strikes a balance between fixing the building's envelope and upgrading systems and equipment within buildings to maximize energy efficiency and use of low carbon fuels.[92]

These improvements are commonly triggered when equipment reaches its end-of-life, the building is remodeled, or when provided incentives. Some jurisdictions are also implementing mandatory retrofits supported by energy performance reporting. For example, New York City requires that buildings over 25,000 square feet conduct periodic audits and retro-commissioning and report to the city every 10 years. The City of Boulder requires that after reporting, the building owner must conduct retro-commissioning and implement measures that have a financial payback of two years or less. These programs can accelerate the standard improvement cycle that occurs in the building stock, while avoiding long-term "lock in" of equipment that is low efficiency and reliant on fossil fuels. They can also allow for GHG emissions reduction to be used as a decision-making criterion rather than solely energy savings, which may allow electricity-based equipment and systems to more easily compete with minimum efficiency fossil-fuel versions.

Integrating Net-Zero Design and Performance into New Buildings

Newly built structures can incorporate design and performance requirements so their overall energy footprint is low-to-no CO2 emissions. The "net-zero or zero-energy" building or home is a highly-efficient structure that is fully powered or offset by carbon-neutral energy sources. While there are an increasing number of projects tackling net-zero retrofits to existing buildings, the most cost-effective and holistic approach is to incorporate these elements into the design and construction of new buildings and major remodels. Critical components to this process include: energy modeling towards performance requirements, use of high-efficiency equipment and low-energy use design, integrated and whole-building planning, and performance verification and ongoing monitoring. For both retrofits and new construction, using building materials that are less carbon intensive where possible, such as wood instead of concrete and steel, may also have benefits for the climate, though these would not be traditionally quantified under most GHG accounting protocols.[93,94]

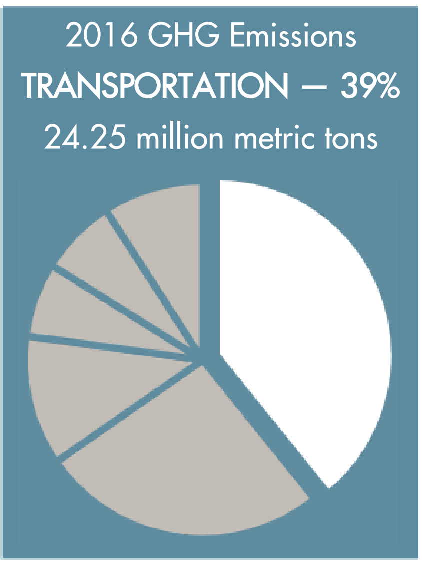
Fueling Buildings with Low Carbon Electricity While Also Providing Decarbonized Gas

Most deep decarbonization scenarios project that most or a significant portion of appliances and equipment used in residential and commercial settings will be fueled by low carbon electricity.[62,82] But studies also acknowledge that full electrification of these end uses will be challenging for reasons such as cost or customer acceptance.[62,81,85] As discussed above, RNG can help reduce emissions of remaining natural gas end uses (see *Electricity* and *Natural Gas* strategies).

Increasing Efficiency Throughout the Refrigeration Lifecycle

Fluorinated GHGs are in products used in all types of buildings, including commercial refrigeration, cold storage warehouses, air conditioning, heat pumps, foams, and aerosols. Hydrofluorocarbons are of particular concern because they are the fastest growing source of GHG emissions in the U.S. and their effect on the climate is hundreds to thousands of times greater than CO2.[16] For example, just one pound of R-404A, an HFC refrigerant used in supermarkets, is comparable to two tons of CO2 in terms of its effect on the climate.

Some estimates indicate that nationwide, GHG emissions from refrigeration and air conditioning can be reduced by 77 percent below baseline levels by 2030, and that over half of those reductions can be had at negative cost.[95] Reductions can be achieved through: (1) switching to alternatives that have a much lower climate effect than HFCs, while also not harming the Earth's ozone layer, and (2) through proper handling, servicing, and recycling or safe disposal of refrigerants at the product's end-of-life.[95] There are a number of natural refrigerant alternatives to HFCs that are commercially available or expected to be available soon, including CO2, ammonia, hydrocarbons, and hydrofluoroolefins (HFOs). Climate and ozone-friendly natural refrigerants have been found to have better thermodynamic properties compared to standard synthetic refrigerants, which means that their use can also increase energy efficiency in some applications.[96]



Transportation

Oregon's transportation sector is the state's largest single source of GHG emissions, at 36 percent of the statewide total in 2015 and 39 percent in 2016.[1] Estimates from 2015 indicate that 47 percent of emissions are generated from light-duty vehicles, while approximately 23 percent are from heavy-duty vehicles.[1] In its Statewide Transportation Strategy, ODOT identified strategies related to vehicles and fuels as the most direct and high-impact options for switching to low-carbon transportation energy sources and reducing the sector's GHG emissions.[97] This is consistent with recent research that identifies sets of related strategies to support deep decarbonization for the transportation sector, which are summarized below.

