Oregon Global Warming Commission

2018 Biennial Report to the Legislature

FOR THE 2019 LEGISLATIVE SESSION

TOP Mt. Washington from Black Butte Ranch near Sisters, Oregon. Smoke from Mili Fire, 2017 BOTTOM Oregon Convention Center towers on a smoky day in Portland, Oregon.

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Oregon Global Warming Commission

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Catherine Macdonald (Vice-Chair)	North America Natural Climate Solutions Director, The Nature Conservancy
David Anderson	CEO, NW Natural
Sam Pardue	CEO, Indow Windows
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Alan Olsen	Oregon State Legislature, Senate
David Brock Smith	Oregon State Legislature, House of Representatives
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*Four voting member positions of the Commission are vacant at the time of this Report

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Our children, and theirs, will be living for decades with the worsening consequences of our failure to take timely action when we knew we should.

Executive Summary

The Oregon Global Warming Commission (OGWC) is submitting this Biennial Report in advance of the 2019 legislative session. This is the first report to be published in an even-numbered year, an approach that the Commission will seek to follow in future in order to allow its insights and input to be considered earlier in the legislative development process. Since this report comes close on the heels of the 2017 OGWC Biennial Report, we are emphasizing three previous key takeaways that are further supported by another year's worth of data. We are also drawing two new conclusions based on new data from Oregon's largest electric utilities and from Oregon's consumption-based greenhouse gas (GHG) emissions inventory.

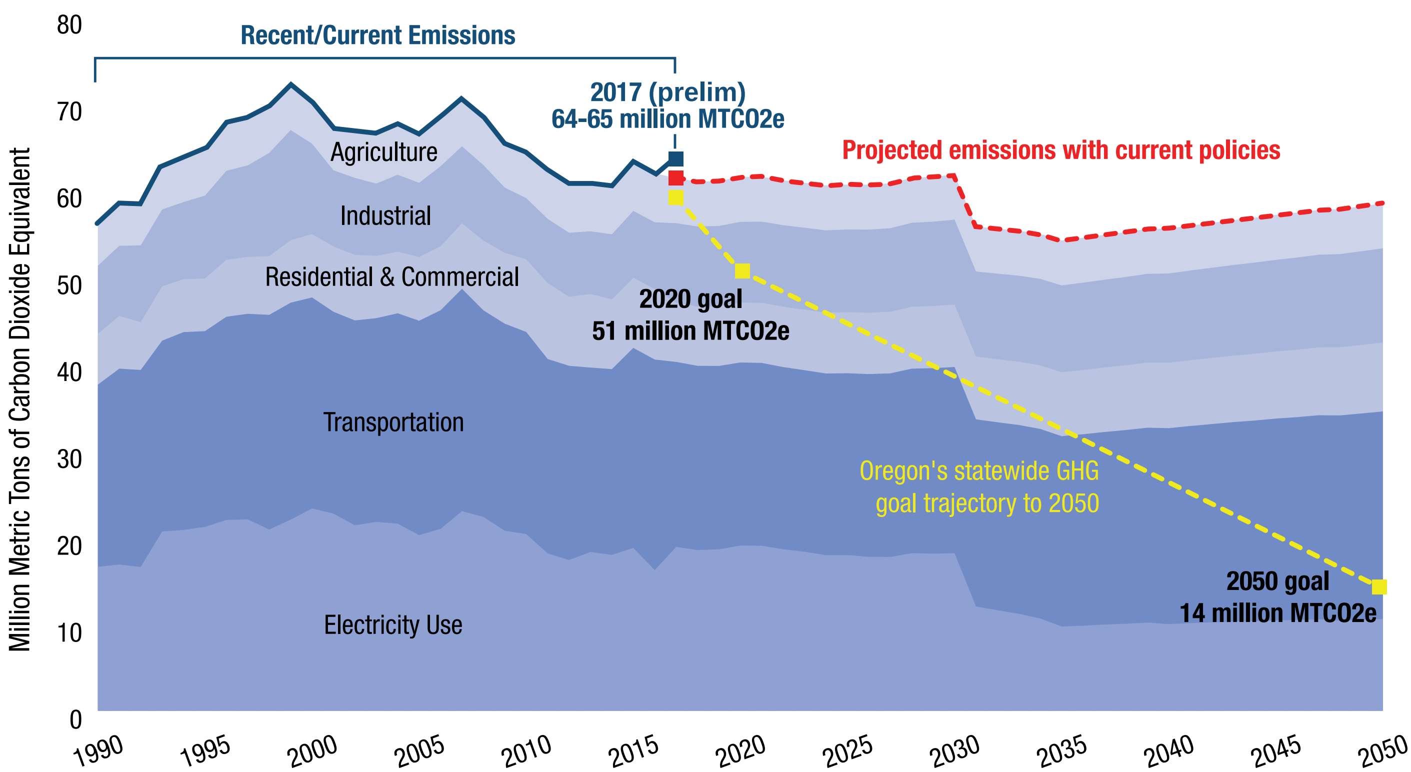
1. Oregon is warming. The consequences are already becoming challenging for many Oregonians. Adaptation actions are necessary, as mitigation alone will not prevent serious impacts.

On a plain reading of the evidence, climate change is occurring in real time. Its effects are being felt in Oregon and around the world today, and not in some distant and uncertain future. If we ended GHG emissions tomorrow, climate change effects would persist and worsen for decades to come. Cutting climate change off from its GHG fuel is like stopping a ship's engines: it does not stop the inertial forward motion but only allows it to gradually slow. Our children, and theirs, will be living for decades with the worsening consequences of our failure to take timely action when we knew we should. Bad as that is, further delay only makes it worse.

2. Oregon's GHG goals are not likely to be met with existing and currently planned actions.

Although we do not yet have a verified 2017 total from Oregon Department of Environmental Quality (DEQ), we are able to report a preliminary value of 64-65 million metric tons of carbon dioxide equivalent (MTCO2e) for the state's total GHG emissions in 2017. This reverses the slight decrease the state achieved in 2016, returning to approximately the same level as in 2015. This level is well above the state's goal of 51 million MTCO2e by 2020 and the Commission's adopted interim goal of 32.7 million MTCO2e by 2035, and it does not put Oregon on a path toward achieving its long-term goal of 14 million MTCO2e by 2050 (Figure 1).

Figure 1. Oregon past and projected greenhouse gas emissions compared to goals



These data and trends make abundantly clear that additional climate action is needed. With this in mind, the OGWC passed a resolution in October 2018 acknowledging the critical work to date of the Legislature's Joint Committee on Carbon Reduction. The resolution urges the state of Oregon to fully develop an economy-wide GHG cap and trade proposal — or a comparably effective pricing mechanism — for legislative action in 2019. Such a proposal will, in combination with other state and local government investments and policies, and private sector initiatives, bring Oregon's GHG emissions under control and on a trajectory to comply with the state's legislatively-enacted reduction goals; and will identify and act on priority climate change adaptation measures.

3. Rising transportation emissions are driving increases in statewide sector-based GHG emissions.

Adapting Oregon communities to facilitate public transit, biking, and walking is an important part of reducing transportation emissions.

Transportation GHG emissions have risen during each of the past three years and have grown from 35% of the statewide total in 2014 to 39% in 2016. In 2018, the Oregon Department of Transportation (ODOT) published a Monitoring Report to document progress — and the absence of progress — in implementing the 2013 *Statewide Transportation Strategy* (STS) to reduce GHGs. The Oregon Transportation Commission also formally adopted the STS in the Oregon Transportation Plan in 2018. However, STS adoption is only advisory and has no specific programmatic implications unless the Legislature chooses otherwise.

ODOT's Monitoring Report identified a number of areas of short-term positive progress offset by other areas of stalled progress or negative trends, particularly in the rising GHG emissions from light-duty vehicles. Oregon should prioritize moving STS recommendations forward, especially policies that incentivize low-carbon choices such as deploying electric vehicles and charging systems; electrifying transit and increasing transit service; and adapting Oregon's communities to facilitate public transit, biking, and walking. Adopting an economy-wide cap on GHG emissions would reinforce these programmatic incentives for cleaner vehicles and fuels.

4. New data from Oregon's largest electric utilities indicate an emissions reduction trajectory that is in general alignment with Oregon's 2050 goal. GHG emissions from natural gas use appear to be relatively constant, but there is ongoing interest in strategies, for reducing the carbon intensity of natural gas.

From 2014 to 2016, emissions from electricity use decreased from 30% to 26% of the state's total emissions. New projections provided by Oregon's two largest electric utilities indicate that by 2050, given certain assumptions, they expect to achieve reductions of at least 80% below their 2005 levels. This reflects both steep declines in

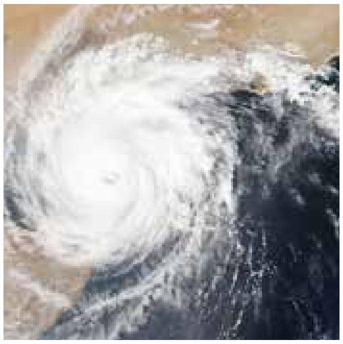
the cost of renewable generation and the anticipated outcomes of recent changes to state laws that will displace coal generation and require new renewables. Adopting an economy-wide GHG emissions cap, in addition to ensuring continued investment in energy efficiency and renewables, would lock in these electricity-sector reductions.

GHG emissions from natural gas use are expected to remain at their current levels (about 11 to 14% of total sector-based GHG emissions), unless additional actions are taken to reduce the carbon intensity of natural gas. Oregon's largest natural gas utility has a GHG reduction goal of 30% from 2015 levels by 2035. A statewide study, requested by the Legislature in SB 334 (2017), inventoried all potential sources of biogas and renewable natural gas available in Oregon and identified financial, informational, market, policy, and regulatory barriers facing project development (Oregon Department of Energy, 2018). The inventory indicates that if barriers can be addressed, there is potential for a substantial amount of renewable natural gas to be produced in Oregon.

5. New data on statewide consumption-based GHG emissions show a steady increase over time driven by household demand.

DEQ reports annual GHG emissions data, using a sector-based emissions inventory approach and on a less frequent basis it also publish a consumption-based inventory to quantify GHG emissions across the life cycle of goods and services consumed in Oregon. Oregon's consumption-based emissions show a steady rise from approximately 61 million MTCO2e in 1990, 79.6 million MTCO2e in 2005, 80.2 million MTCO2e in 2010, and 89 million MTCO2e in 2015. Nearly two-thirds of Oregon's consumption-based emissions are associated with just five highest-emitting categories: vehicles, food and beverages, appliances, services, and construction. Household demand is overwhelmingly the driver of consumption-based emissions. From this perspective, the emissions Oregonians are responsible for are still increasing every year through what we consume, but those emissions are more and more occurring globally, in other countries from which we import these goods. The two inventories viewed together provide a broader understanding of both our emissions and our opportunities to reduce them.

2018 Letter from the Chair



The time of probabilities is now past. The first tangible effects of climate change are upon us. We see it in stronger hurricanes inundating coastal communities around the world. We see it in half-full reservoirs and mountaintops devoid of midwinter snow.

"Owing to past neglect, in the face of the plainest warnings, we have now entered upon a period of danger…The era of procrastination, of half-measures, of soothing and baffling expedients, of delays, is coming to its close. In its place we are entering a period of consequences…We cannot avoid this period; we are in it now."

—

Winston Churchill, in the House of Commons, November 1936

Government and leadership have come a long way from Churchillian rhetoric in those dark days leading up to World War II, and not in any direction that should give us comfort. As grim as the world's prospects were in the 1930s, at least there were Churchills and Roosevelts summoning us to the great tasks of those times.

We've looked for that kind of leadership throughout the 30 years or so that climate change has loomed as an existential threat to our society and our children's future. Rarely have we found it. Identifying such a profound climate threat has been difficult in the absence of immediate physical evidence that the climate is changing, but not more difficult than inferring a threat from a rearming Nazi Germany. Most of the world, and most of the United States, then and now, chose to look elsewhere, to more immediate opportunities, smaller tasks, and narrower challenges. Climate science, after all, spoke in data sets and modeled probabilities. Outcomes remained fuzzy around the edges. Our leaders would have to ask us to make often uncomfortable changes in budgets, policies, and livelihoods, to forestall . . . probabilities.

The time of probabilities is now past. The first tangible effects of climate change are upon us. We see it in stronger hurricanes inundating coastal communities around the world. We see it in the smoke blanketing our state and region from forest fires that start earlier, persist longer, and burn more extensively — smoke that is attacking the lungs of our children, the elderly, and the asthmatic. We see it in half-full reservoirs and mountaintops devoid of midwinter snow. (See Section 1 of this Report for links between earlier projections of climate effects and the realized effects of today.)

Progress and Slippage

In this Report, the Global Warming Commission reviews Oregon's successes and our remaining challenges in meeting our greenhouse gas emissions goals. This letter reflects my profound concern, after 10 years as commission chair, about whether we are rising to the challenges in meaningful and sufficient ways.

I wrote the first of these letters as a foreword to our 2009 Report to the Legislature. In that letter I described as "unvarnished good news" the wind projects and solar cell manufacturing, the "green buildings," and the energy-efficient land use choices that we thought would make Oregon a leader for dark but not hopeless times. The country had just elected a president committed to addressing climate issues. Congress was debating national carbon cap legislation. Countries around the world were telegraphing their parallel commitments to a global climate strategy.

Indeed, much has been accomplished in the 10 years since then, especially in the realm of energy technologies that are replacing the nation's fleet of superannuated coal plants with cleaner (but, let us be clear, still not *clean*) gas supplies, and with wind and solar plants that are offering ever-lower costs and higher efficiencies. This cleaner, carbon-free electricity, we speculated then, could power an emerging fleet of electric cars, trucks, buses, and possibly even aircraft.

Momentum is still evident globally. In 2018, two of the last three holdouts from the Paris Climate Accord, Nicaragua and Syria, signed on. Only the United States of America, once a global leader for responsible climate action, now remains outside the global accord, its policies dominated by feckless politicians who are indifferent or outright hostile to the tested, peer-reviewed findings of science. This is leadership of a sort, but of a sort that will lead the country over the climate cliff.

So it falls to us as Oregonians and Washingtonians and Californians, as citizens of San Francisco and Portland and Chicago and New York, to demonstrate what real leadership is in coping with the slow-motion but inexorable emergency we face. It falls to us to rescue the country from itself, to bear our share of the burden, and realize our share of the promise to the rest of the world.

Oregon's Emissions Inventories

The Inventory Section of this 2018 Report carries both encouraging and challenging news. We can be legitimately energized by accomplishments and opportunities in the electric utility sector. The past 10 years have seen:

- PGE's decision to end coal burning at Oregon's only in-state coal plant at Boardman;
- a negotiated agreement between environmental groups and our two large electric utilities, validated by the 2016 Legislature, to terminate coal-generated electricity imports by 2030 and to sharply increase renewables in the mix;

• PGE's corporate commitment to "deep decarbonization," and the determination of NW Natural to seriously explore the potential of renewable gas and hydrogen.

The combined effects of these commitments, if fully realized, should drive utility emissions to, and below, a proportional share of Oregon's greenhouse gas goals (see Section 3, on Oregon utility emissions).

The mounting challenge we face is with transportation emissions, which have been rising since 2013 after several years of flat-lining or incrementally dropping. Other states are showing the same rise in transportation emissions as the effects of the 2008 Great Recession retreat. More miles (Oregon Office of Economic Analysis, 2017)[1] are being driven in larger and less fuel-efficient cars, while the Trump administration undermines the effectiveness of national vehicle fuel economy standards.

As Oregon consumers purchase more goods and services, a share of these are imported from producers in other countries, often where carbon efficiencies are poorer than here.

And, the strategy of negotiated change that has been successful with two electric utilities may not work so well with Oregon's 3 million vehicle owners/drivers. Alternative vehicles are entering the market, but slowly, notwithstanding that electric vehicle purchase costs are coming down, their operating costs are far lower than those for gasoline and diesel vehicles, and the miles that can be driven between charging sessions is dramatically up.[2]

To lock in real emissions reductions and shore up slippage, leadership on climate issues from the Oregon Legislature and the Governor is crucial in 2019. A carbon cap will inform Oregon drivers of both the costs of failure and the rewards of success, while encouraging movement to more cost- and carbon-efficient travel. The cap (first called for in Governor Kulongoski's Advisory Group Report in 2003) is the largest missing building block in Oregon's carbon strategy. The Joint Committee on Carbon Reduction chaired by Senate President Peter Courtney and House Speaker Tina Kotek, and including admirable membership from both chambers, ensures that this issue is getting serious legislative treatment at long last.

Consumption-Based Emissions

Oregon's consumption-based inventory tracks our state's greenhouse gas footprint as measured by the emissions we create with our consumption choices. Through it, we can calculate — and choose to take responsibility for — the emissions associated with the overseas fabrication of a product, its transport to Oregon, and its use and disposal here, even if some of the emissions may originate in Europe or Asia. These emissions numbers are rising also. This outcome is a function of increased consumption by Oregon households and businesses and is consistent with post-recession economic growth. As Oregon consumers purchase more goods and services, a share of these are imported from producers in other countries, where carbon efficiencies are often poorer than here. Increased consumption of imported goods means increased total and per capita *consumption-based emissions*. In the near future, Oregon will need to

[1] A 14% increase since 2012, or more than 4.5 billion more vehicle miles traveled in Oregon in 2016 (37.5 billion) compared to 2012 (33.0 billion), based on statistics from U.S. Federal Highway Administration, Oregon Department of Transportation, and Oregon Office of Economic Analysis. Available at https://oregon-economicanalysis.com/

[2] >300 miles for the latest Kia Niro.

confront these findings by considering consumption-based emissions reduction goals and tools, because, wherever those emissions occur, they are an outcome of our choices and will result in global climate change that affects Oregonians.

Oregon Forest Carbon Accounting

Oregon's forests are world class at capturing and holding atmospheric carbon in their trunks, roots, and soils, on a par with equally dense tropical and Alaskan rain forests. The Oregon Global Warming Commission's Forest Carbon Accounting Project worked with the U.S. Forest Service and Oregon State University scientists to reveal some striking findings: Approximately 11 billion tons of carbon dioxide equivalent are packed into Oregon forests today, and we appear to be increasing that store at somewhere between 15 million and 60 million tons CO2e annually (Oregon Global Warming Commission [OGWC], 2017).[3] We were further advised that the opportunity exists to substantially increase this uptake and storage through modest changes in forest management and harvest practices. Reducing our (mostly) energy-related emissions plus increasing forest carbon capture and sequestration could move Oregon toward overall carbon neutrality by the 2030s, and to negative carbon thereafter. That is, Oregon could go from being part of the problem to being a notable part of the global solution. In the process, we could pioneer forest carbon measures for other forested jurisdictions. The 2019 Legislature can take a significant step in this direction by including forest carbon incentives in its carbon cap legislation.

Extreme Climate Events

Section 1 of this Report outlines, in sometimes painful detail, the climate change effects Oregon and the wider world have already begun to suffer. The Fourth National Climate Assessment (2017, vol. 1) allocates a chapter to "Potential Surprises: Compound Extremes and Tipping Elements." Chapter 15 of the Assessment notes the significant ways in which "average" projections could be decidedly worse. It observes that "climatemodels are more likely to underestimate than to overestimate the amount of long-termfuture change." It notes that "compound extreme events (such as simultaneous heatand drought, wildfires associated with hot and dry conditions, or flooding associatedwith high precipitation on top of snow or waterlogged ground) can be greater thanthe sum of the parts."

"Tipping points" are generally stable conditions that can be "tipped" into highly unstable ones by a small increment of climate change — a needle that breaks the camel's back — such as a small degree of Antarctic warming that could release a rapid disintegration and melting of glacial ice, raising sea levels more rapidly than humans can adapt to them. It warns us that, as devastating as linear effects of climate change will be, the nonlinear effects may be far more so because we are unprepared to cope with them (U.S. Global Change Research Program, 2017, vol. 1, chap. 15).

[3] Forest carbon can be released or converted into different carbon pools through respiration, harvest, decomposition (e.g., after trees die from old age, disease, or pests), and fire. We can restate quantities of forest carbon as a "carbon dioxide equivalent" (CO2e) to allow one-to-one comparisons of carbon stored in trees with annual carbon dioxide emissions released when fossil fuels are burned, using standard conversion factors. Oregon's total annual sector inventory emissions are about 60 million tonnes, or metric tons, CO2e. A tonne is equal to 2,200 pounds, or 1.1 short tons.

In Oregon, those effects might include a dramatic die-off of forests (such as has occurred already in Canadian and Alaskan boreal forests and in the Russian taiga forests) or an unexpected sea-level rise that swamps Oregon coastal communities, economies, and highways.

We applaud the real progress Oregon has made in resetting our electric utilities toward a low-carbon future, and regret our failure to do the same in transportation.

Oil Companies: A Final Note

We applaud the real progress Oregon has made in resetting our electric utilities toward a low-carbon future, and regret our failure to do the same in transportation. Much of this slow slog is due to the well-financed[4] resistance from oil companies determined to extract the last dollar of profit out of a product that has no place in a decarbonized world. Upton Sinclair, the quotable muckraker from this country's first Gilded Age, said it best:

> *It is difficult to get a man to understand something when his salary depends upon his not understanding it.*

But even Upton Sinclair could not have imagined the irony of this same oil industry, while pumping more U.S. oil than ever before and laboring to protect its markets, at the same time asking for oceanfront "protection" from rising sea levels along the Texas Gulf Coast. The State of Texas is seeking $12 billion in federal funding to build "a 60-mile spine of concrete seawalls, earthen barriers, floating gates, and steel levees" to protect "one of the world's largest concentrations of petrochemical facilities, including most of Texas' 30 refineries, which represent 30% of the nation's refining capacity." The spine would include works that would reach from Louisiana to south of Houston.

"Our overall economy … is so much at risk from a high storm surge," said Republican Brazoria County Judge Matt Sebesta. Republican Senators John Cornyn and Ted Cruz both support this use of taxpayer funds to protect the oil industry from, in effect, itself. The first commitment of $3.9 billion was fast-tracked by the administration after Hurricane Harvey hit the Texas coast a year ago, knocking out a quarter of the area's oil refining capability. A Texas commission is also seeking $61 billion from Congress to "future proof" the state (Weissert, 2018).

Not Upton Sinclair, not Doonesbury, not even *The Onion* could imagine theater as absurd as this. I leave readers to draw their own conclusions.

Angus Duncan, Chair
Oregon Global Warming Commission
September 24, 2018

[4] Most recent financial filings in Washington's Measure 1631, which was on the ballot this fall, and which would have established a carbon fee in that state, showed that >75%—and perhaps as much as 99%—ofthe $31 million received by the "No on 1631" campaign was from oil companies (Lavelle, 2018).

Section 1:

Climate Change Comes to Oregon 2018

The Oregonian for Wednesday, August 15, 2018, led with the story of smoke that "choked" the Portland airshed from forest fires "filtering into Northwest Oregon from blazes in almost all directions … Washington, British Columbia, Eastern Oregon … [and] Northern California." The Oregon Department of Environmental Quality (DEQ) issued an air quality advisory warning people to stay indoors if possible, especially children, seniors, and those with respiratory conditions.

The Oregon Smoke Blog for August 21 read: "Currently all Oregon counties except Coos and Curry are under air quality advisories."[5]

Less than a year earlier, Portlanders had awakened to a similar brownish haze obscuring the sky and the same public health advisory. DEQ said 2017 was "different" from earlier bad fire years in that "the entire state is … blanketed by smoke" coming not only from the Eagle Creek Fire in the Columbia Gorge but also from a dozen fires ranging from the Rogue River to Mt. Hood, as well as from fires in Canada and California. DEQ called the condition "rare" (DEQ, 2018).