Integrated Approaches for Passenger Transportation

Climate studies for passenger transportation emphasize an integrated, multi-modal climate change mitigation strategy given its cost effectiveness and ability to generate co-benefits such as human health, air quality, and traffic congestion improvements. For more detail about policies and strategies, see Chapter 4.

- **Accelerating build out of electric vehicle charging infrastructure:** Studies consistently identify developing a widespread and robust electric vehicle (EV) charging network, both public and privately-owned, as key for increased EV adoption. This will require collaboration with private sector developers on moving towards an industry standard for all classes of vehicles, as well as for development of fast chargers.
- **Expanding access to light-duty electric cars and trucks as they come to market:** Existing market barriers to more widespread adoption of EVs can be addressed through converting a greater share of fleets to EVs, providing other opportunities to enhance consumers' familiarity with driving EVs, and consumer and dealer education.
- **Electrifying public transit**: A number of cities around the country are shifting away from diesel-powered to electric public transit to save money, improve health, and cut air pollutant and GHG

emissions. Nashville and Park City, Utah are some of the first cities to have integrated electric buses into their routes, and the mayors of 12 major cities, including Los Angeles, Seattle, London, Paris and Mexico City, have committed to purchasing only zero-emissions buses by 2025.[98] TriMet in Portland has committed to replacing its diesel bus fleet by 2040. Its 2018 Non-Diesel Bus Plan evaluated different non-diesel bus technologies (battery electric, renewable natural gas, and hydrogen fuel cells), and the agency is moving forward with testing five electric buses on what will be Oregon's first all-electric bus route in Beaverton.[99] TriMet is partnering with PGE to install and manage six bus charging stations.[100]

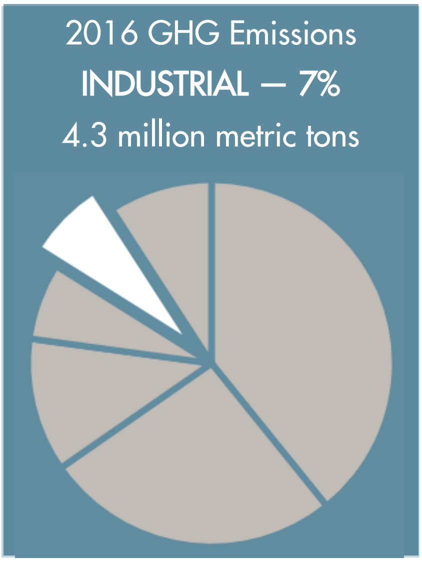
- **Continued focus on multi-modal alternatives**: The most effective programs include a combination of qualitative improvements to alternative modes (walking, cycling, and public transit including bus and light rail) and integrated transport and land-use planning, which creates more compact, mixed, and better connected communities with reduced need to travel.[101] These are key strategies that some of the MPOs in Oregon are evaluating and pursuing in their regional transportation plans (discussed earlier in this chapter in the section *Metropolitan Planning Organizations*).

Decarbonized Natural Gas for Medium- or Heavy-duty Fleets

Decarbonization strategies for medium- and heavy-duty vehicles are still evolving. The U.S. Mid-Century Strategy[67] concluded that there are substantial opportunities for additional research and innovation in this area. This includes, among other examples, hydrogen powered trucks and buses, fuel cells in medium- and heavy-duty transport applications (delivery vans, short-haul freight trucks, etc.), and improved freight logistics and modal shifting of freight from long-haul trucks to rail and barge.

Medium– or heavy-duty trucks, like this Waste Management fleet truck, can run on CNG.

As noted in ODOE's biogas and renewable natural gas inventory[89], there is substantial opportunity to develop RNG supplies for use as a transportation fuel. This may be particularly true for many medium- and heavy-duty trucks that already run on compressed natural gas or liquefied natural gas. There are examples of these types of projects throughout the country either in the planning phase or in operation. In Oregon, the Dry Creek Landfill in Medford is installing technology to RNG from landfill gas and are converting their garbage hauling fleet to CNG/RNG. They partnered with ODOE and Avista Natural Gas and built a publicly-accessible CNG fueling station. In California, CR&R Environmental Services in Perris, California converts food waste to biogas in a state of the art digester, cleans the biogas to produce RNG, and then both fuels its garbage trucks and sells that RNG into the transportation market.[102] A similar project is being planned in Philadelphia, PA.[103]



Industrial

The industrial sector accounts for about 20 percent of Oregon's total GHG emissions, primarily from direct use of electricity and natural gas.[1] When electricity and natural gas use are accounted for separately, this drops to 7 percent of the state's emissions and is comprised primarily of emissions from petroleum combustion, industrial waste and wastewater, and industrial process manufacturing (e.g., production of cement, paper products, ammonia, urea, etc.). This indicates that key decarbonization strategies for the industrial sector include increasing efficiencies to reduce overall energy use and switching to low-carbon energy sources where possible.

Increasing Energy Efficiency

Oregon has engaged with large industrial utility customers for many years to increase energy efficiency. ODOE administers the Large Electric Consumer Public Purpose Program where large electric consumers (over one average megawatt or 8,760,000 kilowatt hours per year) may be eligible to self-direct a portion of their public purpose charges and implement qualifying energy efficiency or renewable energy projects. The biennial reports to the Oregon Legislature on Public Purpose Expenditures provide insight into the types of industrial efficiency projects large customers have pursued and estimates of their energy savings.[71] From 2015 to 2016, self-directed efficiency projects included implementing energy management systems, industrial process modifications, lighting modifications, and installing energy efficient pumps. These projects collectively achieve about 3 MWh of energy savings annually. Other climate mitigation studies identify various operational (e.g., waste heat utilization) and maintenance measures (e.g., reducing air or steam leaks) that can have benefits for GHG mitigation.

Fueling Equipment with Low Carbon Electricity While Also Providing Decarbonized Gas

The U.S. Mid-Century Strategy[57] and the U.S. Deep Decarbonization Pathways report[62] find that by 2050, a significantly larger portion of industrial energy demand is met with low carbon electricity compared to today. In many cases, small-scale industrial equipment such as forklifts, pallet jack, or scissor lifts fueled by fossil fuels like diesel, gasoline, or propane now have battery electric versions available. According to the National Renewable Energy Laboratory, electric technologies exist for certain low-temperature energy needs, such as curing and drying, and could lead to increased electrification in the industrial sector.[80] Where electrification of industrial processes is challenging for physical or economic reasons (e.g., some high-heat applications), the use of decarbonized pipeline gas can reduce GHG emissions intensity in this sector.