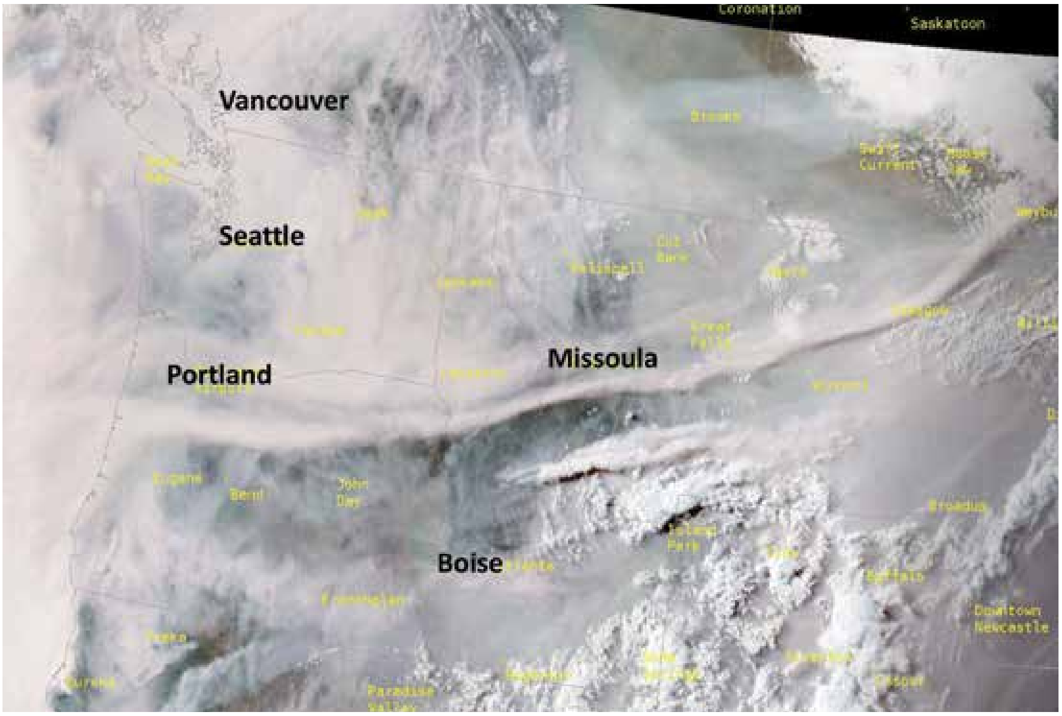
But it's not, anymore.

Larger forest and grassland fires are now more frequent, a consequence of warmer, drier summers. The fire season begins earlier and ends later (Dalton et al., 2017, chapter 5).

On August 15 of this year, the National Interagency Fire Center reported fires burning in all 13 states west of the 100th meridian, a total of 108 "active large fires," four of which were contained. On August 22, the Forest Service reported via Twitter that "23 large fires burning nearly 440,000 acres" in Oregon (@ForestServiceNW). The 80,000-acre "Substation Fire" near The Dalles, Oregon, in July burned 1–2 million bushels of wheat at a cost of >$5 million. Farmers in the fire's path "got wiped out, most of their crop if not all," said Tara Simpson of the Oregon Wheat Commission (*The Oregonian/OregonLive,* July 20, 2018).

Fire season is starting earlier in the spring and lasting later into the fall in Oregon. The Taylor Creek/Klondike Fire was set off by lightning strikes in mid-July 2018. The two fires grew and merged into August, topping 150,000 acres. By mid-September the fires were largely contained at 170,000 acres, and crews were switching over to mop-up duties. Then, dry, warm, and windy fall days allowed

[5] "Oregon Smoke Information," http://oregonsmoke.blogspot.com



Smoke across the Pacific Northwest.

Source: National Weather Service/Spokane, August 13, 2018, satellite image, https://twitter.com/NWSSpokane/status/1029192999446740992

the fire to flare up again on October 15, burning several thousand additional acres of Siskiyou Mountains forestland, threatening homes in Agness, Oregon, on the Rogue River, and forcing evacuations. The Northwest Interagency Coordination Center now estimates containment by November 30.[6]

The Oregon Department of Forestry estimates gross state costs of wildfire control in 2018 at more than $100 million, of which Oregon's share will exceed $40 million after federal cost-sharing. Oregon's net fire-fighting costs averaged $39 million per year over the last six years (2013–2018), or five times the annual average of about $7.5 million per year over the preceding five years (2008–2012).[7]

At least Oregon communities have been spared the devastation suffered in California: deaths and whole neighborhoods destroyed in Redding and Paradise this year and in Santa Rosa last year. Of California's 15 largest fires (by acreage), 12 have occurred since 2000, three of them in the last two years (Berke, 2018). Some Californians are anticipating a near year-round fire season from now on.[8]

Oregon communities have not been spared other impacts, however. Last year's Eagle Creek Fire closed Interstate 84 for three weeks, disrupting personal and commercial traffic, adding costs and delays to shipping. The Oregon Shakespeare Festival in Ashland had to cancel or relocate 26 performances from its outdoor theater in 2018, more than in its smoke-plagued 2017 season. Each cancellation directly costs the

TOP: August 5,2018.
BOTTOM: October 19, 2018.

[6] Photography and Taylor Creek/Klondike Fire information from Facebook fire postings by fire control officials, October 2018, https://www.facebook.com/pg/TaylorCreekandKlondikeFires/photos/?tab=album&album_id=234917240676541

[7] Email communication, October 26, 2018, from Bobbi Doan, public information officer, citing Oregon Department of Forestry estimates for FY 2018 and FY 2019.

[8] "In California, it's always fire season now." Curbed Los Angeles News, June 5, 2018.

festival $50,000 in lost revenues — an estimated $2 million total loss in 2018 — and costs the Ashland community thousands more in forgone lodging, food, and drink revenues (Flaccus, September 25, 2018). In 2017, the central Oregon town of Sisters canceled its September Folk Festival, a major tourist draw and community moneymaker (estimated lost community earnings in excess of $1 million).

Over the last several decades, warmer and drier conditions during the summer months have contributed to an increase in fuel aridity and enabled more frequent large fires, an increase in the total area burned, and a longer fire season.

Here's how the Oregon Climate Change Research Institute, in its 2017 *Oregon Climate Assessment*, described prevailing conditions:

> Over the last several decades, warmer and drier conditions during the summer months have contributed to an increase in fuel aridity and enabled more frequent large fires, an increase in the total area burned, and a longer fire season (Dalton et al., 2017, p. 46).

And here is the Research Institute's prediction about forest wildfire from its 2010 Assessment:

> Wildfire is projected to increase in all Oregon forest types in the coming decades. Warmer and drier summers leave forests more vulnerable to the stresses from fire danger west of the Cascades. Wildfire in forests east of the Cascades is mainly influenced by vegetation growth in the winters that provides fuel for future fires. An increase in fire activity is expected for all major forest types in the state under climate change. Large fires could become more common in western Oregon forests (Oregon Climate Change Research Institute [OCCRI], 2010, p. 6).

Even earlier, in 1999, the University of Washington Climate Impacts Group wrote:

> … the net direct effect of the climatic changes is not likely to be favorable to the productivity and stability of existing forests. Warmer summers, leading to increased evapotranspiration, are likely to overwhelm any benefits of increased CO2 fertilization. Predicted climatic changes are likely to have profound … immediate and easily observed impacts — most obvious in the case of fire where increased summer temperatures and moisture deficits will substantially increase the potential for the occurrence, intensity, and extent of wildfires (Mote, Canning, Fluharty, et al, 1999, p. 67).

Past Reports to the Legislature from the Oregon Global Warming Commission and Oregon Climate Change Research Institute have emphasized predicting what Oregonians can expect *in the future* if climate change is not brought under control. But those predictions of climate effects in Oregon, predictions made in 2010 and earlier, have arrived on our doorstep in 2018: fire; flooding; drought; disease and health impacts; heat; sea-level rise; erosion of Oregon's coastline; and damage to fragile forest, grassland, aquatic, and alpine ecosystems and the plants and animals they contain.

The personal and economic consequences that once were distant predictions are becoming accomplished fact.

Therefore, this Report will be different. It reports how those earlier predictions are coming true. It reports not the future but the present.

It's not a comforting sight.

Elsewhere in the country in 2018, summer fires raged across California. Yosemite Valley closed for three weeks due to smoke and fire risk. Residences in large sections of Santa Rosa (2017) and the communities of Redding and Paradise (2018) burned, with loss of life and property. Notwithstanding adequate soil moisture content from winter precipitation in both 2017 and 2018, California experienced intense fires.

Robinson Meyer, in an article in *The Atlantic*, cited the conclusions of Professor A. Park Williams of Columbia University:

> The factor that clearly made the difference in 2017, and again in 2018, is heat. Last summer was record-breaking, or near record-breaking, hot across much of the West, and I believe July 2018 will break records or come close to it again this year. Even if the deep soils are wet following winter and spring, a hot and dry atmosphere seems to be able to overwhelm that effect (Meyer, August 10, 2018).

In fact, July 2018 was the hottest month California has ever recorded.

And, with reference to the increased extent of forest fires: "We estimate that human-caused climate change contributed to an additional 4.2 million ha [hectares] of forest fire area during 1984–2015, nearly doubling the forest fire area expected in its absence" (Abatzoglou and Williams, 2016).

Elsewhere on the planet in 2018, intense and rapidly moving fires in Greece in the summer of 2018 left 97 dead and communities devastated, with more than 1,000 buildings destroyed or damaged (Wikipedia, 2018, "2018 Attica Wildfires"). Europe coped with its worst heat wave and drought in decades; countries as far north as

Sweden were fighting forest fires above the Arctic Circle (*Daily Express*, July 25, 2018). Millions of hectares (one hectare = 2.47 acres) of Russian/Siberian taiga forest appear to have burned in 2018 (*The Siberian Times*, 13 July 2018).

Although predictions of these and other climate impacts can be summoned up from three or four decades back, just reading OCCRI's 2010 and 2017 Assessments side by side should be sobering to Oregonians and their leaders alike.

A note of qualification for what follows: Heat waves, drought, intense storms, forest fires, and other inconveniences and disasters have been suffered throughout human history. Oregon has seen its share of these events, such as the very large West-side fires during a cyclical dry period[9] in the 1930s. The difference today is in the *amplification* of naturally occurring weather events. The National Academies of Sciences, Engineering, and Medicine stated (in 2016) that:

> In many cases, it is now often possible to make and defend quantitative statements about the extent to which human-induced climate change (or another causal factor, such as a specific mode of natural variability) has influenced either the magnitude or the probability of occurrence of specific types of events or event classes (National Academies of Sciences, Engineering, and Medicine [NASEM], 2016, p.14).

Thus, climate change does not start forest fires (either lightning or careless humans do this), but climate change lengthens the calendar window for weather conducive to such fires and supplies the fire with more tinder-dry fuel that can contribute to larger and more persistent fires.

A parallel example might be a baseball player who might naturally hit 40 home runs a season; playing with performance-enhancing drugs, he might hit 60 instead. The drugs don't make him a better hitter but do increase his chances, each time he bats, of sending one into the bleachers.

So what other climate change predictions are coming about, and with what consequences? The following references should be read as illustrative; for a complete accounting, look to Oregon Climate Change Research Institute's *Third Oregon Climate Assessment Report* and to the Northwest regional section of the U.S. government's 2018 *Fourth National Climate Assessment*. Note that both data-based and anecdotal evidence of current effects are 2018 snapshots; these effects will continue to intensify in future years even if emissions growth is reversed today and systematically reduced over the next two decades or so.

The "***Then***" predictions are from the 2010 Assessment (OCCRI, 2010), unless noted otherwise.

[9] The recurring Pacific Decadal Oscillation is a naturally occurring climate cycle of roughly 30 years' duration, alternating between drier and wetter weather periods. Another naturally occurring, shorter-term cycle affecting the Pacific Northwest is from El Niño (drier, warmer) to La Niña (wetter, cooler). Climate change is superimposed on these cycles, amplifying warmer effects and, in different geographies, amplifying or diminishing precipitation.

HEAT

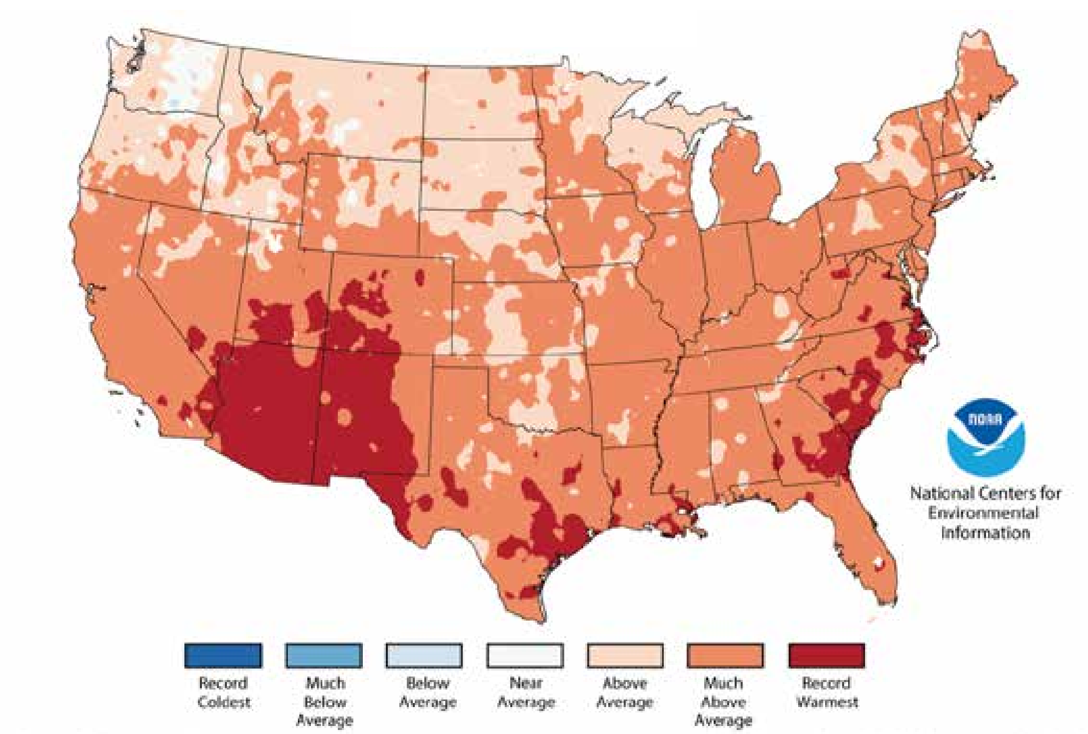
Then: The 2010 Assessment predicted that Oregon would see average temperature increases of “0.2-1ºF” per decade.

Now: Oregon’s average temperature has risen 1 degree F in the last 30 years (OCCRI, 2017). By August 22 of this year, Portland had set a new record for hottest days (30 days above 90 degrees F) (*Willamette Week*, August 22, 2018). Higher maximum nighttime temperatures also were recorded over the last century.

> … rising greenhouse gases have added almost 2ºF to the Northwest’s average temperature over the past 100 years. It follows, then, that when Oregon experienced a year (2015) that was about 5°F warmer than the 20th-century average, greenhouse gases contributed about 2°F of that (Abatzoglou, Rupp, and Mote, 2014.

In 2017, “For the third consecutive year, every state across the contiguous U.S. and Alaska had an above-average annual temperature” (NOAA, 2018).

Figure 2. Average annual temperature in 2017 ranked against average from 1895-2017



Source: National Oceanic and Atmospheric Administration (NOAA), 2018, https://www.ncdc.noaa.gov/temp-and-precip/us-maps/12/201712#us-maps-select

Elsewhere: Globally, 2018 is on track to be the fourth hottest year on record. Including 2018, the hottest four years on record have been the last four; and 17 of the 18 warmest years have occurred since 2001 (*The New York Times*, August 9, 2018). Heat waves and record temperatures have been recorded across the globe, from the Arctic to the tropics. The World Meteorological Society reports that "… heat is drying out forests and making them more susceptible to burn. A recent study found that Earth's boreal forests are now burning at a rate unseen in at least 10,000 years" (Achenbach and Fritz, July 30, 2018).

Globally, each of the decades since 1950 has been warmer than any of the decades preceding. 2010–2019 is on a course to be 1.31 degrees F warmer than the 1951–1980 mean temperature (National Oceanic and Atmospheric Administration, 2018.).

The National Oceanic and Atmospheric Administration reported in 2015 that nighttime temperatures are slightly outpacing daytime temperatures in the rate of warming. In 2017, a nationally averaged minimum was 60.9 degrees F in the contiguous U.S. — 2.5 degrees F above average (Gustin, July 11, 2018).[10] The inability of cities, and especially of their inhabitants, to cool off at night is a public health threat. It is an even greater threat in many third-world cities (and "third-world neighborhoods" in a first-world country like the U.S.), where air conditioning is rare and humidity levels are high, limiting the ability of bodies to shed heat.

Warmer nighttime temperatures close off what firefighters call the "nighttime recovery window" and allow fires to burn hot through the night, making containment more difficult (*Statesman Journal*, 10 August 2018.)

In 2018, the El Paso Chapin High School Huskies football team starts its practices at 6 a.m., when the temperature is a cool 82 degrees F in August, instead of following the more usual mid-afternoon schedule, when temperatures are expected to go above 100 degrees F (Moore and Davis-Young, August 29, 2018).

Scientists analyzed the exceptionally deadly 2003 heat wave in Europe — the hottest summer on record since 1540 — to which 70,000 deaths were attributed. They found that in Paris, the hottest city, 70% of the deaths (506 out of 735) could be ascribed to climate change amplifying the heat (Mitchell, Heaviside, Vardoulakis et al., 2016).[11]

[10] Updated 7 September with record summer 2018 temperatures.

[11] Overall, France recorded 14,802 heat-related deaths in 2003.

PUBLIC HEALTH

Apart from the direct effects of heat stress and other weather extremes on those without the means of protection — usually the poor — climate change can aggravate certain chronic disease conditions like asthma and heart disease and increase exposure to illnesses usually associated with warmer climates.

During the heat waves in the summer of 2015, the Oregon Health Authority recorded a spike in heat-related emergency room visits.

Then: The 2010 Assessment warns that:
Incidents of extreme weather (such as floods, droughts, severe storms, heat waves and fires) can directly affect human health. …Increases in summer temperatures will make heat waves a greater likelihood, causing heat-related morbidity and mortality, especially among vulnerable populations [and] could raise the threat of vector-borne diseases and emerging infections. Respiratory insults, especially among persons with preexisting lung health problems would be exacerbated by exposure to smoke from wild land and forest fires. … Air pollution and increases in pollen counts (and a prolonged pollen producing season) may increase cases of allergies, asthma and other respiratory conditions among susceptible populations (OCCRI, 2010, p. 403).

Now: "In Oregon, analysis of hospitalization and climate data showed that each 1°F increase in daily maximum temperature was associated with a nearly 3-fold increase in the incidence of heat-related illness" (Dalton, Mote, and Snover [Eds.], 2013).

The Oregon Health Authority recorded a 29% rise in emergency room visits for respiratory symptoms in the Portland metro region during the 2017 Eagle Creek Fire, indicating the increased health risks of smoke from more extensive wildfire (Oregon Health Authority, 2017). Heat-related emergency room visits spiked during the heat waves of summer 2015 (Oregon Health Authority, 2018).

Changes in our climate are also a factor in infectious diseases. Two examples in our state include (1) the number of cases of tick-borne disease in Oregon is steadily rising and is associated with warmer temperatures and changing tick habitat, and (2) the spread of a fungus that causes cryptococcal infections, which before 1999 was limited to the tropics, but is now established in Northwest soil and caused 76 cases in Oregon in 2015 (Oregon Health Authority, 2018).

In May, 2018, Oregon experienced its first-ever drinking water advisory due to cyanotoxins in finished drinking water.

The Oregon Health Authority issues health “advisories” to warn Oregonians of health risks. These include recreational use advisories for cyanotoxins produced by harmful algal blooms (HABs) that can arise in freshwater bodies across the state. The recreational use advisories warn Oregonians against ingesting water affected by the toxins through swimming, water skiing, and other water-based recreational activities. Health risks can range from gastrointestinal illness and dizziness to seizures and liver failure; young children, dogs, and livestock are especially susceptible. Conditions that foster freshwater HABs are increasing — higher air temperatures, more sunlight, lower snowpack (and thus higher water temperatures), and more intense rain events causing higher runoff of organic matter to water bodies.

While recreational use advisories have become a routine spring-through-fall occurrence, in May, 2018, Oregon experienced its first-ever drinking water advisory due to cyanotoxins in finished drinking water. Detroit Reservoir, the source of drinking-water supplies for the city of Salem and other communities, experienced a persistent bloom of cyanobacteria (blue-green algae) that resulted not only in recreational use advisories at Detroit Lake, but also led to cyanotoxin levels above safe drinking-water levels for sensitive populations such as children, the elderly, and those with compromised immune systems in downstream communities. The state declared a “state of emergency,” and the Oregon National Guard distributed drinking water in affected communities (Ross, June 7, 2018; Oregon Environmental Council, 2018).

Forest wildfires can emit high levels of fine particulate matter (PM2.5), and western states, including Oregon, have high exposure risk to these toxic air pollutants. Fires from 2008 to 2012 resulted in increased premature deaths and respiratory ailments, with long-term U.S. costs, principally in the West and Southeast, upwards of $450 billion (Fann, Alman, Broome, et al., 2018). As fires and smoke become more ubiquitous, disease and cost impacts will rise.

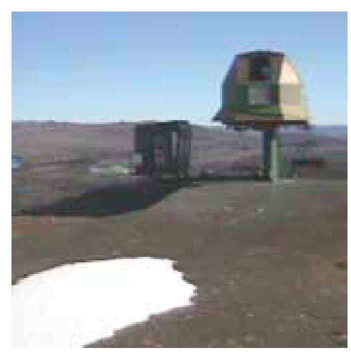
Elsewhere: Of 244 U.S. cities analyzed for increased risk of mosquito-borne diseases (including Zika, West Nile, and Dengue fever), 94% saw significant increases in days warm enough to sustain disease-carrying mosquito species. While most of these are southern cities, they include middle and northern urban areas such as San Francisco (47 more days since 1970), Helena, Montana, and Erie, Pennsylvania Ironically, some southern cities (Phoenix, Arizona) may see a lower risk — because it becomes too hot for the mosquitos to survive (Climate Central, August 8, 2018).

Drought and Snowpack

Then: "By mid [21st] century, Cascade Mountain snowpacks are projected to be less than half of what they were in the 20th Century" (OCCRI, 2010).

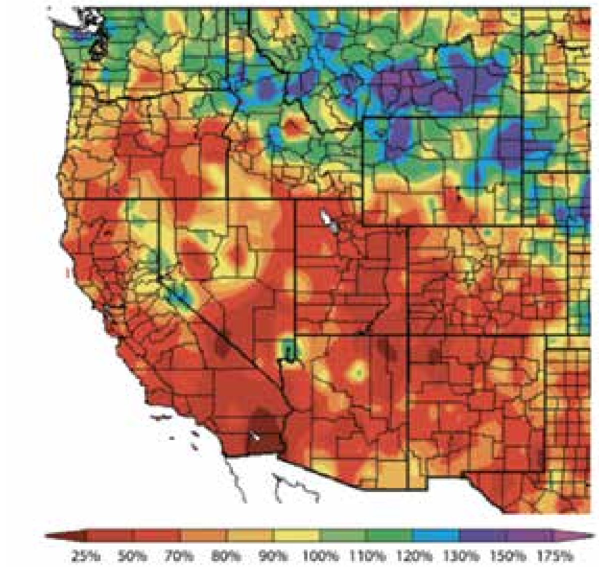
Now: While total precipitation shows no great variance, as predicted, it shows more moisture arriving as rain rather than as snow. The OCCRI Third Assessment (2017) reports the following about the year 2015, in which this effect was exceptional:

> The 2015 snow drought was a glimpse into Oregon's future. Precipitation during the winter of that year was near normal, but winter temperatures that were 5–68°F above average caused precipitation to fall more as rain instead of snow, reducing mountain snowpack accumulation (Mote, Rupp, Li, et al., October 12, 2016). This resulted in record low snowpack across the state, earning official drought declarations for 25 of Oregon's 36 counties (OCCRI, 2017, page 13). … "For each 1.8°F of warming, peak snow water equivalent in the Cascade Range can be expected to decline 22%–30% (p. 14). … Spring snowpack … decreased at nearly all stations in Oregon over the period 1955–2015 with an average decline of about 37%" (p. 19).



TOP: Detroit Reservoir, 2015, Dave Reinert, Oregon State University.
BOTTOM: Hoodoo Ski Summit, Feb. 2015 Hoodoo webcam, 23 February 2015.

Figure 3. Western Drought 2017-2018



Most of Oregon saw percipitation levels 20% to 50% below average

Percentage of average precipitation October 1, 2017-September 27, 2018

Source: National Oceanic and Atmospheric Administration, 2018. US Drought Monitor, https://www.ncdc.noaa.gov/sotc/drought/201810

OCCRI Director Dr. Phil Mote and colleagues confirmed earlier predictions in reporting that "… a decline in average April 1 snow water equivalent since mid-century is roughly 15–30%. … Declining trends (in western winter snowpack) are observed across all months, states and climates, but are largest in spring, in the Pacific states, and in locations with mild winter climate" (Mote, Li, Lettenmaier, et al., 2018).

That's Oregon.

OCCRI's website posting includes an August 2, 2018, article by Dr. John Abatzoglou titled "Drought Returns to the Pacific Northwest," in which the author identifies five "flavors" of drought, including low precipitation but also low surface supply and low snowpack. He then maps these effects from 2018 to date and observes that "the maps all show an awful lot of red, indicating extreme to exceptional drought across parts of western Oregon [with] impacts that cover the gamut from fire to farms to fish" (Abatzoglou, 2018).

OCCRI Deputy Director Kathie Dello summarized the Institute's review of the 2017/18 drought summers as follows: "Low snowpack and a hot and dry summer caused water shortages for livestock, small water systems and stressed forests and other ecosystems. Multiple years of hot and dry summers [have] caused damage to Douglas-fir trees in western Oregon."[12]

[12] Personal communication/email from Kathie Dello to Angus Duncan, 1 October 2018.

Elsewhere: The Mote, Li, Lettenmaier article showed that snowpack decreases in excess of 70% also occurred at locations in California, Montana, Washington, Idaho, and Arizona (Mote, Li, Lettenmaier, et al., 2018). The Arizona State Climate Office reports that the state "is currently in our 21st year of a long-term drought." While California has a long history of wet and dry periods, in 2015 the state "experienced its lowest snowpack in at least 500 years [and] the 2012–15 period was the driest in at least 1,200 years" (Griffin and Anchukaitis, 2014; Wikipedia, 2018, "Droughts in California"). A related study ascribes "8–27 % of the observed anomaly in 2012–2014" to global warming (Williams, Seager, Abatzoglou, et al., 2015).

A 2016 NASA study found that drought conditions beginning in 1998 and afflicting countries in the Middle East are "likely the worst drought of the past nine centuries … and well outside the range of natural variability for modern times" (Cook, Anchukaitis, Touchan, et al., 2016).

Droughts in 2018 affected countries from western and northern Europe to South Africa to Australia. Another NASA study suggests, consistent with predictions of climate effects, that there is a "redistribution"of fresh water supplies from the middle latitudes (SW U.S./Mexico; North Africa and the Middle East; India) to the north and south. "The data are not sufficient to discern a clear climate fingerprint," says Jay Famiglietti, one of the NASA researchers, "but it sure … matches that pattern [and is] cause for concern" (Famiglietti, 2018).[13]

In 2007, the town of Vernonia in Oregon's Coast Range suffered severe flooding for the third time in 19 years as the Nehalem River responded to 6.–7.5 inches of rain in 24 hours; other north coastal towns were hit as well.

Extreme Weather and Flooding; Sea-Level Rise

Then: The 2010 OCCRI report noted the following: Stronger ocean storms and coastal flooding; "significant physical impacts along the coast and estuarine shorelands of Oregon; increased erosion and inundation; … wetland loss … > 1.0-meter sea level rise by 2100; … increasing storm intensities and the heights of the waves."

Now: In 2007, the town of Vernonia in Oregon's Coast Range suffered severe flooding for the third time in 19 years as the Nehalem River responded to 6.–7.5 inches of rain in 24 hours; other north coastal towns were hit as well. In November 2015, flooding shut down U.S. 101 in Tillamook, Oregon Other incidents of heavier than expected rain events have been associated with storm activity in the past two decades. However, it is not yet clear whether these recent precipitation patterns have resulted in significant new levels of winter flooding in Oregon that can be "fingerprinted" as climate-change induced. (OCCRI, 2017)

[13] Results of 2002-2016 GRACE Mission, reported in *The Washington Post*, May 16, 2018.

North Oregon coast showing 1997 high-water line (red line) moving inland by 2008 (Allan, 2009). Photos by Don Best.

Closer to the ocean, some 7,400 north coast residents live in the "inundation" zone (Dalton et al., 2017, p.35),[14] at risk from a predicted sea-level rise in 2100. Sea-level rise has been accelerating to (at least) 3.2 millimeters per year since 1993 (up from 1.2 millimeters per year between 1901 and 1990). "Tall waves, intense storms and El Niño combine with sea level rise to produce amplified coastal erosion. … The cost of adaptation to sea level rise and storm surge may be on the order of $1.5 billion through 2100" (Dalton et al., 2017, p.34-35).

Elsewhere: On average, global sea levels are rising at more than 3 millimeters per year (and rose 17 centimeters during the 20th century,[15] or almost 7 inches, from two effects of climate change: melting ice sheets and thermal expansion of ocean waters. The effect puts at risk coastal populations around the world; threatens to submerge many low-lying island nations; increases the risk of coastal flooding from stronger storm surges acting on higher sea levels (see Hurricanes Florence, Harvey, Irma, Sandy, Katrina, etc.); leads to contamination of fresh water supplies with salt water; and alters ecological habitats for many animal and plant species.

"One-hundred-year" flood zones are becoming 50-year or riskier zones. New York City, battered by flooding into lower Manhattan from Hurricane Sandy, is planning for the much worse flooding expected with a 2.5-foot global sea-level rise

[14] Defined as "within reach of the mean highest high tide projected for 2100."

[15] NASA, https://climate.nasa.gov/resources/education/pbs_modules/lesson3Overview/

by 2050. Some 40% of the U.S. population lives in coastal zones, while elsewhere around the world much poorer populations are at equivalent risk but without the means to construct barriers and other coping structures.

Hurricane Florence is pounding the Carolinas as this Report is being written, with rainfall 50% greater than it would have been without climate change, according to new analytic tools for distinguishing the climate "footprint" in extreme weather events. Fueled by ocean temperatures 2–4 degrees F above historic averages, the storm was larger (by 8–9%) and slower moving (allowing more rain intensity) than it would have been without the climate change bump (Reed, 2018).

In August 2017, Hurricane Harvey flooded Houston with up to 51 inches of rain in some areas (30 trillion gallons of water) (Schwartz, August 24, 2018), causing some 106 deaths and $125 billion in damages. Harvey's precipitation accumulations appear to have been more than 38% higher than they would have been without climate change effects (Risser and Wehner, December 12, 2017).

In the United States, 2017 was notable for its destructive hurricane season, with Irma and Maria piling atop Harvey. Updated casualty figures attributed 2,975 deaths in Puerto Rico to Maria, along with major impacts to infrastructure (e.g., nearly a year's delays in restoring electrical service island wide, estimated damage costs of $90 billion). New Orleans has yet to recover from 2005's Katrina (1,833 deaths, $160 billion in damages) (*The Economist*, 22 September 2018, pp. 54-55).

2018 saw extreme flooding events in Japan (200 dead), India (350 dead, 800,000 displaced), Southeast Asia (notable for the 12 teenaged soccer players rescued from their flooded cave in Thailand), and elsewhere.

While the impacts of tropical storms and flooding are hardly unknown in human history, their extent, intensity (wind strength), and moisture content (rainfall) have measurably increased as climate change effects have become more pronounced (Wikipedia, 2018, "Tropical Cyclones and Climate Change").

In 2018, Category 5-equivalent Typhoon Mangkut hit the Philippines with winds up to 125 mph and gusts over 200 mph,[16] doubling down on the destruction from last year's Typhoon Haima and from 2013's deadly Haiyan. ("Yolanda," as Haiyan was known, with sustained winds of 195 mph, left more than 7,000 people dead or missing and caused estimated damages of $14.5 billion). There is emerging consensus that such extreme storm events in the Pacific are becoming more intense and destructive, and that these changes are fueled by warming ocean temperatures.[17]

[16] BBC News, 15 September 2018.

[17] "… typhoons in the north-west Pacific had intensified by 12–15% on average since 1977. The proportion of the most violent storms — categories 4 and 5 — doubled and even tripled in some regions over that time and the intensification was most marked for those storms which hit land. … The intensity of a typhoon is measured by the maximum sustained wind speed, but the damage caused by its high winds, storm surges, intense rains and floods increases disproportionately, meaning a 15% rise in intensity leads to a 50% rise in destructive power" (Wei and Xie, September 5, 2016). And, "the strongest future storms will exceed the strength of any in the past" (Rahmstorf, Emanuel, Mann, et al., May 30, 2018).

OCEAN CONDITIONS

Then: According to the Oregon Climate Change Research Institute 2010 Assessment: "Substantial increases in water temperatures in the ocean are likely and will exceed natural variability. The ocean also absorbs carbon dioxide (CO2) from the atmosphere, which forms carbonic acid and is making waters corrosive to certain species. … The combination of these climate and near-shore ocean changes will exert stress on the communities of near-coastal and estuarine organisms."[18]

Now: The West Coast has already reached an acidification threshold and negative impacts are already evident, such as dissolved shells in pteropod[19] populations and impaired oyster hatchery operations. … 60 percent of the dissolved inorganic carbon in surface waters off Oregon's coast in 2013 is attributed to increasing greenhouse gas concentrations (Dalton et al., 2017).

Sixty percent of the dissolved inorganic carbon in surface waters off Oregon's coast in 2013 is attributed to increasing greenhouse gas concentrations.

Heat in Oregon's offshore waters is contributing to marine harmful algal blooms (HABs) adverse to the $70 million annual Oregon Dungeness crab catch (McCabe, Hickey, Kudela, et al., 2016), also impacts to salmon food species (Barth, Fram, Dever, et al., 2018).[20] "Ocean acidification … impairs the ability [of shellfish] to build shells" (OCCRI, 2017, p. 36). Scientists project that the West Coast "will face some of the earliest, most severe changes in ocean carbon chemistry [driven by climate change, including] intensification and expansion of low dissolved oxygen — or hypoxic — zones" (Chan, Boehm, Barth, et al., 2016). Oregon's commercial and recreational fisheries together amount to around $200 million annually (Oregon Department of Fish and Wildlife, 2017).

Elsewhere: The years 1982 to 2016 saw a doubling of the number of marine heat waves (exceeding the 99th percentile) globally, affecting phytoplankton (Frölicher, Fischer, and Gruber, 2018) that are the base of the ocean food chain and increasing the "Blob," a large area of persistent warm Pacific Ocean water present 2013–2016, reflecting wider abnormal ocean temperatures that depressed phytoplankton production, causing widespread declines in the ocean food web that, among other effects, led to death by starvation for thousands of California sea lion pups (Cavole, Demko, Diner, et al., 2016, http://dx.doi.org/10.5670/oceanog.2016.3).

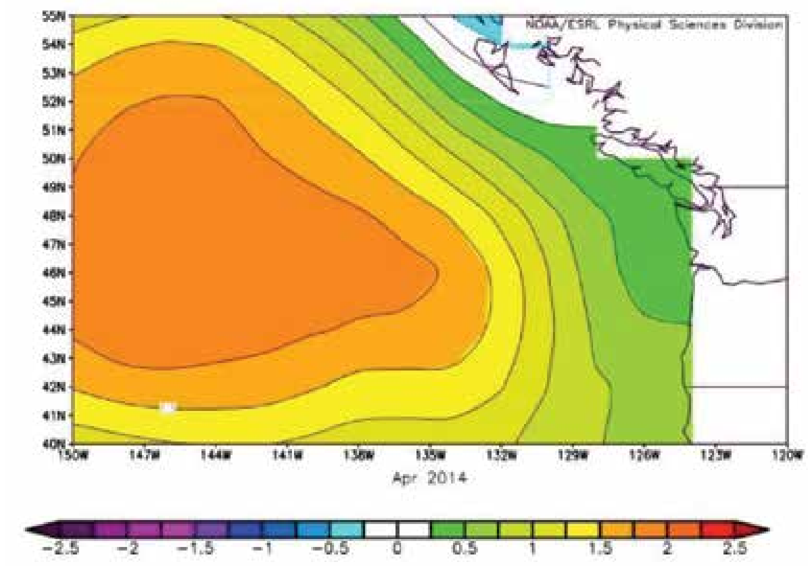
Kelp forests off the Pacific Coast have collapsed to less than 10% of their original density and range in just the last 10 years, the result of a food web disrupted by ocean warming, including effects of the "Blob." The red urchin and abalone commercial fisheries, collectively involving some $40 million in coastal business, are suffering (Pierre-Louis, October 22, 2018).

[18] See OCCRI, 2010, Legislative Summary, Executive Summary, and Chapter 6.

[19] Pteropods are small free-swimming mollusks that are a critical base species on which marine food webs, and the marine populations above, depend. (See *Third Climate Assessment*, 2017, chap. 4 — "Coastal Issues" — p. 37).

[20] Additional information via direct communication from Dr. Caren Braby, Oregon Department of Fish and Wildlife, October 2, 2018, on the value of Oregon Dungeness crab fishery.

Figure 4. The Blob (Pacific Ocean)



"The Blob is an anomalous body having sea surface temperature much above the normal (+2.5ºC), seen here in a graphic of April 2014 by the NOAA" (from Wikipedia article: "The Blob (Pacific Ocean)."

The phenomenon was detectable into the fall of 2018. It is thought to affect West Coast weather patterns as well as ocean food web nutrient levels by dampening upwelling of deep, cold, nutrient-rich ocean waters.

Source: Wikipedia, 2016, "The Blob (Pacific Ocean)," https://en.wikipedia.org/wiki/The_Blob_(Pacific_Ocean)

Infrastructure

Then: "Projected climate changes in precipitation rates and temperatures are likely to threaten the integrity of the built environment, including buildings, roads, highways and railroads, water and sewage systems, and energy facilities throughout Oregon" (OCCRI, 2010, p. 393).

Now: The Eagle Creek Fire interrupts commercial traffic on I-84; flooding occurs (e.g., Vernonia, 2007). Unseasonable warming in November 2006 melted ice and released a rock slide that closed OR 35 for >30 days. (OR 35 has a history of such washouts, more than 20 since 1907; five have occurred since 1998 [Wikipedia, "Oregon Route 35," 2018].)

Some 2,800 miles of roads in Oregon and Washington are in the 100-year floodplain; some highways may face increased inundation with 2 feet of sea-level rise (Dalton, Mote, and Snover [Eds.], 2013). An Oregon Department of Transportation 2012 analysis notes that "Oregon's coastal roadways already experience the effects of climate change. U.S. Highway 101 near the City of Seaside, Oregon, experiences habitual flooding problems causing road closures and delays multiple times every year." Impacts to coastal roadways will come, according to Oregon Department of Transportation, from "2–4 feet of sea-level by 2100 … Increases in wave heights … [and] inundation and erosion, [leading to slides] along the entire coastline" (Oregon Department of Transportation [ODOT], 2012, p. 16).

Summer 2018 heat in Portland forces MAX lines to slow down when temperatures exceed 95 degrees F, in turn slowing the overall commute.[22]

[21] Bureau of Reclamation, "Climate Change Initiative Briefing to NW Power Planning Council," July 13, 2011.

[22] See Njus, August 4, 2016, "Why do TriMet MAX and WES trains have to slow down in the heat?"

Less predictable river/reservoir flows make scheduling flood drawdowns and hydro generation more difficult,[21] while potential low summer stream flows put Oregon's irrigated agriculture sector at risk.

Elsewhere: The integrity of dikes and levees in Netherlands is threatened during the 2018 drought because of the scarcity of the fresh water flows necessary to offset sea water pressure (*Daily Express*, July 5, 2018). Elsewhere, Hurricanes Sandy (New York City subway flooding), Katrina (all New Orleans city services interrupted), and Maria (Puerto Rico electricity service failed and not fully restored for almost a year) illustrate the potential infrastructure impacts, always remembering that third-world infrastructure is already often unsteady and fragile, prone to interruption from lesser forces than those threatened by climate change, and far slower to recover (see Puerto Rico power system recovery).

"Nearly $51 million in tourism revenue was lost in Oregon [in 2017] because of wildfires," according to a study conducted by Travel Oregon

In 2017, the U.S. Government Accountability Office reported that direct federal government costs for responding to "extreme weather and fire events" were $350 billion more than in the prior decade (U.S. Government Accountability Office, 2017).[23] The report repeated the prediction in the *Third National Climate Assessment* that "the impacts and costs of extreme events — such as floods, drought, and other events — will increase in significance as what are considered rare events become more common and intense because of climate change."

ECONOMY

Then: The 2010 Oregon Climate Change Research Institute Report warned that "climate change poses economic risks to the state" (OCCRI, 2010, Legislative Summary).

Now: "Nearly $51 million in tourism revenue was lost in Oregon [in 2017] because of wildfires," according to a study conducted by Travel Oregon (Oregon Public Broadcasting, August 23, 2018). By the end of August 2018, the Oregon Shakespeare Festival in Ashland estimated that it had already lost 10% of its budgeted revenues, or $2 million, to smoke-driven performance cancellations or relocations (Flaccus, September 25, 2018). Costs for health care, fire fighting, commercial freight interruptions, reduced hydropower generation, drought effects on agriculture, and coping with other economic impacts of advancing climate change are increasingly apparent to Oregonians.

Since 1915, the western U.S. snowpack has declined by 21%, or 36 square kilometers (Dalton, Mote, and Snover, 2013, Executive Summary, p. 14) greater than the volume of water stored in the West's largest reservoir, Lake Mead, creating a challenge to western water managers. Irrigation, hydropower generation, navigation, recreation, and ecological sustainability are all put at risk. In recent years such as 2014–15, Oregon ski resorts have struggled to open (e.g., Mt. Ashland failed to open at all that year).

[23] Based on information from the Office of Management and Budget, FY 2017 Budget: "… including $205 billion for domestic disaster response and relief; $90 billion for crop and flood insurance; $34 billion for wildland fire management; and $28 billion for maintenance and repairs to federal facilities and federally managed lands, infrastructure, and waterways."

Oregon's forests provide Oregonians with "ecosystem services," the value of which can in many cases be quantified. Intact, sustainably functioning forest ecosystems provide the Pacific Northwest with $3.2 million per year in water purification, $5.5 million in erosion control (in the Willamette Valley alone), and $144 per household per year in cultural and aesthetic benefits (e.g., hiking, camping, and viewing). Climate change in Pacific Northwest forests could cost the region $650 million in recreation revenue losses by 2060 (Dalton, Mote, and Snover, 2013, Executive Summary, p. 14).

Some agricultural crops may benefit from added carbon dioxide supporting growth, but other crops (and farm earnings) stand to suffer from heat, insect predation, weed growth, reduced precipitation and irrigation water during summer months, excessive precipitation in winter months, reduced temperatures for fruit set, and impaired nutrient value of food crops.

An analysis of the costs associated with the public health effects of wildland smoke exposure estimated the "value" (cost) of long-term exposure, nationwide, at between $76 billion and $130 billion annually. Six states, including Oregon, were judged to be most affected (Fann, Alman, Broome, et al., 2018)

The Pacific Northwest seafood industries (including scallops, oysters, mussels, and crabs), which subject to ocean acidification and hypoxia, will be affected, as will commercial and recreational fishing (a $9.5 billion industry in the two states, with 84,000 jobs at stake). Ocean salmon, herring, mackerel, and other commercial finfish, dependent on food chain base species such as pteropods, whose shells are being damaged by ocean acidification, are likely to be adversely affected (OCCRI, 2017, chap. 4; Barth, Fram, Dever, et al., 2018).

The Pacific Northwest seafood industries (including scallops, oysters, mussels, and crabs), which are subject to ocean acidification and hypoxia, will be affected, as will commercial and recreational fishing (a $9.5 billion industry in the two states, with 84,000 jobs at stake).

Elsewhere: Extreme weather ("cold winter and baking summer") is projected to increase household food bills in the United Kingdom by 5% in 2018; harvest of European wheat and other grains could be down in 2018 by 5% (Davis, August 27, 2018).[24] A U.N. report on global hunger identifies "climate shocks, such as droughts and floods, as 'among the key drivers' for the rise [in global hunger] in 2017." That would be the third such year since 2015, after years of progress in reducing this affliction; (the U.N. report issued this year does not take account of 2018's weather extremes, but Oxfam GB warns that "a hotter world is proving to be a hungrier world") (Harvey and McVeigh, September 11, 2018).

Few third-world countries are positioned to fund both decarbonization of their energy sectors and sufficient adaptation and preparation strategies for expected public health, food supply, infrastructure, and other impacts.

[24] Center for Economics and Business Research, reported in *Guardian Weekly*, August 27, 2018. Also of note: "… for every degree Celsius (about 1.8 °F) that temperatures increase, the world loses about 6% of its wheat crop." University of Florida professor of agriculture and biological engineering Senthold Asseng determined these findings through computer modeling. "Global food production needs to *grow* [italics added] by 60% by 2050 to keep up with population increases" (*Farm Journal*, 2018. Agweb).

There are ample additional examples of climate change effects locally and globally. From these we can infer three broad truths:

1. On a plain reading of the evidence, climate change is occurring in real time. Its effects are being felt, in Oregon and around the world, today and not in some distant and uncertain future. Discerning these effects no longer requires scientific instruments and models, only stepping outdoors to take in the heat and smoke.

2. Over the last three decades we have been repeatedly warned of higher deferred costs if we fail to intervene early, both to reduce emissions and to adapt to the effects of climate change. It is now later, and in many cases — not all — costs are occurring as predicted. The happy exception is that the costs of certain critical renewable resources and clean vehicle technologies have come down (but these would have come down earlier, with greater savings, if we'd forced the technologies earlier). Notwithstanding these examples of how to successfully deal with this challenge, we still drag our feet.