Electric battery forklift.
Photo: Toyota Material Handling

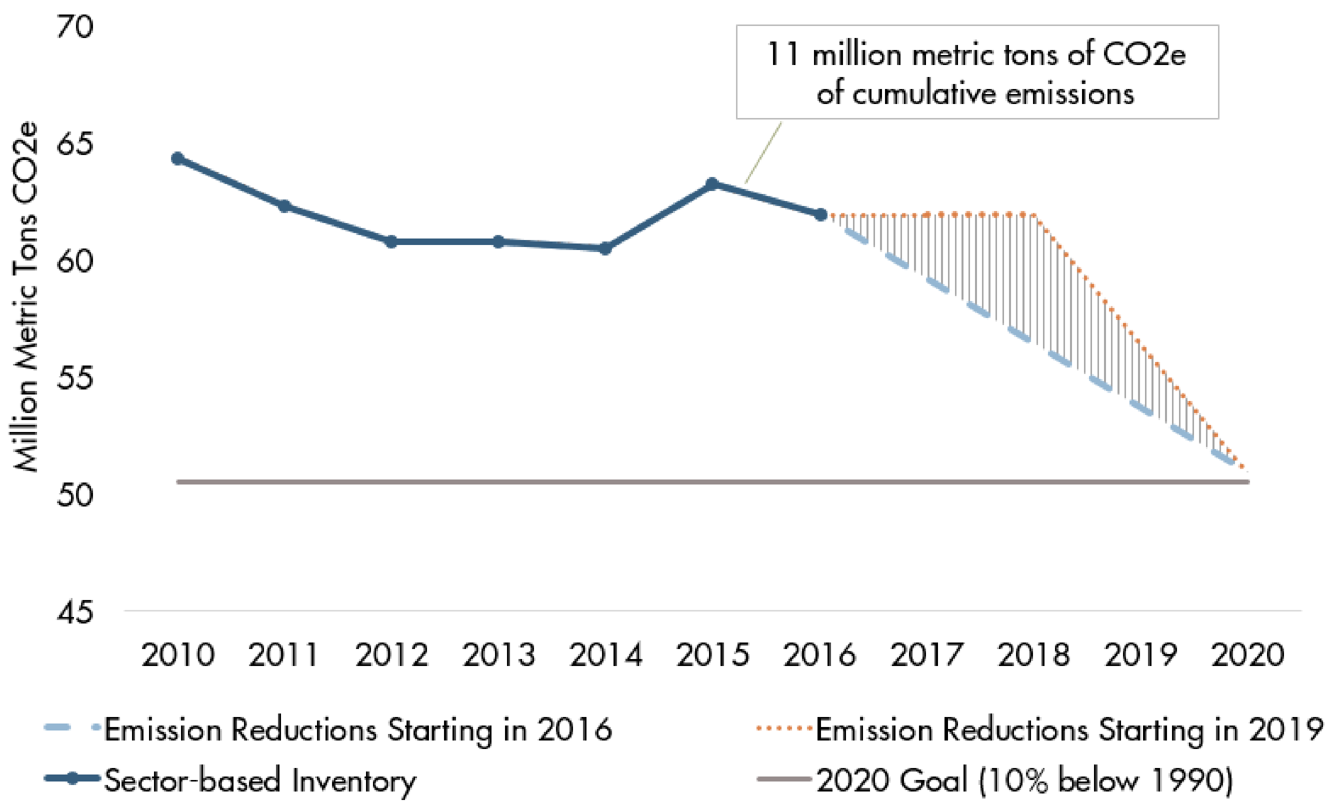
Deep Decarbonization Considerations and Potential Tradeoffs

As with any large-scale transformation, transitioning Oregon's energy systems to achieve the state's climate mitigation goals will create challenges and tradeoffs that are important factors influencing policy design. Key considerations include timing of when action begins, costs and benefits, social and intergenerational equity, and potential policy interactions and tradeoffs.

Timing of Action

The IPCC concluded that "delaying mitigation efforts beyond those in place today through 2030 is estimated to substantially increase the difficulty of the transition to low longer-term emissions levels and narrow the range of options consistent with maintaining temperature change below 2°C relative to pre-industrial levels (high confidence)."[61] This means that the longer we take to address climate change, the harder it will be to make the transition. For example, Figure 2.16 shows two hypothetical pathways from 2010 to 2020, the year when Oregon set a goal to reduce its emissions 10 percent below 1990 levels. A steady, smooth progression illustrated by the blue dashed line down to the target level from the most recent year of emissions data, 2016, to the year 2020 requires an annual reduction of approximately 3 million $MTCO_2e$.[1] If emissions reductions are delayed until 2019, Oregon would have a much steeper pathway illustrated by the orange dotted line, and would need to annually reduce emissions by 5 million $MTCO_2e$ in 2019 and again in 2020 to achieve the same goal.