3. If we ended greenhouse gas emissions tomorrow, climate change effects would persist and worsen for decades to come. Cutting climate change off from its greenhouse gas fuel is like stopping a ship's engines: It does not stop the inertial forward motion but only allows it to gradually slow. Our children, and theirs, will be living for decades with the worsening consequences of our failure to take timely action when we knew we should. Bad as that is, further delay only makes it worse.

Oregon, and the nation, must also anticipate that climate change may not be linear. While average temperatures and other effects may take place predictably, their consequences may surprise and shock us with a kind of climatic "suddenness." *The Fourth National Climate Assessment Volume 1* (USGCRP, 2017) includes Chapter 15, "Potential Surprises, Compound Extremes and Tipping Elements." It contemplates multiple events reinforcing each other and compounding their effects, such as warm, wet winters followed by early and drier springs and summers; heavy rain on snow exacerbating flooding; or powerful ocean wind storms leveraging higher sea levels to create extreme tidal storm surges.

We have already seen some of these effects (e.g., Hurricanes Sandy, Harvey, and Florence). Other effects (e.g., release of frozen methane from melting permafrost) could have more far-reaching consequences.

And the Report acknowledges that "climate models … are more likely to underestimate than to overestimate the amount of long-term future change" (U.S. Global Change Research Program, 2017).

Even if they are not right about this, but more so if they are . . . we have only begun to sense the change that our children will be called upon to cope with.

Section 2:

Update on Oregon's Greenhouse Gas Emissions Inventories

In May 2018, the Oregon Department of Environmental Quality published a comprehensive report evaluating Oregon's greenhouse gas emissions (Oregon Department of Environmental Quality DEQ, 2018), using both "sector-based" and "consumption-based" accounting frameworks. This Oregon Global Warming Commission Report builds on a history of statewide inventory work:

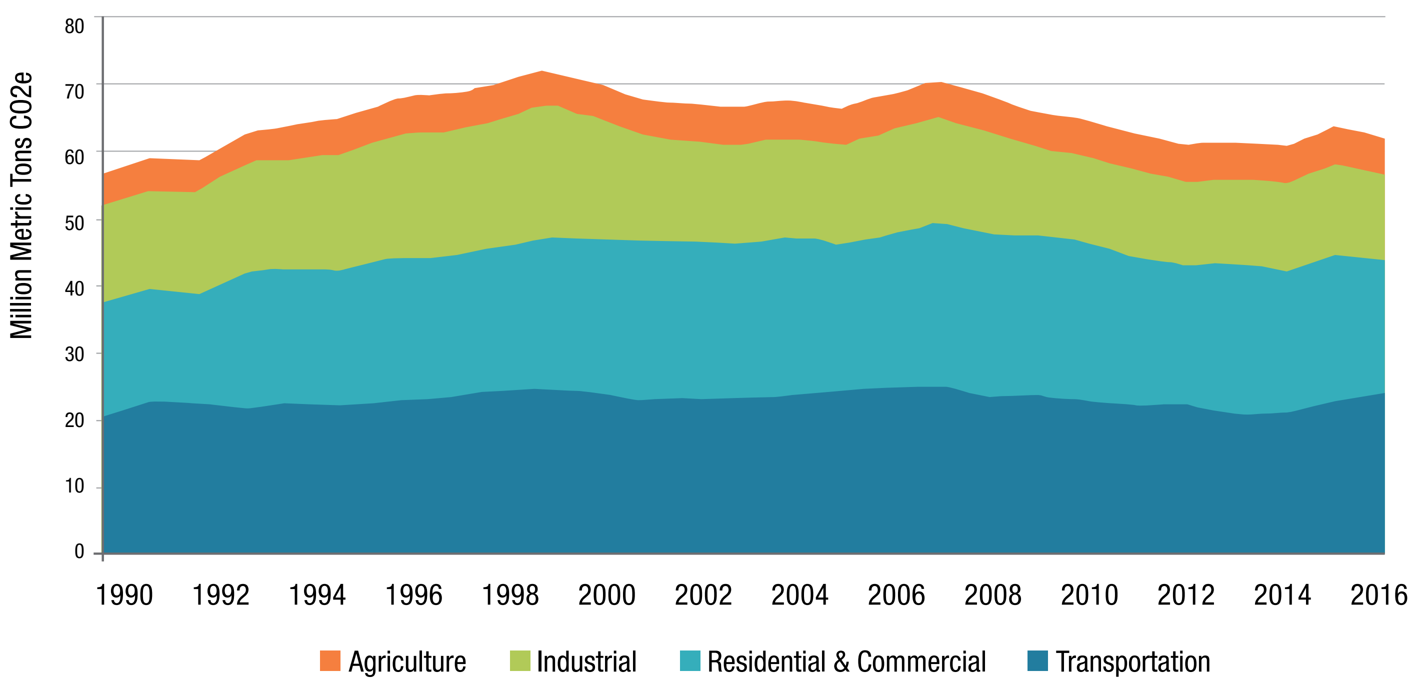
- Prior to 2011, Oregon's greenhouse gas inventory was limited to a single accounting framework (now called "sector-based") that included in-state emissions as well as emissions from generating electricity used in Oregon, regardless of where the generation occurred. Historically, this sector-based inventory was constructed in a "top-down" fashion, using an inventory tool published by the U.S. Environmental Protection Agency.
- In 2010, Oregon's largest emitters of GHGs began reporting their emissions to the Oregon DEQ as part of the mandatory greenhouse gas reporting program, allowing the DEQ to begin estimating most sector-based emissions using a "bottom-up" method.
- In 2011, DEQ published its first estimate of Oregon's emissions using an alternative, supplemental accounting framework: Oregon's consumption-based emissions inventory for 2005.
- In 2013, the Oregon Departments of Environmental Quality, Energy, and Transportation produced an integrated report that combined three inventories, using data up to 2010: (1) "in-boundary" emissions (now called "sector-based" emissions), which are those that occur within Oregon's borders plus emissions associated with the generation of electricity used in Oregon; (2) consumption-based emissions, which are those global emissions associated with satisfying Oregon's consumption of goods and services, including energy; and (3) expanded transportation sector emissions, which evaluated the full life-cycle emissions from fuel use by ground and commercial vehicles, freight movement of in-bound goods, and air passenger travel.
- In 2015, the *Oregon Global Warming Commission Biennial Report to the Legislature* included updates to these three inventories.
- In 2017, the *OGWC Biennial Report to the Legislature* included updates to the sector-based inventory.

Following is a summary of the results from the 2018 DEQ report. Appendix A provides a more detailed look at the underlying data. For more information and to download copies of the report, please see: https://www.oregon.gov/deq/FilterDocs/OregonGHGreport.pdf.

Sector-Based Inventory

Oregon's sector-based emissions from 1990 through 2016 are shown in Figure 5 and Table 1. The graph illustrates trends in emissions in this period within the key sectors, including emissions from the generation of electricity used in Oregon, regardless of where that electricity was generated. Statewide emissions declined from2007 through 2012 but have since increased. Sector-based emissions were 63 million metric tons of carbon dioxide equivalents (MTCO2e) in 2015, 62 million MTCO2e in 2016, and our preliminary estimate is ~64 million MTCO2e for 2017. Transportation continues to be Oregon's largest in-state contributor to emissions and accounted for 39% of the statewide sector-based total in 2016. In fact, transportation emissions have risen during each of the past three years. The second largest sector of emissions originates from the generation of electricity used in Oregon, with the residential sector creating the greatest demand. Emission trends in the electricity sector reflect both the impact associated with electricity demand and the influence of the availability of hydroelectricity, Oregon's largest source of zero-emitting energy.

Figure 5. Statewide sector-based greenhouse gas emissions: 1990-2016



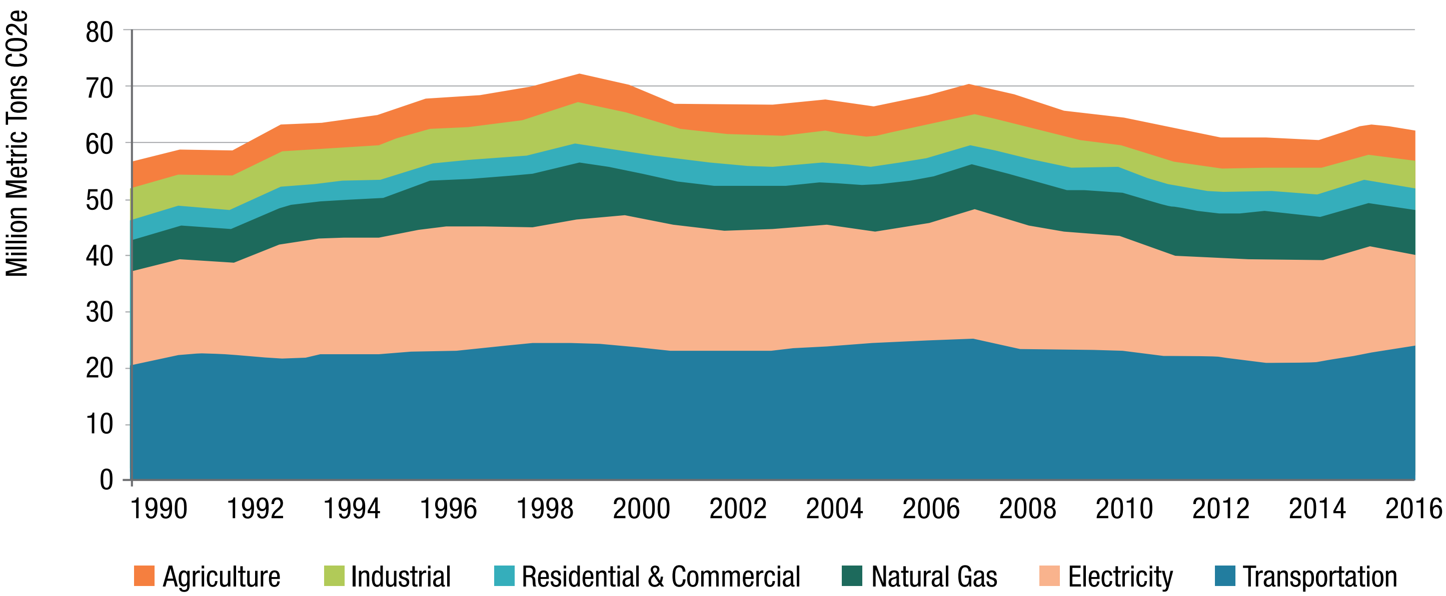
Source: DEQ, 2018

Table 1. Oregon emissions by sector: 1990-2017
(in million MTCO2e by 5-year increments + 8 most recent years)

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017
Transportation	21	23	24	25	23	22	22	21	21	23	24	25.7 (prelim)
Residential & Commercial	16	20	23	22	24	22	21	22	21	22	20	21.1 (prelim)
Industrial	14	17	18	14	12	12	12	12	12	13	12	12* (2016 data)
Agriculture	5	5	5	6	5	6	6	6	6	6	6	6* (2016 data)
Total	**56**	**65**	**70**	**66**	**64**	**62**	**61**	**61**	**60**	**63**	**62**	**64-65* (prelim)**

* These values are not yet available for 2017, but because emissions from Oregon's industrial and agriculture sectors do not generally vary greatly from year to year, we report a preliminary range for the state's total GHG emissions in 2017.

Figure 6. Sector-based emissions with electricity and natural gas aggregated for all sectors: 1990-2016



Source: DEQ, 2018. Note that this figure is identical to Figure 1 except that it shows electricity and natural gas usage taken out of the emissions of the other sectors and aggregated separately.

Table 2. Oregon sector-based emissions with an energy lens: 1990-2017 (in million MTCO2e by 5-year increments + 8 most recent years)

	1990	1995	2000	2005	'10	'11	'12	'13	'14	'15	'16	2017
Transportation	21	23	24	25	23	22	22	21	21	23	24	25.7 (prelim)
Electricity Use	17	21	23	20	20	18	17	18	18	19	16	17.1 (prelim)
Natural Gas Use	5	7	8	7	8	8	8	8	8	7	7	7* (2016 data)
Other Residential & Commercial[25]	3	3	4	4	4	4	4	4	4	4	4	4* (2016 data)
Other Industrial[26]	5	6	6	5	4	4	4	4	4	4	4	4* (2016 data)
Agriculture	5	5	5	6	5	5	6	6	6	6	6	6* (2016 data)
Total	**56**	**65**	**70**	**66**	**64**	**62**	**61**	**61**	**60**	**63**	**62**	**64-65* (prelim)**

Source: DEQ, 2018. A more detailed breakdown is provided in Appendix A.
* These values are not yet available for 2017, but because emissions associated with natural gas use, other residential and commercial, other industrial, and agriculture do not generally vary greatly from year to year, we report a preliminary range for the state's total GHG emissions in 2017.

Figure 6 and Table 2 present a different view of statewide emissions, breaking out and aggregating electricity and natural gas emissions from all sectors separately from the residential, commercial, and industrial sectors. When viewed this way, transportation is still Oregon's largest sector of emissions, followed by statewide electricity use and natural gas combustion. Emissions in the remaining sectors primarily include petroleum combustion (e.g., fuel oil for heating), waste and wastewater, and industrial process manufacturing.

More than half of the recent increased level of emissions is due to gasoline and diesel use (DEQ, 2018). 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% of the statewide total in 2014 to 39% in 2016, while electricity

[25] This row presents the remaining GHG emissions after emissions from electricity and natural gas use are separated out. These are primarily associated with petroleum combustion (e.g., fuel oil for heating) and GHG emissions from waste and wastewater originating in the residential and commercial sectors.

[26] This row presents the remaining GHG emissions after emissions from electricity and natural gas use are separated out. These are composed primarily of emissions from petroleum combustion, industrial waste and wastewater, and industrial process manufacturing (e.g., production of cement, paper products, ammonia, urea, etc.).

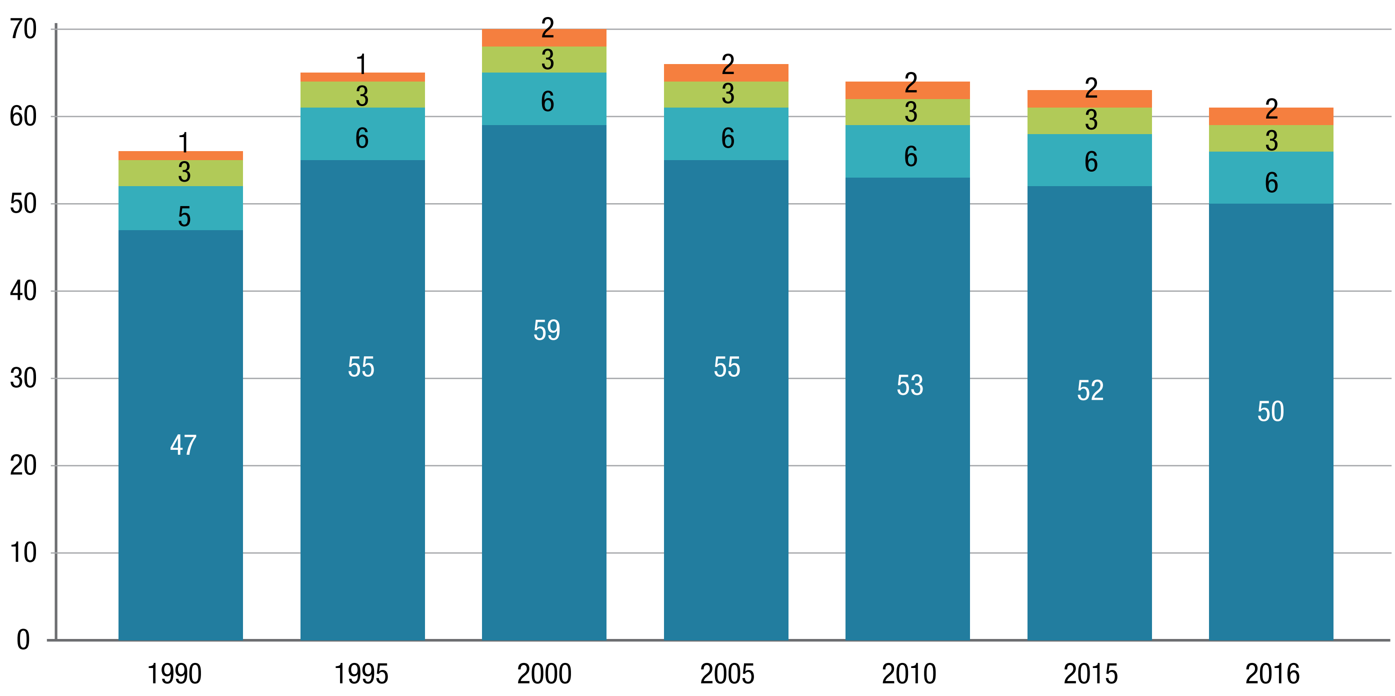
use emissions decreased from 30% to 26% of the state's total emissions, and all other sectors stayed relatively constant over the same period. Section 3 of this OGWC report will provide a deeper dive into transportation and electricity sector emissions and future projections.

Figure 7 shows the breakdown of Oregon's emissions by key greenhouse gases, including carbon dioxide, methane, nitrous oxide, and high global warming potential (HGWP) gases. Carbon dioxide makes up approximately 80% of statewide sector-based emissions and primarily originates from the combustion of fuels, including the generation of electricity. The second most abundant gas, methane, makes up approximately 10% of the statewide sector-based total. Methane emissions are primarily a result of agricultural activity but also originate from landfills and natural gas distribution.

Over time, the relative contributions from carbon dioxide, methane, and nitrous oxide have stayed relatively constant, while the share of HGWP gases has grown from 1% of statewide emissions in 1990 to 4% of emissions in 2016. Although HGWP gases are emitted in small quantities, their impact is significant due to their long atmospheric lifetimes and their ability to absorb energy, which is hundreds to thousands of times higher than carbon dioxide.[27]

Figure 8 compares Oregon's historical and projected GHG emissions to our statewide goals. Projected emissions are a forecast of Oregon's emissions assuming compliance with existing state policies, such as the Renewable Portfolio Standard and Clean Fuels program, and the continuation of certain federal standards like for fuel efficiency of cars and light-duty trucks (Section 4 of this report will describe why these assumptions may not hold true moving forward). The red dashed line in Figure 8 shows the trajectory of Oregon's projected emissions with these existing policies taken into account. This level is well above the state's goal of 51 million MTCO2e by 2020 and the Commission's adopted interim goal of 32.7 million MTCO2e by 2035, and it does not put Oregon on a path toward achieving its long-term goal of 14 million MTCO2e by 2050.

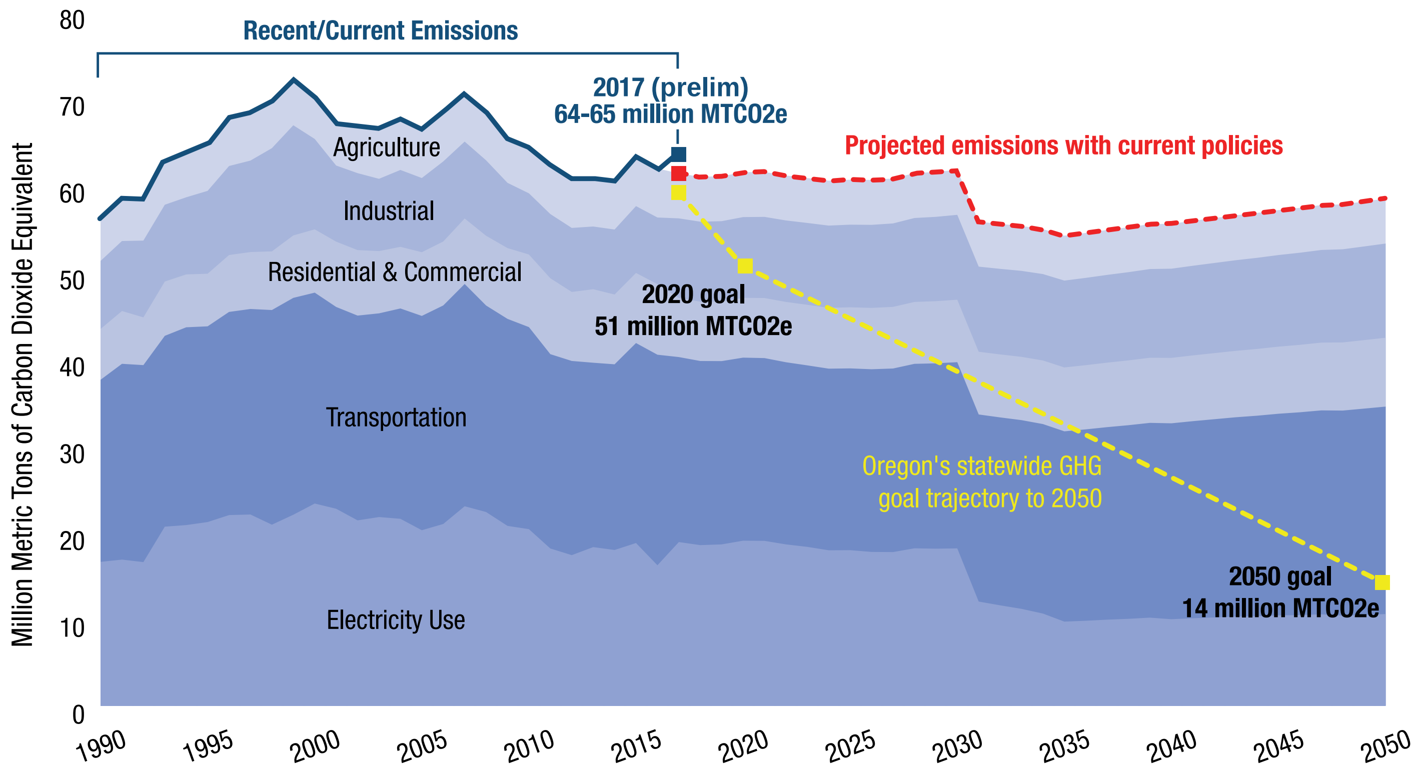
Figure 7. Statewide greenhouse gas emissions by gas over time



Source: DEQ, 2018

[27] DEQ uses 100-year global warming potentials from the *Fourth Assessment Report* of the Intergovernmental Panel on Climate Change (2007) to quantify greenhouse gas emissions in accordance with the most current accounting guidance from the United Nations Framework Convention on Climate Change.

Figure 8. Oregon past and projected greenhouse gas emissions compared to goals



Consumption-Based Inventory

Oregon also estimates its contribution to global greenhouse gas emissions using a consumption-based inventory. The consumption-based inventory estimates the global emissions resulting from consumption of goods and services (including energy) by Oregon consumers. Consistent with standards for national economic accounting, "consumers" include households and governments, as well as certain types of business expenditures (capital investment and inventory formation). Consumption-based emissions are calculated across the life cycle of items consumed. The consumption-based inventory supplements the sector-based inventory primarily by highlighting emissions resulting from the consumption of imported goods and services. Combined, the two inventories tell a more comprehensive story of how Oregon contributes to greenhouse gases and, by extension, to potential opportunities to reduce emissions.

Oregon's consumption-based greenhouse gas emissions in 2015 were 88.7 million MTCO2e, up from 79.6 million MTCO2e in 2005 and 80.2 million MTCO2e in 2010. Data from the consumption-based inventory also indicates that household demand is overwhelmingly the driver of consumption-based emissions, and that lower-income households on average consume less and generate fewer emissions (per household), while higher-income households on average generate more emissions.

Figure 9 illustrates how these and other emissions have changed between 2005 and 2015. The use of vehicles, production of food, and use of appliances (primarily for heating and cooling) contribute the most to these emissions, followed by emissions from provision of services, construction, and health care. Figure 10 shows that one category — vehicles and parts — represents fully 20% of all of Oregon's consumption-based emissions,

Figure 9. Consumption-based emissions by major category: 2005 – 2015

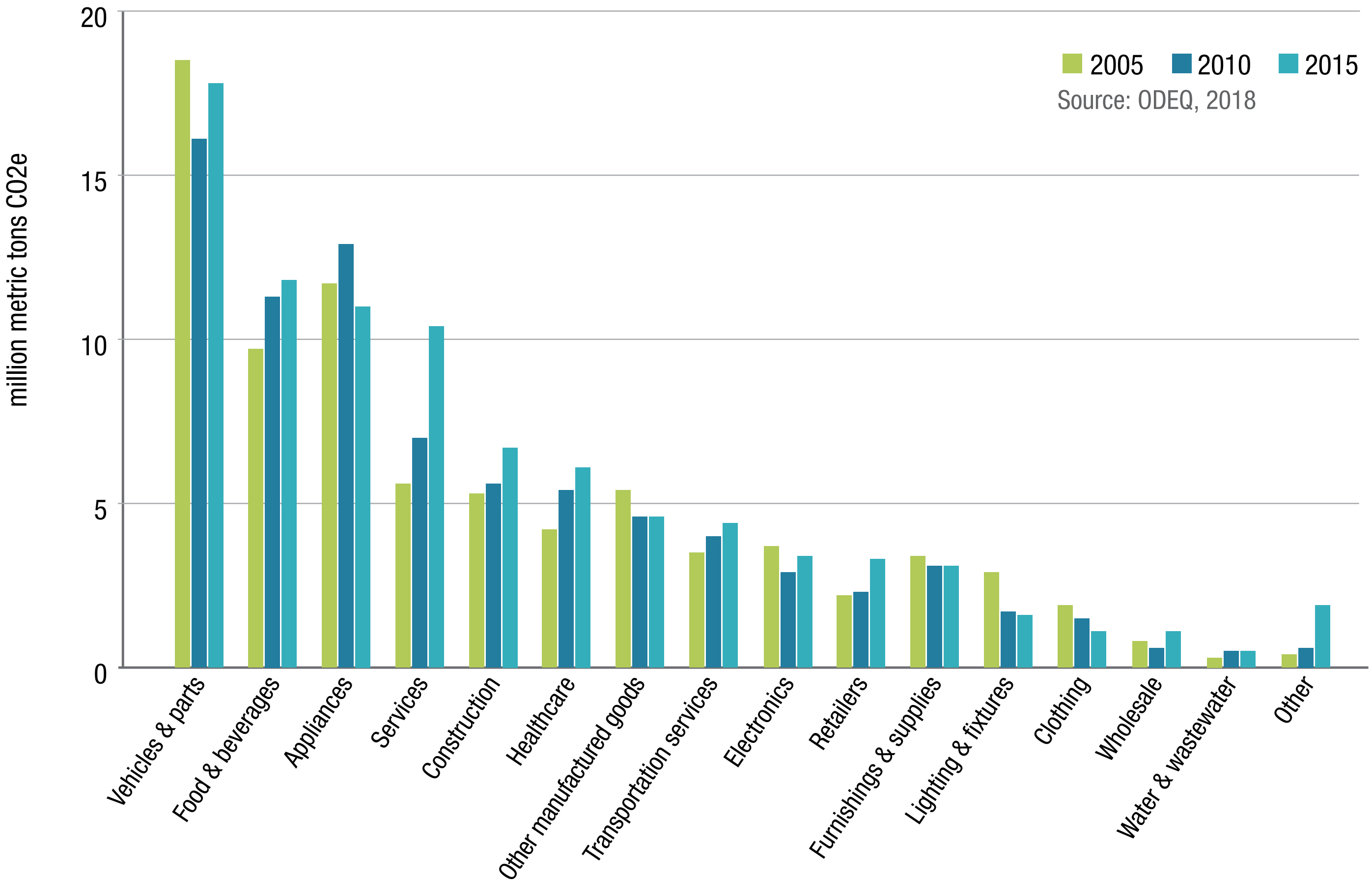
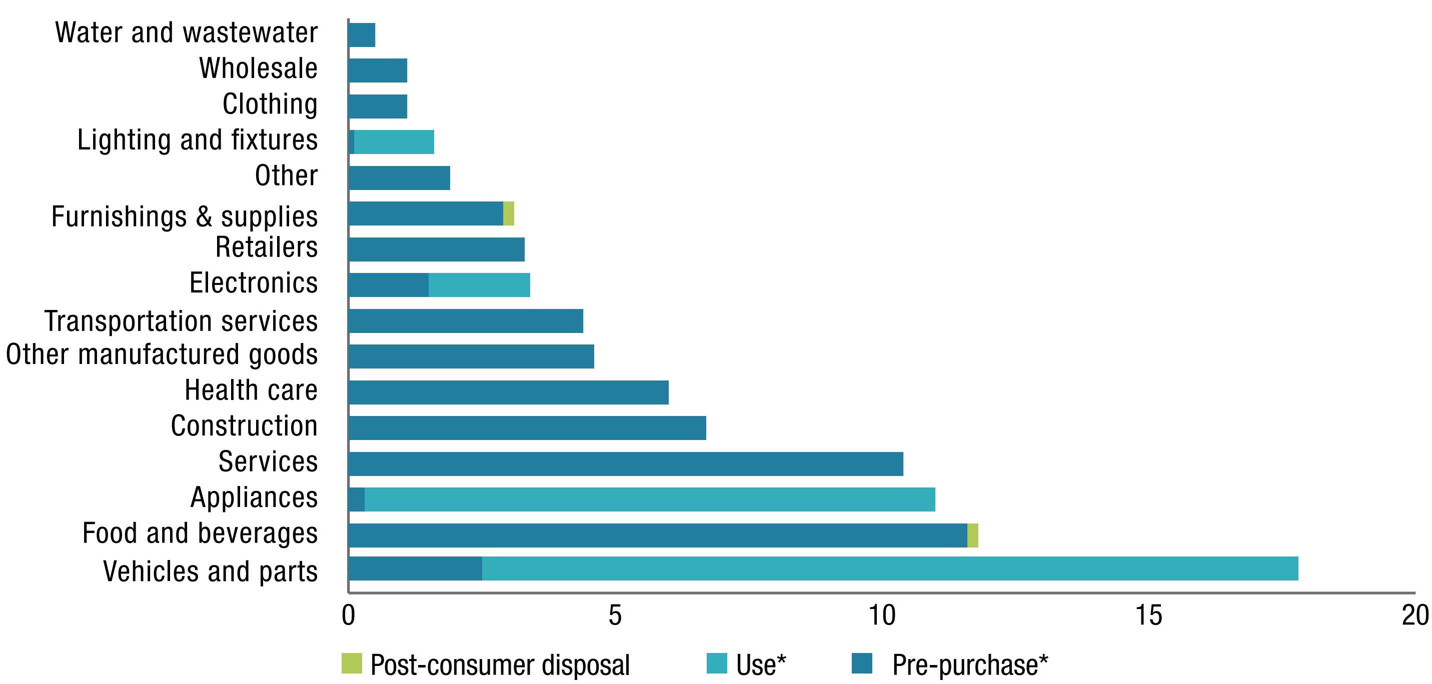


Figure 10. 2015 Oregon consumption-based greenhouse gas emissions, by category and life-cycle stage



"Pre-purchase" are all emissions that occur prior to final purchase, including production, supply chain, transport, retail and wholesale. "Use" refers to emissions resulting from the use of vehicles, appliances, electronics and lighting. Other categories (e.g., food and clothing) have use phase emissions that are accounted for elsewhere. For example, emissions from cooking and laundering are both assigned to the category of "appliances," which includes ranges and clothes dryers.

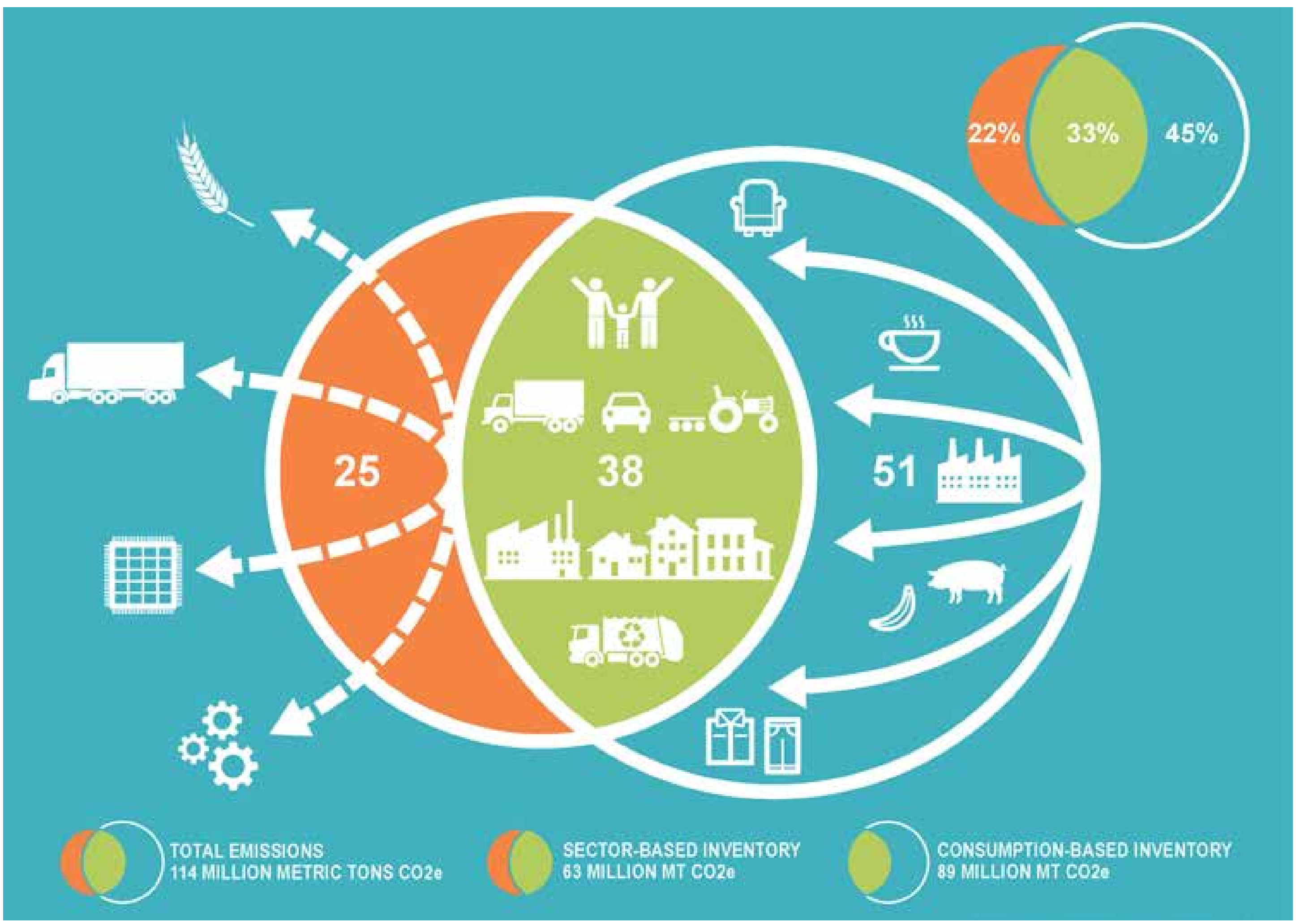
Source: DEQ, 2018

while the next highest category is food and beverages at 13% of the total. The figure also illustrates that the majority of emissions associated with vehicles and their parts are from vehicle use, while for food and beverages the majority of emissions are "pre-purchase" — i.e., associated with their production and sale. Nearly two-thirds of Oregon's consumption-based emissions are associated with just the five highest-emitting categories: vehicles, food and beverages, appliances, services, and construction.

Comparison

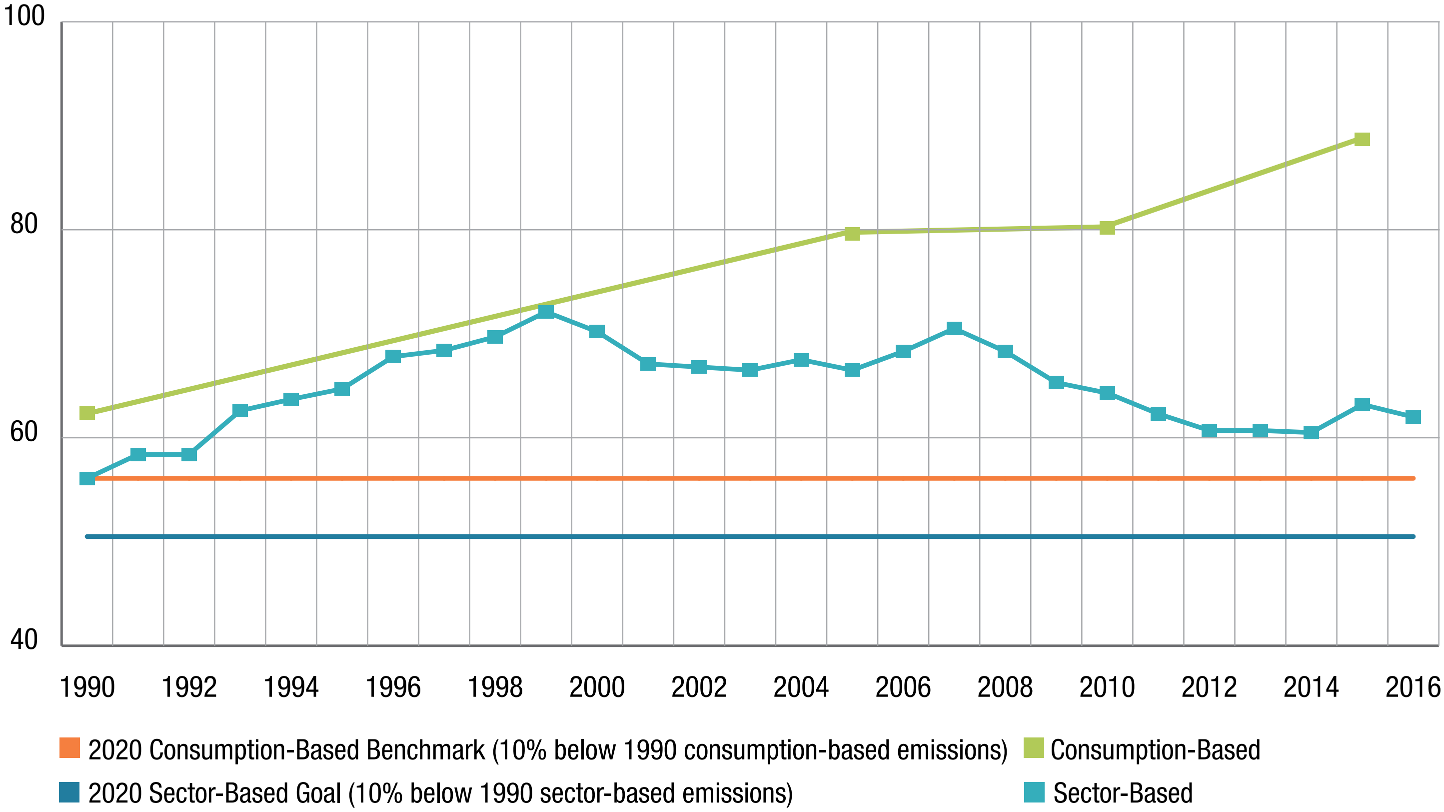
Figure 11 illustrates the relationship between the two inventories. Sector-based emissions for 2015 were approximately 63 million MTCO2e, while consumption-based emissions were approximately 89 million MTCO2e. The inventories share about 38 million MTCO2e in common. These shared emissions are from household and government use of energy and waste disposal, as well as commercial and industrial emissions associated with producing goods and services in Oregon that are consumed in Oregon, such as Oregonians' purchases of local ice cream or health care.

Figure 11. Comparison of Oregon's 2015 sector- and consumption-based greenhouse gas emissions expressed in millions of tons of CO2e



Source: DEQ, 2018. Note that the *left segment* shows emissions occurring in Oregon from making products and services that are exported. The *right segment* shows emissions occurring elsewhere in making products and services imported into Oregon. The *middle segment* shows emissions occurring in Oregon from making products and services in Oregon that are also used in Oregon.

Figure 12. Trends from Oregon's updated GHG inventories



Source: https://www.oregon.gov/deq/aq/programs/Pages/GHG-Oregon-Emissions.aspx

This overlap between the two inventories creates the potential for double counting, which is why the inventory totals are never simply added together.

Approximately 25 million MTCO2e of emissions in the sector-based inventory are distinct, and are associated with the in-state production of exported goods and services. These include Oregon's signature exports: foods, transportation equipment, semiconductors and electrical devices, and machinery. It also includes services that are "exported" to the extent that they are purchased by non-Oregonians, such as hotel stays and restaurant visits by tourists.

Oregon's imported emissions — at 51 million MTCO2e — are double those of our exports. These imported emissions are unique to the consumption-based inventory and include emissions associated with a wide variety of imported finished goods. It also includes additional out-of-state emissions that are not otherwise included in the sector-based inventory, such as out-of-state emissions associated with extracting and producing fossil fuels consumed by Oregonians and the out-of-state emissions embedded in the supply chains of many services and goods consumed by Oregonians, such as Chinese cement and steel.

After eliminating any overlap, the sum of Oregon's 2015 emissions demonstrates a carbon footprint of 114 million metric tons of CO2e — more than either inventory alone. Indeed, Oregon contributes to climate change in many different ways, and when viewed together, these distinct inventories provide a broader understanding of both our emissions and the opportunities to reduce them.

Additional Key Findings

Results from Oregon's updated inventories indicate that Oregon's contribution to global concentrations of greenhouse gases is not subsiding. The combustion of fossil fuel, whether occurring within Oregon or as a result of our consumption, is the key driver of greenhouse gas emissions. Figure 12 shows that Oregon is not on track to reduce statewide emissions 10 % below 1990 levels by 2020, in accordance with its goals. Rather, consumption-based emissions are rising, while sector-based emissions are not declining. The gap between the inventories has also grown over time. Consumption-based emissions were approximately 6 million MTCO2e higher than sector-based emissions in 1990. Fifteen years later, in 2005, that gap doubled (to 13 million MTCO2e), and 10 years later it doubled again (to 26 million MTCO2e in 2015). The Oregon Global Warming Commission will continue to rely on the research and analysis at DEQ and other state agencies to monitor and report on the course of current trends in Oregon's greenhouse gas emissions.

Emissions Intensity Data: A Different Way of Viewing Statewide GHG Emissions

Emissions intensity refers to the emissions of a given pollutant relative to a measurement of a specific activity or number of people. In past OGWC biennial reports, we have presented GHG emissions per capita and emissions per dollar of state gross domestic product (GDP). This helps provide insight about the effects of net population migration and economic activity on the state's absolute (total) emissions numbers. However *only total emissions count* when determining Oregon's contribution to either the forcing of climate change and its effects, or the abatement of climate change and effects.

Tables 3 through 6 present Oregon's per capita and per GDP emissions using both the sector-based and consumption-based emission inventories. Where data are available, we also present estimates of per capita emissions from other jurisdictions nationally and internationally. These are rough comparisons for scale only, since other GHG inventories are not always entirely comparable to Oregon's given differences in accounting methods for GHG emissions from the electricity sector (Oregon's is based on consumption regardless of where the electricity was produced, while other inventories can differ in how they account for electricity production emissions). While the emissions intesity data are a useful comparison to the absolute inventory data, it is important to note that solving the problem of climate change will require absolute reductions in GHGs, not only reductions in emissions per person or per unit of output. It is for this reason that GHG reduction goals and targets around the world – including ours – are expressed in absolute terms. Nonetheless, we endeavor to present these additional data points wherever possible.

The tables present the data and supporting sources for the GHG emissions intensity calculations for Oregon. For the other jurisdictions presented in Tables 4 and 5, GHG data came from those state or country GHG inventories and population data from the U.S. Census Bureau and Eurostat. Dashed boxes in all tables indicate years for which comparable data are not available.

Table 3. Data and supporting sources for emissions intensity calculations

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016
Total sector-based GHG emissions (MMT)[1]	56.4	64.9	70.7	66.2	63.9	62.4	60.2	60.3	60.3	63.4	61.9
Total consumption-based GHG emissions (MMT)[1]	62.4	-	-	79.6	80.2	-	-	-	-	88.7	-
Population (millions)[2]	2.8	3.2	3.4	3.6	3.8	3.9	3.9	3.9	4.0	4.0	4.1
State GDP (millions of real 2009 dollars)[3]	92,850	114,805	130,992	153,771	190,371	198,298	192,598	188,806	190,626	199,682	207,367
Total	**56**	**65**	**70**	**66**	**64**	**62**	**61**	**61**	**60**	**63**	**62**

Sources:
1. Oregon GHG Inventory (www.oregon.gov/deq/aq/programs/Pages/GHG-Oregon-Emissions.aspx)
2. Portland State University Population Research Center (www.pdx.edu/prc/home)
3. U.S. Department of Commerce (https://www.bea.gov/data/gdp/gdp-state). Note that Oregon's GDP and emissions per GDP are expressed on the basis of real (inflation-adjusted) 2009 dollars. Because of changes in accounting standards at the U.S. Bureau of Economic Analysis, 1990 and 1995 data are only approximately comparable to data from later years. Data for 2000 and later years are expressed on the basis of chained 2009 dollars, while earlier years are expressed as real (inflation-adjusted) 2009 dollars, calculated using simple ratios of the consumer price index. Pre- and post-1997 economic data are not exactly comparable, but the inconsistency is expected to be fairly small.

Table 4. Oregon's per capita sector-based GHG emissions compared to other jurisdictions (million MT CO2e per person)

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016
Oregon	19.7	20.3	20.5	18.3	16.8	16.1	15.6	15.5	15.3	15.7	15.2
California	-	-	-	-	12.0	11.8	11.8	11.7	11.5	11.3	10.9
Washington	18	-	-	-	14	14	14	14	-	-	-
European Union	12	11	11	11	10	9	9	9	8	9	8
United States	26	26	26	25	22	22	21	21	21	21	20

Table 5. Oregon's per capita consumption-based GHG emissions compared to other jurisdictions (million MT CO2e per person)

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016
Oregon[28]	21.9	-	-	22	20.9	-	-	-	-	22.1	-
Minnesota[1]	-	-	-	-	-	-	24.7	-	-	-	-
United States[29]	25.0	25.9	29.0	29.2	25.6	25.0	24.2	24.5	24.3	23.6	-
United Kingdom[30]	15.7	15.6	16.4	16.7	14.4	13.5	13.7	13.5	13.0	12.5	-

Table 6. Oregon's per GDP greenhouse gas emissions (million MT CO2e per GDP, in millions of real 2009 dollars)

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016
Sector-based emissions per GDP	605	564	536	432	338	314	315	322	317	316	298
Consumption-based emissions per GDP	672	-	-	518	421	-	-	-	-	444	-

[28] Oregon and Minnesota consumption-based emissions are estimated using a similar methodology and data sets and are relatively comparable. U.S. and U.K. consumption-based emissions are estimated using somewhat different methods and are not as comparable to Oregon.

[29] U.S. consumption-based emissions estimated from the U.S. national GHG inventory (U.S. EPA, 2018), multiplied by a ratio of consumption-to-territorial CO2 emissions for the U.S. estimated at www.worldmrio.com.