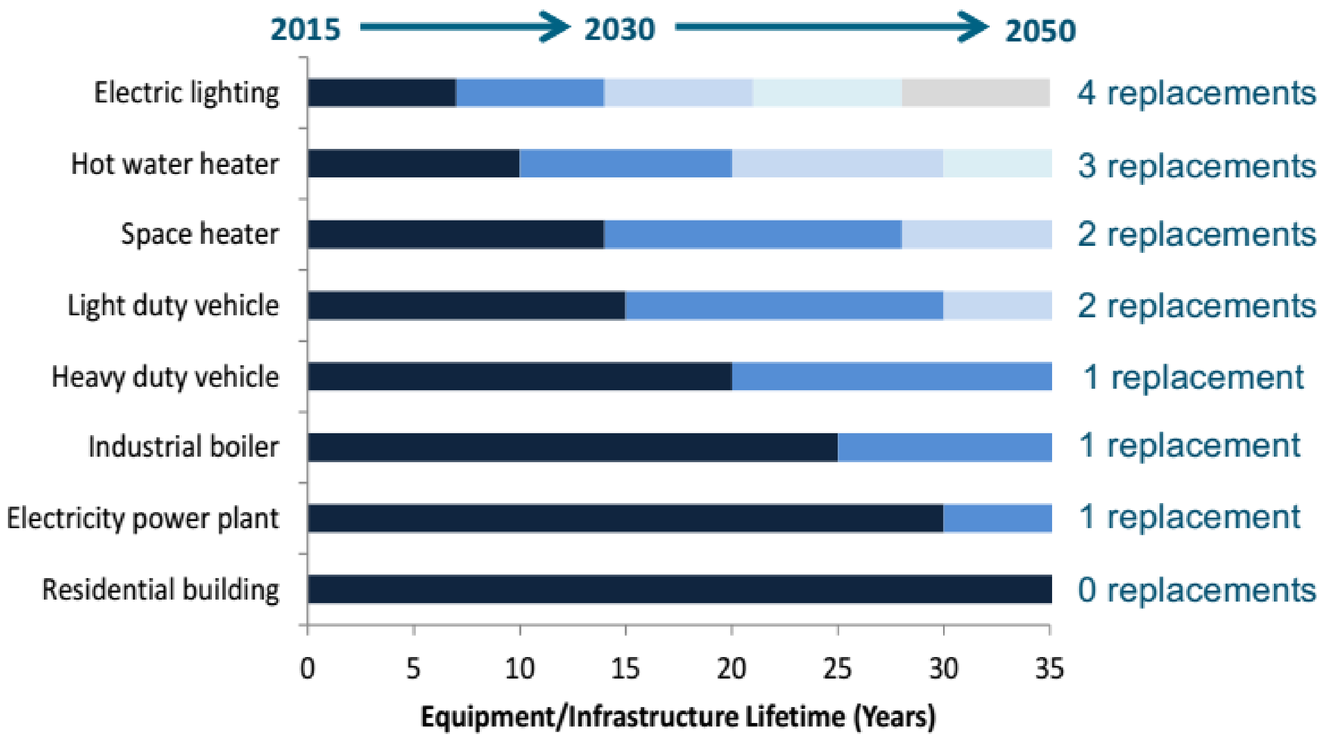
Figure 2.16: Hypothetical emission reduction trajectories for scenarios beginning from the most recent year of GHG emissions data, 2016[1]



So "bending the curve" on emissions sooner means fewer reductions will be needed annually, while waiting to begin would mean that steeper reductions are required each year in order to reach the state's reduction target. Importantly, delaying action for 3 years also results in an additional 11 million $MTCO_2e$ being released into the atmosphere, increasing the cumulative environmental impact of the state's emissions.

Another important aspect for climate mitigation policy design is optimizing timing for replacing high-carbon equipment and infrastructure with low-carbon alternatives. Figure 2.17 shows best estimates of natural stock turnover cycles of various types of goods or infrastructure, comparing the number of replacement opportunities in the timespan leading up to when 2050 climate goals should be met. For example, by 2050, electric lighting is expected to need four replacements, while an industrial boiler needs one. This underscores the need and importance of advance planning, particularly for long-lived infrastructure like power plants and buildings, to pave the way for selection of low-carbon alternatives when that natural replacement window of opportunity opens. The U.S. Deep Decarbonization report[62] concluded that 2050 climate goals could still be met by relying on natural stock turnover. This would largely avoid stranded assets or other lost economic value related to "early retirement" (compared to assumed life at the original time of investment) of equipment or infrastructure.

Figure 2.17: Equipment and Infrastructure Stock Turnover Cycles[63]



Costs and Benefits

Closely related to issues of timing are issues of costs and benefits. There is broad consensus that delayed action makes climate mitigation more expensive.[61,63] This is because larger GHG emissions reductions would be required over a shorter, more compressed timeframe, which limits the available range of mitigation options (i.e., less flexibility to choose cost-effective options), affects the optimal timing of replacements and other measures, and may create carbon intensive "lock-in" if long-lived equipment or infrastructure is purchased or built during the period of delay. Lock-in can make meeting long-term climate goals substantially more expensive to achieve.[104]

Delayed climate action at the global scale also delays the time it will take to stabilize atmospheric concentrations of GHGs and in effect, stabilize Earth's climate. This increases the risks associated with climate change itself that were discussed above, which have very significant economic implications for Oregon. Quantifying the costs of climate impacts and the economic benefits of avoiding those impacts is still an evolving area of research. Some of the studies breaking ground in this area have used a variety of economic valuation methodologies at the global level[105] and for the United States.[106,107] But most analyses of climate mitigation policies rely on traditional cost-benefit methodologies that only account for economic costs of implementing the policy.