[30] U.K. consumption-based emissions estimated from the U.K. national GHG inventory (U.K. Department for Business, Energy, and Industrial Strategy, 2017), multiplied by a ratio of consumption-to-territorial CO2 emissions for the U.K. estimated at www.worldmrio.com.

Section 3:

A Closer Look at Oregon Utility Emissions

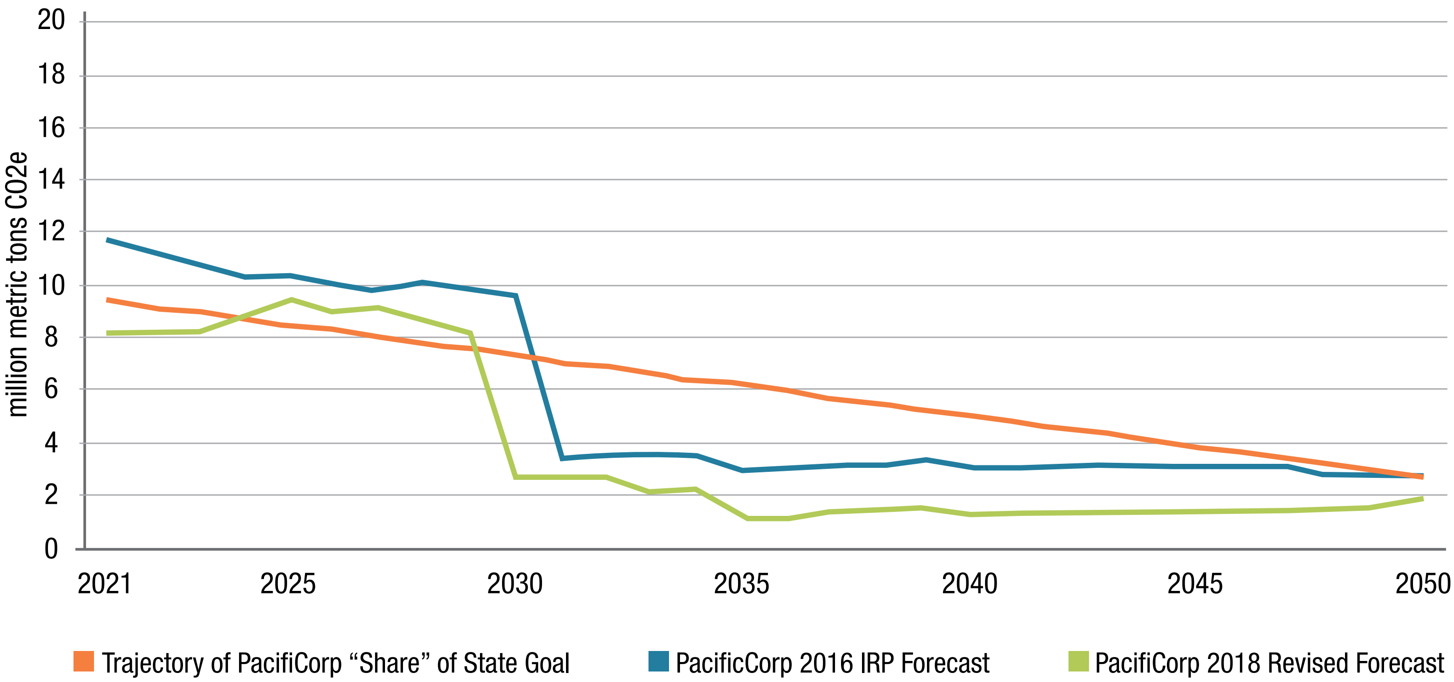
Electricity emissions in Oregon are largely a tale of the two largest investor-owned utilities, Portland General Electric (PGE) and PacifiCorp (called “PAC” in this report, also known as Pacific Power to customers in Oregon). The former serves customers only within the state of Oregon, while the latter has customers spread over six western states (we focus on the share of PAC’s deliveries just to Oregon customers). PGE and PAC together serve about two-thirds of Oregon’s utility customers. The other third is mostly served by Oregon’s consumer-owned utilities, who are primarily supplied by the Bonneville Power Administration, which provides an electricity mix that is almost entirely hydroelectricity with a near-zero carbon content. A small subset of consumer-owned utilities generate or purchase additional electricity beyond what they receive from Bonneville Power Administration. Idaho Power Company serves approximately 18,000 people in far eastern Oregon (Baker, Harney, and Malheur Counties).

Both PGE and PAC have generating facilities within and outside Oregon’s boundaries. PGE owns Oregon’s only in-state coal facility (Boardman), numerous gas-fired facilities, and a share of the Colstrip coal plant in eastern Montana. PAC generates >60% of its power from coal facilities in several western states, but not in Oregon. For years in which the region’s snowpack allows greater than average hydroelectric generation, both utilities will purchase lower-cost hydro and operate their thermal plants less, resulting in some unevenness of year-to-year carbon emissions and some difficulty in making comparisons.

Nevertheless, the story of PGE/PAC carbon emissions is largely one of how long the utilities’ coal plants will continue to operate, and what will replace any terminated plants. It is also a story of a consistent commitment over the last four decades, driven by public policy and implemented by the utilities and others, to invest in energy efficiency before building new power plants. And it is becoming, as well, a story of renewable energy technologies that are not new but have gained new traction as their costs come down and carbon concerns grow.

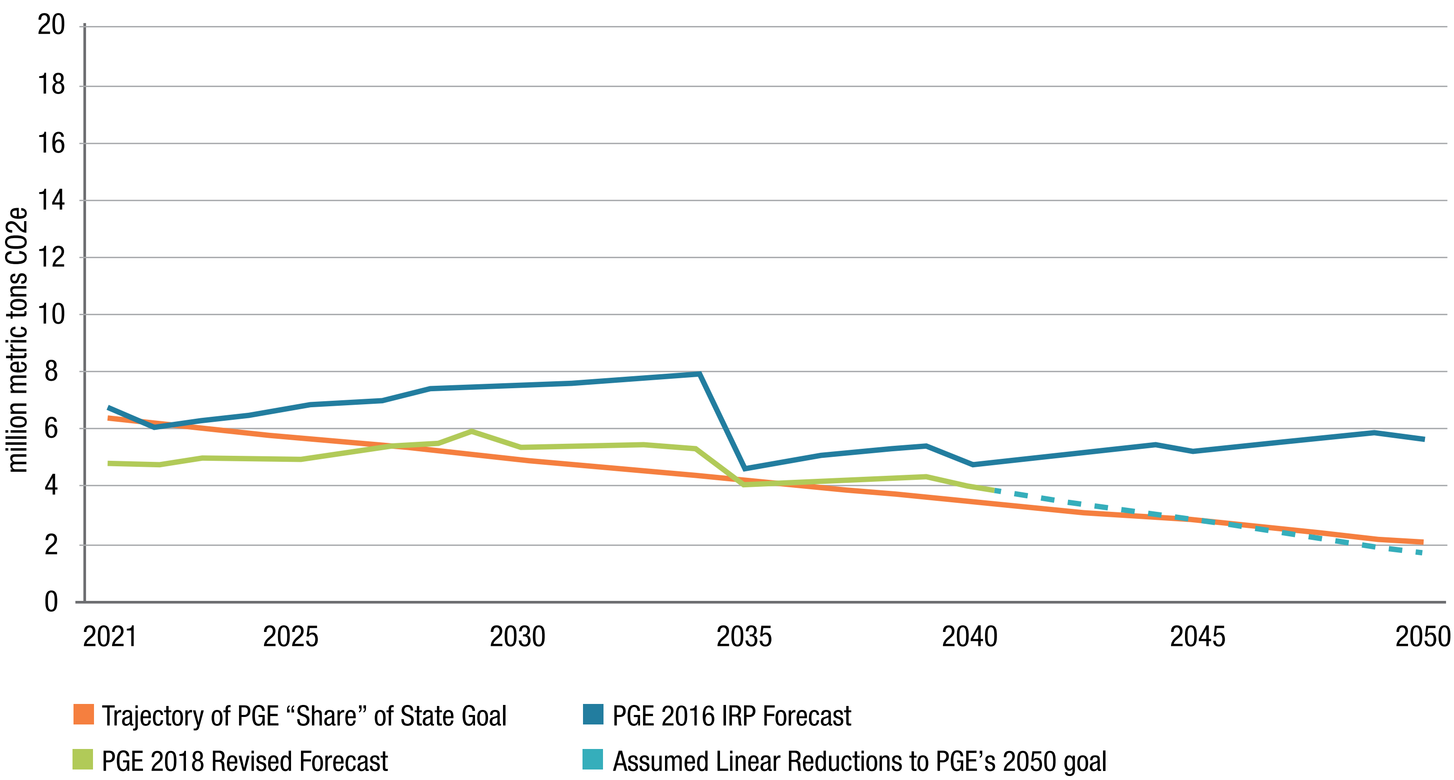
While greenhouse gas emissions from natural gas deliveries and onsite combustion have remained relatively stable in Oregon within a range of about 7–9 million metric tons since 2000 (or about 11–14% of total state emissions), the record looks better on a per customer basis. NW Natural, formerly Northwest Natural Gas Company, which supplies about two-thirds of gas deliveries in the state — mostly to residential and commercial heating loads — has itself seen a steady level of emissions but a per customer decline in usage (weather adjusted) of 19% since 2000.

Figure 13. Comparison of PacifiCorp forecasted emissions to OGWC proposed utility trajectory



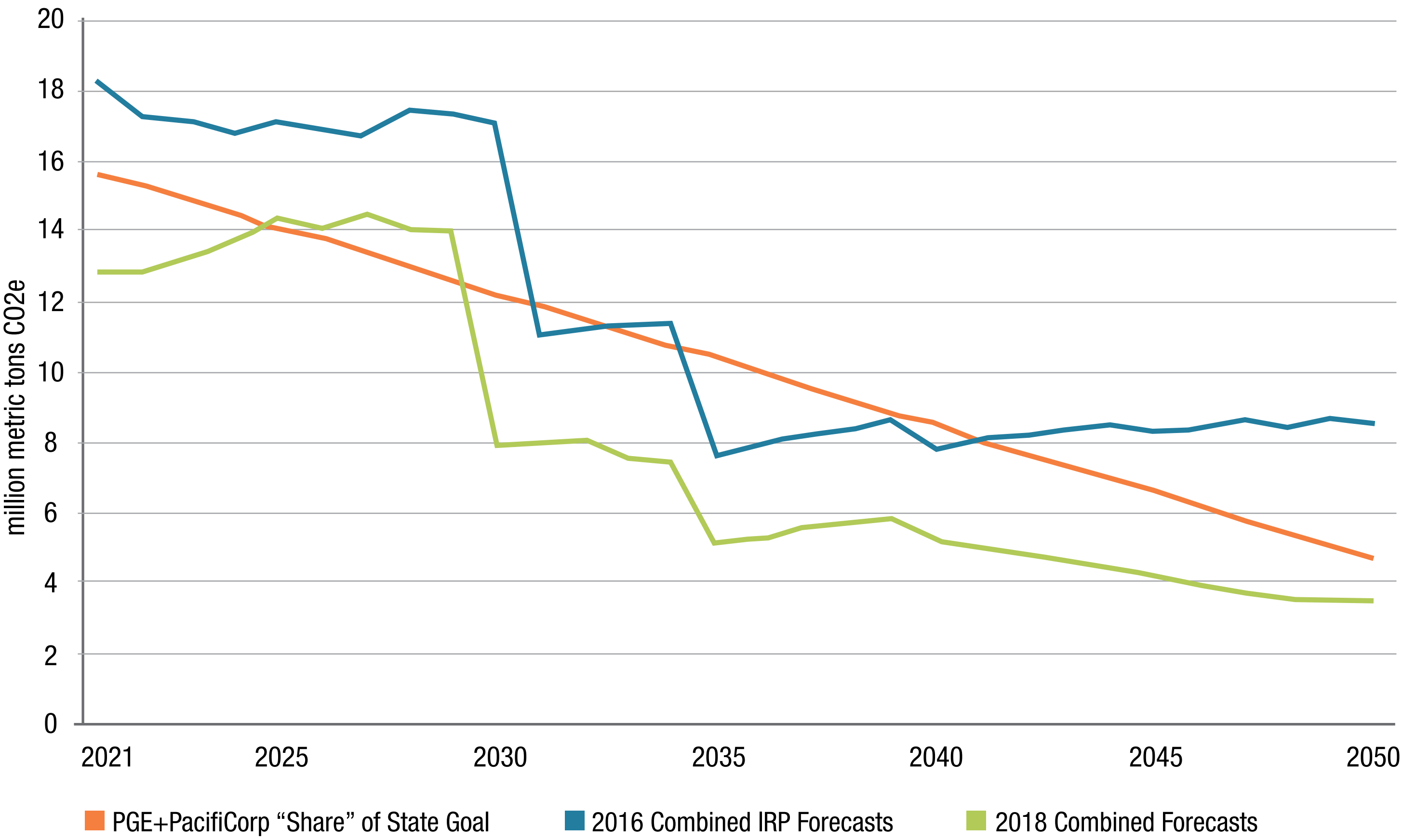
Source: OGWC staff analysis

Figure 14. Comparison of Portland General Electric forecasted emissions to OGWC proposed utility trajectory



Source: OGWC staff analysis

Figure 15. Comparison of combined Portland General Electric and PacifiCorp forecasted emissions to OGWC proposed utility trajectory



Source: OGWC staff analysis

A Tale of Two Years

In the year 2005, Oregon's largest electric utilities, PGE and PAC, emitted 22.72 million metric tons of CO2e, or 33% of the state's total.

By 2016 these emissions had dropped to 14.95 million metric tons (24% of total Oregon CO2e), of almost 30%. A large share of this reduction is associated with a 22% reduction in electricity generation, mostly associated with lower levels of energy generated for resale to industrial customers and other utilities. Because sales to industrial customers and for resale to other utilities are numbers that can bounce around, we can understand underlying trends best by focusing on residential customers and loads.

Both utilities have seen their numbers of residential customer accounts grow in this period by about 11%. But total kilowatt hours delivered to these customers have remained level, which should mean that each customer is using less. And, in fact, data from the Oregon Public Utility Commission show a reduction in kilowatt hours per customer of 9% (PGE) and 8% (PAC). So customers are using electricity more efficiently, notwithstanding that households are increasing their use of appliances and amenities that plug into the wall sockets (hence, "plug loads"). Increasing use of televisions, phones, computers, kitchen appliances, air conditioning, and other conveniences is being offset by increasingly efficient lighting, appliances, and heating/cooling electrical equipment.

But carbon reductions are not achieved by holding electrical loads steady. Either loads have to decrease, or carbon efficiencies in generating electricity have to gain traction. In addition, if there is to be a significant shift in vehicle fuels from gasoline and diesel to electricity, the sources of generated electricity become more important still.

The Carbon Chapter

While electricity deliveries have remained flat in the face of population growth and the spread of plug loads, electric utility carbon emissions have actually declined. PGE's carbon emissions in 2005 were 10.35 million metric tons; by 2016 they were down to 6.45 million metric tons.

PAC's emissions, for the share of its overall generation allocated to Oregon loads, dropped from 12.37 million metric tons in 2005 to 8.50 million metric tons in 2016.

The Oregon Department of Energy reports that from 2014 through 2016 the average kilowatt hour of electricity from PGE resulted in 0.896 pounds of carbon dioxide emissions. For PAC, the comparable figure was 1.552 pounds, reflecting the greater concentration of coal-fired generation in the PAC resource portfolio (ODOE, 2017).

While electricity deliveries have remained flat in the face of population growth and the spread of plug loads, electric utility carbon emissions have actually declined.

The reductions achieved early in the 2005–2016 period came from the utilities using their coal plants less heavily as reliance shifted to natural gas produced from new drilling and recovery techniques. The newest, most efficient gas power plants produce electricity at a carbon intensity roughly half that of coal, and their all-in costs (capital + operations) are challenging the operating costs of existing coal plants.

In the last eight to 10 years, the challenge to coal is coming increasingly from wind and solar renewable generation, where production costs have fallen even more dramatically than with gas. The most efficient new wind projects are competitive with new gas. While there are very modest carbon emissions embedded in fabricating wind and solar equipment, they will operate for 20 years or more at emissions per-kilowatt-hour levels that are effectively zero.

As these low-carbon alternative resources have become increasingly available and cost competitive, the economic logic for continuing to burn coal at often old and inefficient facilities — some from as far back as the 1950s and 1960s — becomes increasingly threadbare. When coal plants also come under pressure to meet other environmental emissions standards (e.g., for mercury and other heavy metals or for particulate matter), owners are faced with the choice to retrofit using costly emissions control equipment or to close the plants.

Thus PGE, in 2010, had to weigh a retrofit of its Boardman, Oregon, coal plant at a cost of half a billion dollars. Had it made this choice, that added investment would be at risk for the two decades or more it would take to recover the cost from ratepayers. Regulators, stakeholders, and PGE eventually found an alternative: Invest $50 million in equipment that would meet Clean Air Act emissions requirements for 10 years; then end coal combustion at the plant.

PGE's decision to pursue this alternative should result in the utility's overall carbon emissions dropping to below 6 million metric tons in 2021 from more than 10 million metric tons only 15 years earlier. It will then face additional choices, starting with the disposition of its share of Montana's Colstrip coal plant, and finding the right low-carbon path beyond that plant and onward to 2050.

It is notable that the prevailing PAC IRP proposes substantial wind and solar resource additions, along with new transmission to support the wind.

PAC has its own hard choices ahead, with >60% of its generation coal fired, mostly from aging power plants.[31] Oregon law requires it to end "coal-by-wire" deliveries of electricity to Oregon customers not later than 2030. Oregon and Washington regulators are directing the utility to review the cost and operating assumptions under which PAC is entitled to include those costs in bills to customers. PAC's 2017 Integrated Resource Plan, or IRP, projects that most of its coal fleet will be operating through 2036, when half the coal burning capacity will have closed. But it is also proposing, to five of the six states in which it operates, an accelerated depreciation schedule that would bring them in line with Oregon, which has all the plants fully depreciated not later than 2030.

According to Chad Teply, vice president of PAC, "This recommendation supports compliance with Oregon's Senate Bill 1547, and [anticipates] Washington energy policy developments and customer-driven demands" (Clearing Up, 2018). Some of these adjustments shorten depreciation schedules by nearly 20 years. While they do not commit the utility to coal plant termination by these dates, they would ensure that the company substantially recovers its capital investments if the plants are obliged to close earlier than now planned.

It is notable that the prevailing PAC IRP proposes substantial wind and solar resource additions, along with new transmission to support the wind. It includes, for the first time since IRPs were required, no new gas or coal through the 20-year planning horizon. But the schedule for terminating PAC's coal fleet remains uncertain.

Should Oregon's Legislature in 2019 adopt an economy-wide carbon cap, additional pressure will affect the continued operation of both utilities' out-of-state plants. The cap should also accelerate the transition of the state's vehicle fleet from gasoline and diesel to electric vehicles and other low-carbon options.

[31] Dave Johnston Unit 1, in Wyoming, was placed into service in 1959.

Looking Forward

Investor-owned electric utilities, regulated by the Oregon Public Utilities Commission, are required to do IRPs every two years. These plans weigh cost and operational choices, including existing and potential environmental regulation, to bring regulators a least-cost path forward that includes disposition of existing facilities and proposals for developing new ones. The plans include forecasts by each utility of a plausible carbon emissions trajectory. Making use of both historical emissions data and projections contained in each utility's update of its filed 2016 IRP (PacifiCorp, 2017 and 2018; Portland General Electric, 2016 and 2018), we can sketch out what would be a likely path for the state's utility emissions. Table 7 assumes that PGE's "decarbonization" commitment continues after 2040 to drive the utility's emissions downward.

Table 7. Utility forecasts of GHG emissions

Year	PGE (million metric tons)	PAC (million metric tons)
2005[32]	10.02	13.49
2016	6.39	8.41
2021	4.75	8.10
2031	5.31	2.60
2040	3.95	1.20
2050*	1.65*	1.90*

*2050 emissions levels represent post-IRP (2016 Update) emissions reduction goals, for each utility, of more than 85% below 2005 levels. Emissions projections beyond the 2016 IRP planning horizon are aspirational and dependent on technical and policy evolutions that are uncertain, but utility planning and resource strategies that align with state emissions goals should result in intermediate decision-making that will enable their achievement.[33]

The state's 2050 greenhouse gas reduction goal is "at least 75% below 1990 levels." In an earlier (2016) analysis, the Oregon Global Warming Commission proposed a roughly parallel calculation for these two electric utilities of at least 80% below 2005 levels.[34] By this measure, utility emissions in 2050 would be below the combined utilities' proportionate share goal of 4.5 million MTCO2e.

We can't say what these utilities' *share* of Oregon's emissions will be in 2031 and 2040. That depends on whether the state gains control of and succeeds in driving down its transportation emissions, which have risen in the last four years. We can say that Oregon's electric utilities are on a path that, if sustained, will deliver their proportional share — as this Commission calculates such a share — of Oregon's 2050 greenhouse gas reduction goal.

How has this measure of utility emissions reduction success come about to date and what is required to sustain it?

[32] Estimated baseline using a 5-year average (2003-2007).

[33] This forecast is primarily based on PGE's acknowledged 2016 IRP and 2016 IRP Update, which may differ from the emissions forecast resulting from PGE's next IRP. Consistent with PGE's 2016 IRP and 2016 IRP Update, this forecast:

- Incorporates PGE's December 2017 load forecast.
- Simulates dispatch and emissions from PGE's thermal resources in AURORA under the 2016 IRP Update Reference Case, which includes a federal carbon price that starts at $22/short ton CO2 beginning in 2022 and escalates to $90/short ton CO2 by 2040 (all in nominal dollars). To estimate the effects of carbon pricing in 2021 for this forecast, PGE assumed that thermal plant dispatch in 2021 is identical to forecasted thermal plant dispatch in 2022.

The forecast assumes that renewable portfolio standard (RPS) resources are procured incrementally over time to ensure physical compliance with PGE's RPS obligations. With the exception of a proxy resource representing the successful outcome of PGE's ongoing renewables, it does not include RPS-eligible resources in excess of PGE's RPS obligations unless they are already online. This simplifying assumption is applied in part because PGE did not receive acknowledgement of a specific glide path of future RPS procurement in the 2016 IRP. Market purchases are assumed to have a GHG emissions rate of 0.428 MTCO2e/megawatt hour, consistent with the California Air Resources Board's unspecified import emissions rate.

[34] The OGWC suggested this alternative to reflect the complication created by the closure of PGE's Trojan nuclear plant in the early 1990s. Since nuclear energy is effectively a zero-carbon emissions technology, PGE's Trojan closure resulted in higher mid-90s emissions from the replacement gas-fired generation PGE opted to develop. Selecting a 2005 average (2003–2007) as the utility baseline that steps around this anomalous action and outcome while upping the end goal to 80% below 2005 levels keeps a degree of rigor in the goal.

Energy Efficiency

First and foremost, Oregon's utilities have participated in and supported the state's commitment to energy efficiency.

While Oregon's electricity use per capita is about average nationally, this is qualified in several ways.

First, Oregon's electricity costs are on average a third to a half what these costs (especially during peak demand hours) are in states like California and Hawaii, which rank one and two for lowest kilowatt hours per capita. Those higher electricity costs create a strong economic incentive for consumers to conserve, while in Oregon we rely more on individual commitment, state and local incentives, and program outreach and support to achieve efficiency savings. PGE and PAC customer efficiency efforts are supported by technical staff and financing tools from the Energy Trust of Oregon, a nonprofit agency with the sole mission of providing these customers with access to efficiency and renewable energy technologies.