Another valuation approach has been to use the social cost of carbon, which according to the U.S. National Academies of Science, Engineering, and Medicine[108] is a measure of global economic damages associated with releasing one ton of CO2 into atmosphere, expressed as a dollar per ton metric. Social cost of carbon can be easily used to compare two different investment decisions, one with relatively higher and one with lower GHG emissions—applying a social cost of carbon value will make the higher-emitting option more expensive relative to the lower emitting option to reflect the damage it is causing to the environment and human health. A social cost of carbon value can also be used in traditional cost-benefit analyses for regulatory policies—first by quantifying the GHG emissions reductions achieved by the policy and then multiplying that by social cost of carbon values to estimate a dollar value for climate benefits of the policy (see below for more discussion of policy co-benefits in addition to climate benefits).

In addition to approaches for estimating more macro-level costs, there are methodologies for estimating costs of individual emissions reductions measures, also called abatement options. This tool, Marginal Abatement Cost Curves or MACCs, creates estimates of the cost of reducing one more unit of pollution (dollars per ton of CO2 reduced) and the size of potential emissions reductions from a suite of abatement options. Some advantages of MACCs are that they provide an easy-to-digest visual comparison of the relative cost of certain measures, and can incorporate regional, state, and local data to further refine estimates to be specific to a certain geographic area. MACCs are perhaps most useful as directional indicators of potential cost, while their specific dollar values and relative rankings of abatement options should be considered provisional.[109] For example, an Oregon MACC was developed in 2012 that showed that certain types of measures could be implemented for net negative cost (paybacks would be greater than costs)[110], which is a useful starting point for further investigation.

Some critiques of MACCs are that their results are one-dimensional or overly simplistic because they do not account for costs other than direct technology costs (i.e., they do not estimate indirect or transaction costs that would accrue during actual implementation of a measure), and they have difficulty capturing interactions between different measures that would affect cost-effectiveness in reality.[109] In addition, it can be difficult to find accurate or timely data on which to base MACC calculations, especially as the methodology is not easily updatable and cannot easily keep up with the rapid advances in and falling costs of clean energy technology.[111]

Based on its review of hundreds of climate mitigation studies, in 2014 the IPCC[61] drew a number of general observations regarding individual cost-effective mitigation strategies:

- **Well-designed systemic and cross-sectoral mitigation strategies are more cost-effective in cutting emissions than a focus on individual technologies and sectors.**
- **Given substantial recent performance improvements and cost reductions, a growing number of renewable energy technologies have achieved a level of maturity to enable deployment at significant scale.**
- **Building codes and appliance standards, if well designed and implemented, have been among the most environmentally and cost-effective instruments for emission reductions.**

Equity and Justice Perspectives on Climate Change

As researchers, analysts, and policymakers make progress in understanding and quantifying the costs and benefits of climate change and the policies enacted to address it, it becomes equally important to understand how those costs and benefits are distributed across society. Equity and justice, which are concepts explored more in Chapter 2.5, are often considered in two main ways in the context of climate change.

First, an intergenerational equity viewpoint stems from the premise that there are moral duties owed by present to future people, that it is our obligation to avoid triggering dangerous levels of climate change that will impose both near- and long-term harms on future generations that bear no responsibility for creating the problem.[112] From an intergenerational justice perspective, inaction on climate change is not a viable option; global climate action is necessary to reduce the harms future people will face and pass on an environment that supports healthy lives and livelihoods.

Second, a social and environmental equity viewpoint recognizes that certain populations bear a larger, disproportionate share of harmful effects from climate change, are less able to prepare for and respond to climate threats, and that this is occurring within a legacy of social, political, and economic inequalities and a lack of recognition and power to participate in decision-making and shape policy outcomes. Although more research is needed to fully understand how different parts of Oregon's population are experiencing climate change, in general, vulnerable populations include those that have low incomes, are in poverty, or are otherwise economically vulnerable; some communities of color; or those who are already affected by inequitable exposure to pollution and environmental health risks.[67,113]

From a social and environmental justice perspective, climate policies and actions should be designed to avoid potential adverse side effects or unintended consequences so as not add to the current economic, health, and environmental burdens of vulnerable populations. Policymakers should instead proactively and meaningfully involve affected populations in decision-making to ensure that the benefits of climate policies and programs flow to communities that need it the most. Local community organizing groups in Oregon like APANO and OPAL Environmental Justice, as well as national civil rights organizations like the NAACP, among others, have included climate change as a priority focus area for their social and environmental justice work.[114,115,116,117,118]

The following section examines some of the key potential challenges and co-benefits of climate policy, identifying those that may be particularly relevant to considerations of social and environmental justice in Oregon.

Policy Interactions and Potential Tradeoffs

Climate policy intersects with other societal goals, such as those related to human health, food security, environmental quality, energy access, livelihoods and jobs, and sustainable economic development.[61] Depending on their design, polices in these areas can be mutually reinforcing or can hinder the achievement of each other's objectives. There can also be opportunities for co-benefits if these interactions are well-managed, or adverse side effects and unintended consequences if they are not. A number of commonly cited examples of these issues with relevance to Oregon are described below.

Land Use and Natural and Working Lands

Like with any new energy infrastructure, the development of new renewable energy facilities to meet Oregon's climate goals have the potential for conflicts with other values Oregonians hold related to natural and working landscapes, wildlife conservation, and natural and cultural resources. Such conflicts could occur if, for example, areas in which large-scale renewable energy facilities are constructed and operated provide habitat to endangered species and other wildlife, are on high-value agricultural land, or have cultural resources or support traditional lifeways of Oregon's Native American tribes.[119] Similar considerations would apply if additional renewable generation requires additional transmission infrastructure to be built in Oregon or in the region. Strategic renewable energy siting principles have been proposed in the literature to reduce or avoid such tradeoffs, including land use policies and electricity planning processes that focus on development in already-impacted places and emphasizes ecosystem service values (e.g., biodiversity, carbon sequestration, groundwater protection) and other environmental concerns within traditional business case evaluations of local transmission capacity, etc.[120,121] The siting of renewable energy facilities is discussed in Chapter 3.

Some renewable energy technologies can be deployed to meet both climate mitigation and adaptation needs on natural and working lands, while also providing local economic benefits. Examples include:

- Biomass sources eligible for the Renewable Portfolio Standard (see Chapter 3 for more details) could work in tandem with forest restoration/fuel load reduction projects that are intended to reduce wildfire risk that is increasing in the Western U.S. due to climate change.
- Irrigation in-pipe hydropower energy recovery systems generate power from pressurized irrigation water. Conversion to piped irrigation systems improves water use efficiency by eliminating evaporation and seepage and allows agricultural enterprises to better manage the effects of drought that are projected to increase in Oregon due to climate change.

IRRIGATION: WATER MEETS ENERGY

Forty-two percent of Oregon's agricultural land is irrigated, which multiplies its productivity.[123] However, pumping water for irrigation is energy intensive. Updating and improving irrigation systems results in less water wasted and lower energy cost for farmers, while also providing other important benefits.

Several irrigation districts in Oregon are currently working on irrigation modernization.[124] Projects typically involve a variety of energy and conservation organizations, and use federal, state and nonprofit funds.

Modernizing Action	Examples
Install more efficient irrigation equipment. Reduces water use and farmers' energy costs, as well as increases water in-stream.	Switching to variable frequency drives for irrigation pumps saves energy, while replacing leaking nozzles saves water and energy.
Pipe irrigation canals, providing pressurized water. Eliminates the need for pumping energy, and potentially reduces water waste. It can also provide cleaner water for crops, reduce maintenance costs, and increase water in-stream.	Farmers Conservation Alliance[124] analyzed potential benefits of piping in nine Oregon irrigation districts, which would return over 550 cubic feet per second of water to streams and save nearly 60,000 megawatt hours of electricity annually.
Install hydropower generation where appropriate. Replaces fossil fuel-powered energy on farms, provides rural resilience, and provides income to irrigation districts for additional environmental projects.	Farmers Conservation Alliance found 38 megawatt potential in nine irrigation districts. For example, Three Sisters Irrigation District has 400 kilowatts of potential.

Energy Costs, Energy Independence, and Economic Growth Potential

Arguments against deep decarbonization assume that it will necessarily entail high costs or restricted energy services that are barriers to economic development.[63] But the long-term goal of the transition to a low-carbon energy economy is to move away from dependence on fossil fuels as a primary energy source, creating a highly efficient, modern energy system that provides the same or more diversified energy services without the negative effects of the current system.[63] However, getting to this end state requires a period of transition where some individuals and businesses will still need to rely on old fossil fuel-based systems that will become comparatively more expensive to operate or maintain under policies that explicitly put a price on the carbon in fossil fuels, or simply as investors, insurers, and banks eventually seek to limit their carbon liability.[122] Policymakers can manage this transition through program designs that aim to limit cost increases facing consumers and ensure that benefits are prioritized in impacted communities.