Second, over decades, Oregon consumers have benefited from shared access to the region's low-cost hydroelectricity, encouraging disproportionate reliance on electricity for their lighting, heating/cooling, and appliances, while other regions were more reliant on other fuels, such as gas and heating oil. Half the homes in Oregon still heat with electricity, often using old low-efficiency resistance units.[35] In overall energy use (all sources), Oregon ranks 39th in residential energy use (U.S. Energy Information Administration, 2017).

Third, a cooler, wetter Oregon climate means more reliance on energy to keep homes and businesses warm in winter months, compared to California, Hawaii, and other states with warmer winters. This distinction is weakening as these warmer areas of the country ramp up their reliance on summer air conditioning.

Finally, larger house sizes and appliance loads, even if met with efficient heating/cooling and appliances, have acted against lowering electricity use.

Larger house sizes and appliance loads, even if met with efficient heating/cooling and appliances, have acted against lowering electricity use.

These qualifying factors notwithstanding, Oregon consumers, with assists from utilities and the Energy Trust of Oregon, have driven their per household usage down over this period by almost 10%. The American Council for an Energy Efficient Economy annually ranks states by their energy efficiency accomplishments. Oregon and Washington are regularly ranked within the top 10, along with states whose power costs (and therefore economic incentives) are two or three times those in the Pacific Northwest.

That said, the state's energy and carbon goals both militate against resting on these laurels. Achieving the very aggressive carbon goals will require a redoubling of efforts to both identify technological efficiency advances and move them into the marketplace at cost-competitive levels.

[35] Oregon still meets 40% of its electricity demand from hydro, although most of this goes to consumer-owned utilities, while PGE and PAC rely more heavily still on gas- and coal-fired generation.

Renewable Energy

Oregon is used to relying on renewable electricity. Until the 1960s, most electric loads, of all utilities, were served from the region's extensive system of hydroelectric dams. Oregon was an early adopter (2007) of a utility renewable portfolio standard, which required electric utilities of a certain size (PGE, PAC, and certain customer-owned utilities) to be meeting 25% of their loads from *new* renewable generation by 2025. This new generation was added to the existing renewable hydroelectric base.

In 2016 the state, with support from PGE and PAC, increased the portfolio standard to 50% new renewables by 2040.

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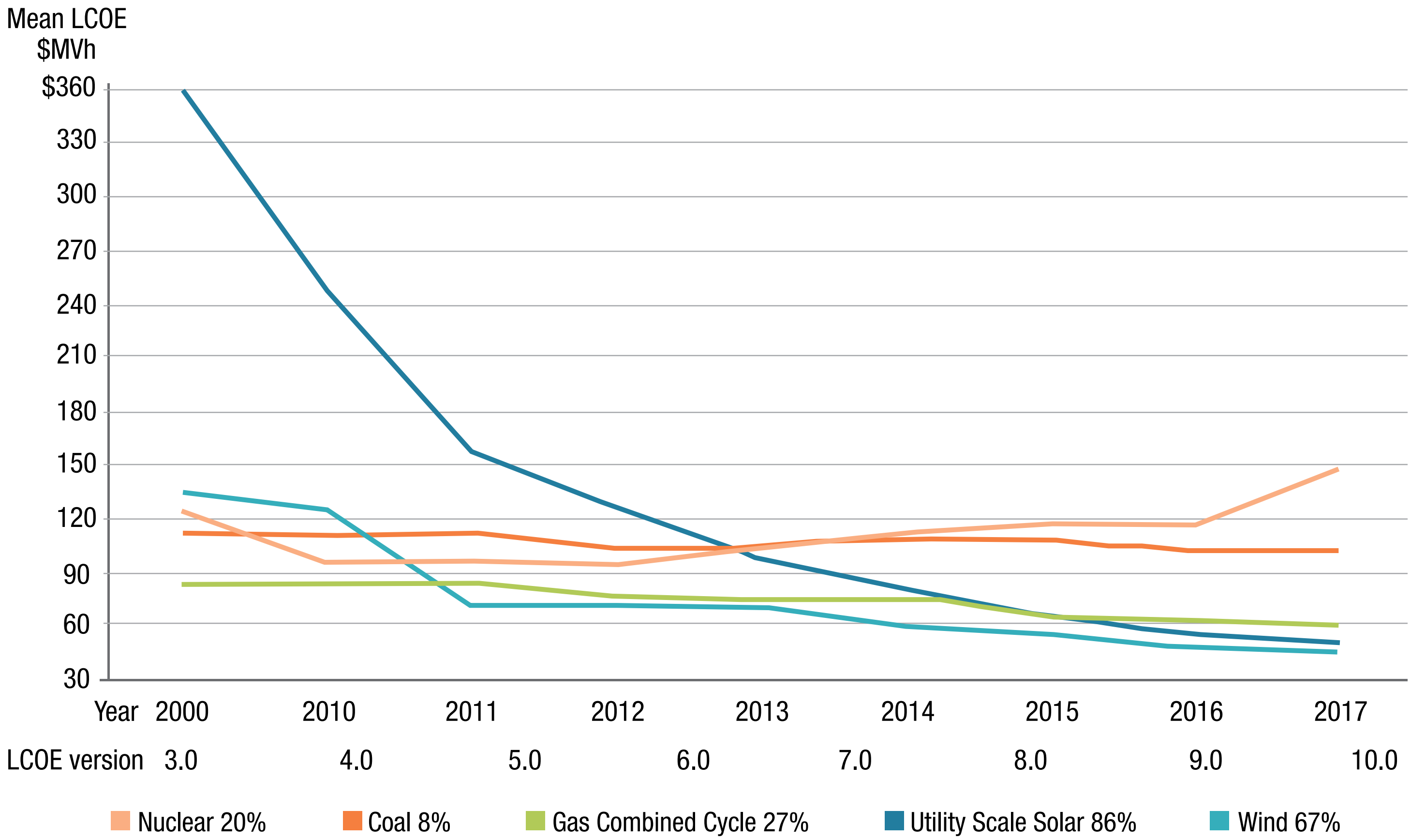
Both utilities were on compliance paths for meeting the earlier standard, and both have expressed their expectations of meeting the new standards in a manner that achieves both affordability and system reliability.

In 2016, Oregon was receiving almost 7% of its electric energy from new renewables, up from more than 1% only 10 years earlier. Both utilities were proposing significant new wind and solar facility investments in their 2016 Integrated Resource Plans.

Going forward, neither utility is proposing any significant new gas-fired generation. Both are proposing several hundred (PGE) to several thousand (PAC) megawatts of new wind and solar, anticipating the prospects that the two technologies continue to achieve significant new cost reductions, efficiency gains, and wider deployment. Figures 16 - 19 illustrate trends in falling costs of renewable electricity generation technologies and the projected shares these technologies will have in the global energy mix of the future.

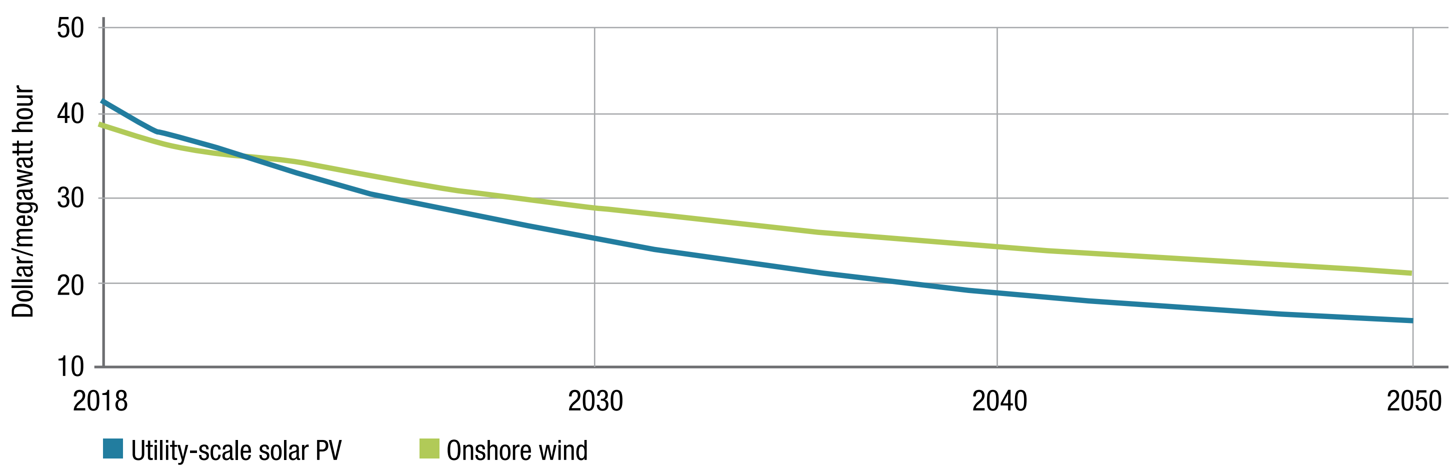
Utilities, regulators, and technical staff express prudent concern about integrating the variable generating output of wind and solar into a grid that sets and attains very high reliability and power quality standards. To date, these criteria have been largely met by searching the grid for additional flexibility to achieve integration while respecting reliability standards. Wider energy imbalance markets have allowed the grids to have peaks and valleys as they find and offset themselves. Going forward, some observers believe these flexibilities will continue to be discovered in sufficient depth and breadth. Others argue that additional short- and intermediate-term electricity storage — batteries, pumped storage, underground compressed air, among other technologies — will be required. Much attention is going into these, especially short-term battery storage, where a $100/kilowatt hour threshold is posited as the target for new battery technologies.

Figure 16. Trends in average levelized cost of energy (LCOE)[36] for selected generation technologies



Source: Lazard, 2017. Reflects average of unsubsidized high and low LCOE ranges from past reports, starting with LCOE version 3.0. Primarily reflects North American alternative energy landscape, but also broader/global cost declines.

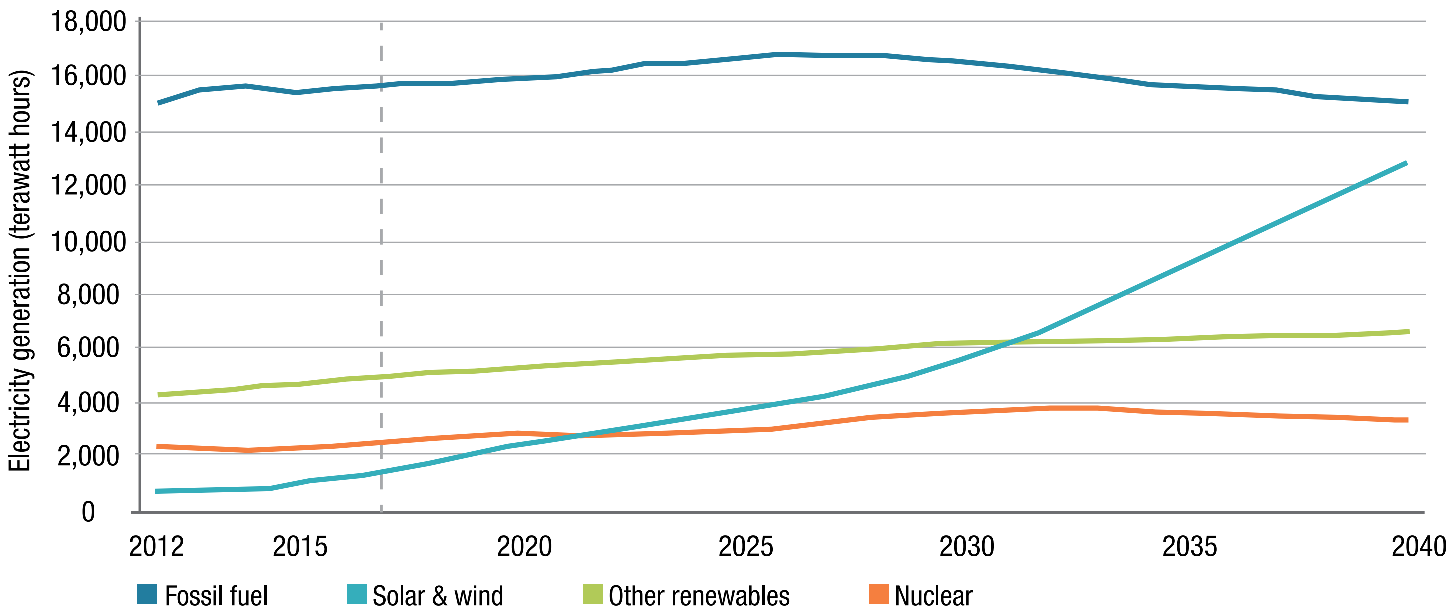
Figure 17. U.S. forceast of utility-scale solar and wind levelized costs



Source: Landberg and Hirtenstein, 2018, in Bloomberg New Energy Finance.

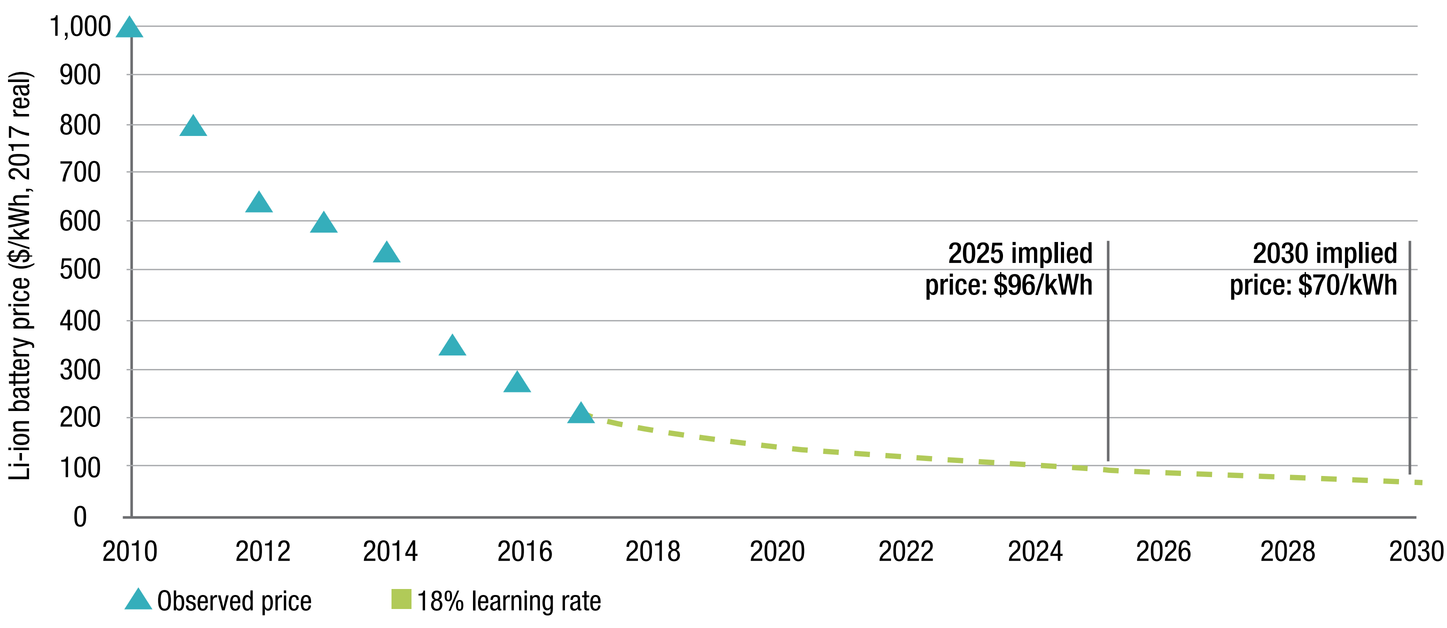
[36] LCOE calculations provide a convenient summary measure of the overall competitiveness of different generating technologies. It represents the per-megawatt-hour cost (in discounted real dollars) of building and operating a generating plant over its assumed lifetime. Calculating LCOE relies principally on information about capital costs, fuel costs, fixed and variable operations and maintenance (O&M) costs, financing costs, and an assumed utilization rate for each plant type. The importance of these factors varies among the technologies — for instance, solar and wind generation have no fuel costs and relatively small variable O&M costs, so their LCOE calculation changes in rough proportion to the estimated capital cost of generation capacity. For technologies with significant fuel cost, like coal, both fuel cost and overnight cost estimates significantly affect LCOE.

Figure 18. Historical and projected global electricity generation by technology



Source: Bloomberg *New Energy Finance*, 2017. In a 2018 analysis, Bloomberg projects that by 2050, the global electricity mix will be 63% renewables, 29% fossil fuels, and 7% nuclear (Landberg and Hirtenstein, 2018).

Figure 19. Lithium-ion battery price, historical and forecast



Source: Climate Home News Ltd., 2018.

Natural Gas

Homes and commercial establishments in the urban areas of Oregon and the Pacific Northwest are reliant on natural gas utilities to meet a substantial share of winter peaking needs for space and water heating, while many industrial processes use significant quantities of gas as well. Three gas utilities operate in Oregon: Avista Corporation, Cascade Natural Gas, and NW Natural (formerly called Northwest Natural Gas Company). Direct use of gas (in home furnaces and water heaters, for example) is a more efficient way to derive useful energy than burning the same gas in a power plant, but the combustion remains a significant source of greenhouse gas emissions.[37] From 2005 to 2016, GHG emissions from all gas users in Oregon have stayed relatively level, ranging from a low of 7.1 million metric tons of carbon dioxide equivalent in 2009 to a high of 8.2 million MTCO2e in 2013 and making up from 11 to 14% of Oregon's total annual GHG emissions.

NW Natural enlisted the services of the Energy Trust of Oregon to work with its customers on gas efficiency, weatherization, and other strategies that contribute to lowering GHG emissions.

NW Natural is the largest supplier of gas in Oregon, primarily serving residential and commercial customers.[38] According to the utility, NW Natural's emissions (expressed as CO_2 equivalents) were a little more than 3.5 million metric tons in 2017, or a little less than 6% of the state's total. NW Natural's GHG emissions can vary year by year — especially as winters are colder or warmer — but have remained roughly flat since 2000, while its customer numbers have increased significantly. As described earlier on a weather adjusted basis, NW Natural reports that its emissions per customer have declined 19% since 2000.

The first requirement for GHG reductions for both electricity and natural gas is energy efficiency, and NW Natural has demonstrated its commitment to this strategy. It voluntarily enlisted the services of the Energy Trust of Oregon to work with its customers on gas efficiency, weatherization, and other strategies that contribute to lowering GHG emissions.

NW Natural voluntarily agreed with its regulators to "decoupling" the amount of gas it supplies to customers from the returns the utility earns. This step removes the utility's profit incentive to encourage customers to use more gas, while still allowing it to earn a reasonable return for its product.

NW Natural has invested in modernizing its pipelines, replacing materials susceptible to leakage with coated steel and polyethylene. This reduces gas losses in transit, improves safety, and keeps "fugitive" methane, a powerful greenhouse gas, out of the atmosphere.

The Oregon Clean Fuels Program creates opportunities for producers of alternative fuels — such as electricity, natural gas, renewable natural gas, propane, and hydrogen — to voluntarily opt in and generate credits to trade in the program.

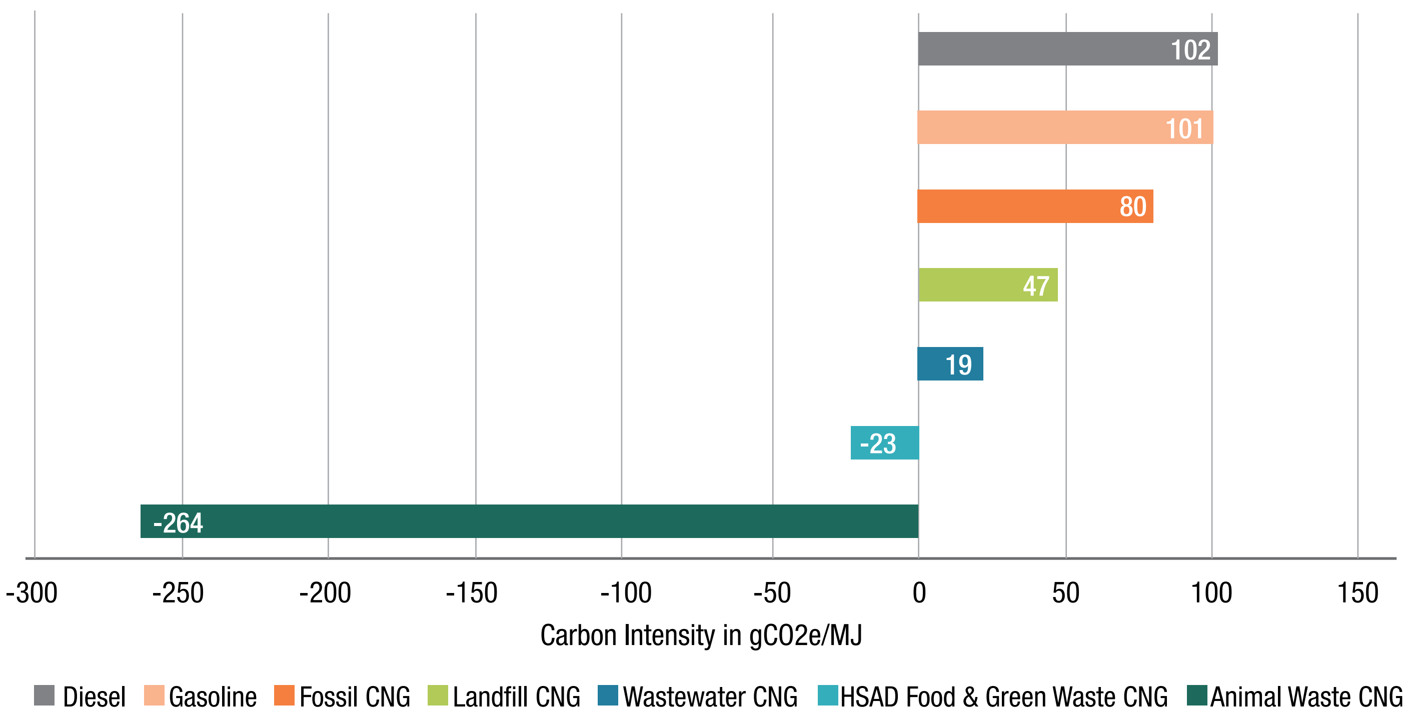
[37] 8.6 million metric tons CO2e in 2015, from inventory data tables published in the Oregon Global Warming Commission's Biennial Report to the Legislature, 2017, or about 14% of total state GHG emissions.

[38] Larger industrial users often buy their gas directly, then contract with NW Natural to transport it.

Specifically, the program allows producers to register fossil- and bio-based compressed natural gas, as well as fossil- and bio-based liquefied natural gas. Compressed natural gas has been advanced by NW Natural and other gas utilities as a lower-carbon transportation fuel compared to gasoline and diesel. There has been some resulting interest by fleets (trucks, buses), though widespread uptake has been hampered by the economic and logistical challenges of developing an efficient, extensive system of compression/distribution networks.