Examples include:

- Coordinating energy efficiency improvements with decarbonization of energy supplies limits increases in total consumer bills even if per unit energy prices increase.[63]
- Policies to reduce the level of consumer up-front spending required to transition their homes and vehicles to low carbon technologies is key to keeping net household costs low, or even producing a net savings.[63]
- Policy design choices with a cap-and-trade system can require regulated utilities to return revenues to specific customer classes to mitigate potential price increases.
- The concept of "just transition" emphasizes that investments in workers should be prioritized, for example, through job training and re-training programs. Just transition and ensuring costs do not disproportionately fall on low income and other vulnerable populations are key social and environmental justice considerations.

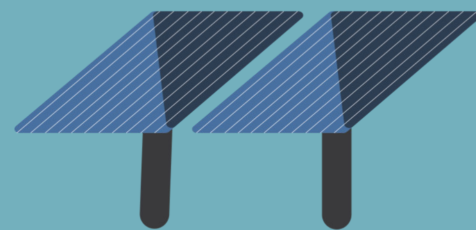
Economic and security benefits of a deeply decarbonized energy system for Oregon include: (1) increased energy independence, (2) native sources of energy that create local jobs and enhance resiliency (see Ch. 2.6 for additional detail on resiliency benefits of distributed energy and microgrids), and (3) larger proportion of Oregonians' dollars spent on energy staying in the local or state economy.[70] Reduced dependence on imported fossil fuels, particularly petroleum, means that a low carbon economy will be more shielded from the impacts of price volatility and insecurity over resource availability, particularly for a globally traded commodity like oil, considering the outsized influence in the global oil market of the Organization of the Petroleum Exporting Countries (OPEC) and the history of political instability in many oil-producing regions[63] (see Chapter 4 for additional discussion of energy independence). Less exposure to financial risk associated with price shocks creates a more stable investment environment that has more predictable energy costs for consumers and reduces business risk.[63,106] The deep decarbonization transition has also been identified as a catalyst for business innovation, with potential to create new jobs across multiple types of clean energy-related industries and to capture a first-mover competitive advantage in global markets for low-carbon energy technology, meaning Oregon businesses would have an edge as one of the early entrants into a new market segment for low-carbon energy solutions.[63]

Air Quality and Human Health

Fossil fuel-based energy systems have well-studied adverse environmental and human health effects for both children and adults.[125] Industrial fossil fuel use also has implications for occupational exposures and negative health effects for workers.

Exposure to air pollution has been linked to increased risk of heart disease, respiratory disease, stroke, and cancer[48], and these health burdens disproportionately affect low income and minority populations.[127] These diseases are four of the five leading causes of death in Oregon.[128] Nationally, incidences of air pollution-related premature death are attributable to primarily to fossil fuel combustion emissions from road transportation and electricity generation, followed by industrial emissions.[129] A deeply decarbonized energy economy, by moving away from fossil fuels and through use of clean electricity generating technologies, would substantially reduce air pollutants that are co-emitted with greenhouse gases. These co-pollutants include particulate matter, nitrogen dioxide, sulfur dioxide, polycyclic aromatic hydrocarbons, mercury, and volatile organic compounds. Improved air quality reduces the risk of respiratory, cardiovascular, and other documented negative health effects from exposure to air pollution, and can reduce doctor and hospital visits, and therefore health care costs for people with chronic illnesses like asthma and chronic obstructive pulmonary disorder.[130,131]

CONCLUSIONS



The transformation of energy systems throughout the West and in Oregon have begun. Continuing this process to **achieve deep decarbonization** and the state's climate goals will not be without its challenges, but advantages include supporting the state's competitiveness in a global clean energy economy, increasing energy independence, and realizing the substantial health and environmental benefits of reduced pollution. Based on the experiences of other states and jurisdictions, a menu of policy options is available to the State of Oregon to make a deep decarbonization pathway feasible across all sectors of the economy.

Equity, environmental justice, and potential policy interactions and tradeoffs should be considered early on in the design of such policies to account for how costs and benefits are distributed across society. Some data needs are evident that would help refine understanding of appropriate strategies for Oregon, prioritize timing of investments, and track and evaluate outcomes. However, enough is currently known that actions can be taken even now, while gaps in information are addressed and as Oregon determines a path forward for statewide climate action.

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