NW Natural has set itself a target of reducing its overall GHG emissions — not just emissions per customer — with a savings goal of 30% from 2015 levels by 2035. The primary strategies identified in their "low carbon pathway" include reducing the carbon intensity of their product, reducing and offsetting consumption, and replacing more carbon-intensive transportation fuels (NW Natural, 2018). Regarding the first and third strategies, NW Natural is pursuing some measure of fossil-based natural gas displacement with renewable natural gas (RNG) and potentially hydrogen (derived from water by electrolysis technologies). RNG is biogas[39] that has been processed to be interchangeable with conventional natural gas for the purpose of meeting pipeline quality standards or transportation fuel-grade requirements. Combustion of biogas and RNG still releases carbon dioxide to the atmosphere at the point of emission, but it displaces the more potent greenhouse gas effects of methane. On a life-cycle basis of analysis, the California and Oregon Low Carbon Fuels Programs consider certain forms of RNG to be net negative in terms of their GHG emissions impact (Figure 20).

Figure 20. Carbon intensity of approved RNG pathways used in California and Oregon Low Carbon Fuels Programs



Source: ODOE, 2018.[40]

[39] Biogas is a naturally forming gas that is generated from the decomposition of organic wastes or other organic materials in anaerobic environments or processes, such as gasification, pyrolysis, or other technologies that convert organic waste to gas in the absence of oxygen (ODOE, 2018). Biogas has a lower methane content and heating value than natural gas and contains many impurities. In some applications, it can be used directly, but in others it is considered an intermediate product that must undergo additional processing before use as fuel.

[40] https://www.oregon.gov/energy/Data-and-Reports/Documents/2018-RNG-Inventory-Report.pdf

The Oregon Department of Energy recently published the results of a detailed inventory of all potential sources of biogas and RNG available in Oregon (ODOE, 2018), which was requested by the State Legislature in SB 334 (2017). NW Natural served on the advisory committee for the inventory.

The inventory indicates 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, which is about 4.6% of Oregon's total yearly use of natural gas. The gross potential for RNG production when using thermal gasification technology is nearly 40 billion cubic feet of methane per year, which is about 17.5% of Oregon's total yearly use of natural gas. The report estimated the following types of GHG benefits associated with these estimates of gross RNG potential:

NW Natural has made positive progress in this area in partnership with the city of Portland, where they are beginning to produce RNG from the city's Columbia Boulevard Wastewater Treatment Plant for pipeline injection, as well as a natural gas vehicle fueling station.

- RNG production prevents methane from sources like landfills and animal waste from being directly emitted to the atmosphere. The combustion of captured gas results primarily in carbon dioxide, a GHG that is at least 25 times less potent in the atmosphere than methane. If the volume of RNG that could be potentially captured and utilized in Oregon displaced fossil fuel natural gas for stationary combustion (e.g., heating, cooking, electricity generation, or industrial process heat), approximately 2 million MTCO2e would be prevented from entering the atmosphere.

- RNG used as an alternative to diesel fuel could produce significant GHG reductions. When used as an alternative for an equivalent amount of diesel fuel, the state's total RNG production potential from anaerobic digestion reduced net GHG emissions by almost 2.3 million MTCO2e. This is a 33% reduction in diesel fuel's total GHG contributions to the transportation sector, or a 9% reduction in the sector's total emissions of 24 million MTCO2e in 2016.

In order to realize these types of potential benefits, many barriers will need to be overcome, including financial, informational, market, policy, and regulatory (described in detail in the ODOE 2018 Report). NW Natural has made positive progress in this area in partnership with the city of Portland, where they are beginning to produce RNG from the city's Columbia Boulevard Wastewater Treatment Plant for pipeline injection, as well as a natural gas vehicle fueling station. However, more work is needed to enable the development of RNG at scale in Oregon.

NW Natural has chosen an aspirational and challenging — and necessary — path to lower GHG emissions, and now needs to identify and implement more specific ways and means for achieving that outcome.

Conclusion

With the discipline of state law that will displace coal generation and require new renewables, Oregon electric utilities are on an emissions reduction trajectory that is in general alignment with Oregon's overall emissions reduction goals. Without those same statutory incentives, NW Natural has set itself a comparably challenging GHG reduction goal. Oregon's ability to meet its overall emissions goals depends on locking in these utility reductions.

There remains, for the electric utilities, the considerable legacy of aging coal plants needing to be moved to retirement in a prudent but accelerated manner. Both PAC and PGE Integrated Resource Plans would have these facilities operating well into the 2030s (and in PAC's case, beyond). While shifting plant outputs to customers outside our state is an alternative Oregon cannot directly control, it must work with Washington and other allies to bring about earlier retirement.

Coal retirement will leave substantial gas generation in place, most of it today configured for operating to meet base-load customer requirements. To keep emissions going down, these plants will likely need to find a new vocation as integrating units that support increasing levels of variable (wind and solar) renewable generation. New gas plants are unlikely to be approved except in such an integrating role.

New wind and solar generation is clearly the mainstay of the new renewable electrical grid. These technologies may be joined in a decarbonized utility world by other renewable generating technologies (ocean, geothermal, biomass, etc.) and by biogas and hydrogen replacing fossil-derived gas in gas utility pipelines. Wind and solar, while more reliably predictable than many utility observers first thought, nevertheless will require some measure of storage support as they penetrate the grid at higher and higher levels. They also will require rethinking and some refiguring of the transmission grid and operations to optimize their system value.

At the same time, the ability of Oregon's gas suppliers to find, or fabricate, low-carbon versions of natural gas and package these with ongoing energy efficiency savings will determine whether gas remains a significant contributor to Oregon's energy banks.

Utilities are in for interesting times.

Section 4:

Projected GHG Emissions from the Transportation Sector

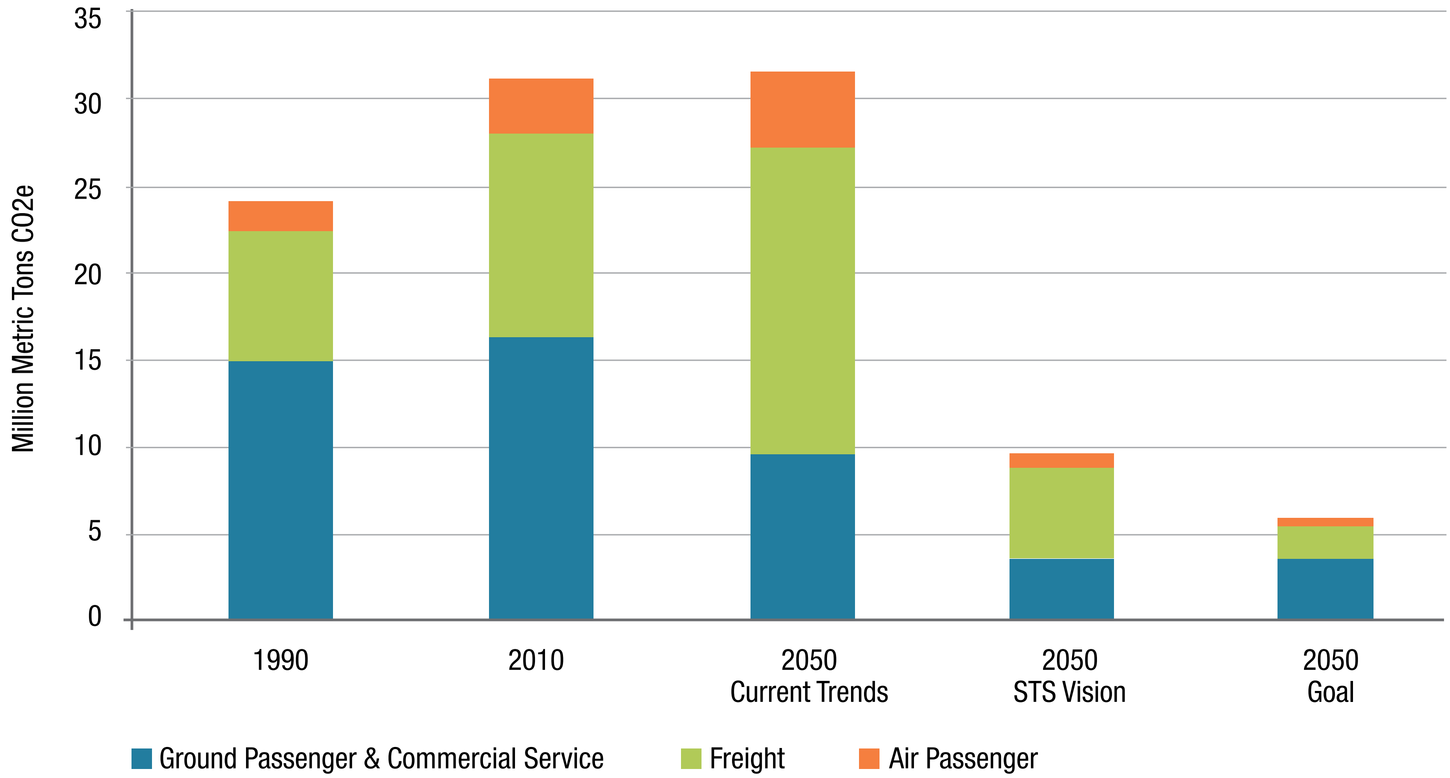
Multiple available data sources provide an understanding of where we think Oregon's transportation emissions are headed. These projections are based on our understanding of the factors affecting overall fossil-fuel consumption, such as vehicle miles traveled, projected vehicle fuel efficiencies, and population growth, which are in turn affected by factors such as economic cycles, global oil market dynamics, human migration and settlement trends, and individual purchasing patterns. Data on these types of factors and modeling capabilities to integrate them are continually being updated and refined. So although emissions projection results are necessarily snapshots in time, they still provide useful points of reference for policy tracking and evaluation.

In 2013, Oregon Department of Transportation modeled what would happen to GHG emissions from the transportation sector if all of the actions called for in their *Statewide Transportation Strategy* vision[41] were fully implemented. Specific details of the STS vision and their implementation status are discussed in this section. Figure 21 shows ODOT's projections compared to actual transportation emissions from 1990 and 2010, and presents the relative contribution of different transport modes to the emissions totals in each column. Under full STS implementation, depicted in the "2050 STS Vision" column, by 2050 transportation emissions would be reduced by 60% (to 9.7 million MTCO2e) compared to 1990 transportation sector emissions (24 million MTCO2e). The column "2050 Goal" shows that an additional reduction of 3.7 million MT would be needed by 2050 if the sector was asked to achieve a 75% total sector reduction (to 6 million MTCO2e) compared to its 1990 level for combined air, ground, and freight modes.

In 2018, ODOT published a Monitoring Report to document progress on implementing the STS since 2013. They identified a number of areas of short-term positive progress offset by other areas of stalled progress or negative trends, particularly in GHG emissions from light-duty or passenger vehicles. Figure 22 shows a projection of GHG reductions from light-duty vehicles attributable to current "plans and trends" (blue line), compared to an STS vision trajectory for light-duty vehicles that would result in a reduction of around 80% below 1990 levels. The blue line shows that, assuming a conservative level of implementation of the current suite of policies in combination with current market trends, passenger vehicle GHG emissions are expected to be reduced by about 15–20% below 1990 levels by 2050.

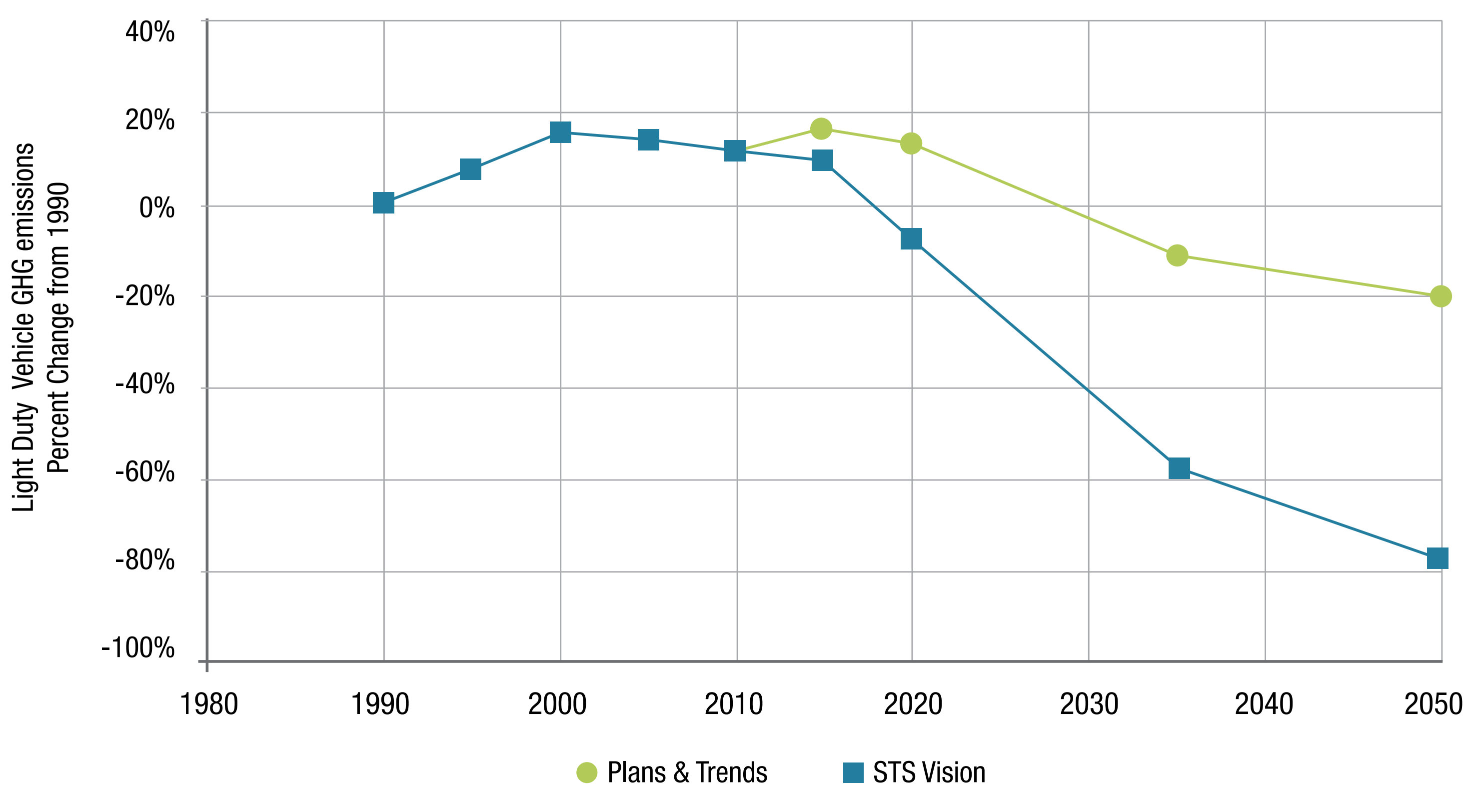
[41] The *Statewide Transportation Strategy* was developed by the Oregon Department of Transportation and supporting groups of stakeholders and technical experts, under direction from the 2010 Oregon Legislature in Senate Bill 1059 (Chapter 85, Oregon Laws 2010, Special Session). The STS sought to describe an integrated universe of actions that, taken together, could meet a proportional transportation share of Oregon's greenhouse gas reduction goals set by the 2007 Oregon Legislature.

Figure 21. Comparison of historic and projected transportation sector GHG emissions



Source: ODOT, 2013.

Figure 22. Projected light-duty GHG emissions of current plans and trends compared to the *Statewide Transportation Strategy* vision



Source: ODOT, 2018.

This projection is based on updated data about multiple drivers of fossil-fuel consumption and GHG emissions in the transportation sector. Policy/plan drivers include Oregon's Clean Fuels Program, public transportation funding from the 2017 Keep Oregon Moving Act, and improved systems operations. With regard to other changing Oregon trends that affect GHG emissions projections from light-duty vehicles, the 2018 Monitoring Report (ODOT, 2018, p. 19) states:

> In 2012, when the majority of work on the STS was completed, fuel prices were at an all-time high. In the six years since, prices have dropped and according to national sources are forecasted to stay low. In addition, Oregonians have held onto their vehicles longer than originally anticipated and have not transitioned to newer more fuel efficient or low/no-emission vehicles. The result is more internal combustion engines in the fleet that get fewer miles per gallon than was anticipated in the STS. Additionally, Oregon's population continues strong growth and incomes have recovered from the recession. As a result, lower gas prices coupled with higher incomes and post-recession increases in driving means that vehicle miles traveled (VMT) have increased in Oregon. … [Figure 22 shows] an uptick in emissions following the recession and projected reductions in the long term. In the long term it is assumed that vehicles get more efficient, which helps to bring the curve down. While the overall trend line is moving in the right direction, it falls short of the levels called for in the STS vision.

Is the Current State Framework for Reducing Transportation GHG Emissions Enough?

The STS development process was the first statewide planning effort targeting a single goal (GHG emissions reduction) and spanning the authority of multiple state agencies. The Oregon Transportation Commission chose to "accept" — a weaker option — rather than "adopt" the STS document outright when it was completed in 2013. In 2018, the STS was formally adopted by the Commission into the Oregon Transportation Plan, calling for a pursuit of strategies in the STS. Still, even an adopted STS is only advisory and has no force of law or programmatic consequences unless the Legislature chooses otherwise.

Six categories of strategies and 133 elements were identified and included in the STS. As summarized in the ODOT 2018 Monitoring Report, the categories for critical actions called for under the STS vision are as follows:

1. Vehicle and Engine Technology Advancements

Strategies in this category increase the operating efficiency of multiple transportation modes through a transition to more fuel-efficient vehicles, improvements in engine technologies, and other technological advancements. Sample elements include zero-emission vehicle programs, electric vehicle charging infrastructure, and fleet turnover to a greater proportion of electric or low-carbon fuel vehicles. Many of the elements in this category require legislative action, are under the authority of the Department of Environmental Quality, or are reliant on market forces to drive change. Multiple state agencies are supporting efforts to increase zero-emission vehicle adoption as a result of the Governor's Executive Order 17-21.[42]

2. Fuel Technology Advancements

This category contains improvements in vehicle efficiency and reductions in the carbon intensity of fuels and electricity used to power vehicles. Strategies in this category increase the operating efficiency of transportation modes through transitions to fuels that produce fewer GHG emissions or have lower life-cycle carbon intensity. Elements include Clean Fuels Standards and transitioning to low-carbon renewable fuels. Many of the elements in this category require federal programs or legislative action, or are under the authority of DEQ and ODOE, or are reliant on market forces to drive change.

3. Systems and Operations Performance

Strategies in this category address intelligent transportation systems, air traffic operational improvements, and other innovative approaches to improving the flow of traffic, reducing delays on transportation systems, and providing travelers with information that helps them drive more fuel efficiently or avoid significant delays. Strategies in this category improve the efficiency of the transportation system and operations through technology, infrastructure investment, and operations management. Elements include in-car displays that notify drivers of fuel efficiency as they travel; providing real-time information on crashes and delays; promoting vehicle-to-vehicle communications; and supporting autonomous vehicles. Many of these elements are under the authority of the private sector, ODOT, local jurisdictions, and Oregon Department of Aviation, or are reliant on market forces to drive change.

4. Transportation Options

This category contains strategies for providing infrastructure and options for public transportation and bicycle and pedestrian travel; enhancing transportation demand management programs; shifting to more efficient modes of goods movement; and providing alternatives to certain air passenger trips. This category encourages a shift to transportation modes that produce fewer emissions and provide for the more efficient movement of people and goods. Sample elements include providing park-and-ride facilities, promoting ride-matching services, adding biking and

[42] https://www.oregon.gov/gov/Documents/executive_orders/eo_17-21.pdf

walking infrastructure, enhancing passenger rail services, and achieving significant growth in public transportation service. Many of these elements are under the authority of ODOT, local jurisdictions, transit agencies, and Oregon Department of Aviation, or are reliant on market forces to drive change.

5. Efficient Land Use

Strategies in this category focus on infill and mixed-use development in urban areas to reduce demand for vehicle travel, expand non-auto travel mode choices for Oregonians, and enhance the effectiveness of public transportation and other modal options. This category promotes more efficient movement throughout the transportation system by supporting compact growth and development. This type of development pattern reduces the distances that people and goods must travel, and provides more opportunities for people to use zero- or low-energy transportation modes. Elements include supporting mixed-use development, limited expansion of urban growth boundaries, and development of urban consolidation centers for freight. Many of these elements are under the authority of Oregon Department of Land Conservation and Development and local jurisdictions, or are reliant on the market forces of housing costs, generational preferences, or job locations to drive change.

6. Pricing Funding and Markets

This category addresses the true costs of using the transportation system and pricing mechanisms for incentivizing less travel or travel on more energy-efficient modes. A "user pays true cost" approach ensures that less-efficient modes are responsible for the true cost of their impacts to the transportation system and the environment. Strategies in this category support a transition to more sustainable funding sources to maintain and operate the transportation system, pay for environmental costs, and provide market incentives for developing and implementing efficient ways to reduce emissions. Elements include transitioning to a user- or mileage-based fee, adding a carbon fee, promoting pay-as-you-drive insurance programs, and diversifying Oregon's economy. Many of the elements in this category require legislative action.

The 2018 STS Monitoring Report assessed progress in each of these areas. ODOT found positive short-term progress in a number of categories, which are summarized below in rows marked with a dark blue circle.

Table 8. Summary of progress from ODOT 2018 STS Monitoring Report

Vehicle Tecnology	
Vehicle Mix	○
Fuel Efficiency (MPG)	◐
Battery Range	●
SUV/Light truck share	⊜
Vehicle Age	⊜
Fuel Technology	
Fuel Carbon Intensity	◐
Electric Carbon Intensity	●
Bus Fuels	⊜
Systems and Operations	
Intelligent Transportation Systems	◐
Managed Road Growth	●
Parking Coverage	●
Parking Price	⊜
Fuel Efficient Driving	⊜
Transportation Options	
Transit Service	◐
Bike	◐
Carshare	●
Demand Management Programs	●
Land Use	
Urban Growth Boundary Expansion	●
Mixed Use Areas	●

● on-track with or exceeding the STS vision;
◐ moving in the direction of the STS vision;
○ little to no progress towards the STS vision; or
⊜ moving away from the STS vision/trending in a negative direction.

For light-duty vehicles, although progress has been noted in several important areas, the projected 15 to 20% reduction is far short of what is needed to achieve the state's sustainable transportation and climate goals. Current efforts under the state's existing policy framework are occurring against a backdrop of relatively rapid and sometimes uncertain changes in the policy and economic/consumer landscape for successfully promoting alternatives to traditional fossil-fueled internal combustion engine passenger cars and trucks.

For light-duty vehicles, although progress has been noted in several important areas, the projected 15 to 20% reduction is far short of what is needed to achieve the state's sustainable transportation and climate goals.

In the passenger vehicle segment especially, ODOT's analysis indicates that effectiveness of efforts that support cleaner vehicles and fuels is most heavily reliant on consumer behavior. Fewer people than anticipated in the STS have transitioned to higher-miles-per-gallon cars or alternative fuel/lower-emission vehicles, including electric vehicles. Some of this is related to market factors — such as lower gasoline prices, higher up-front costs for alternative fuel vehicles, and certain operating aspects of electric vehicles on the market to date (like limited range, limited charging infrastructure, and slow charging times) — that will fluctuate or become less relevant over time as the market changes. Other consumer-related trends observed in Oregon that affect the state's efforts on behalf of cleaner vehicles and fuels include:

- Older vehicles on the road that get fewer miles per gallon: Average vehicle age on Oregon roadways has increased to at least 12 years old (with some estimates up to 13.5 years old).
- The share of larger vehicles (light trucks and SUVs) in the passenger vehicle fleet that get fewer miles per gallon has not decreased as expected, and this continues to be a very popular market segment for automobile consumers in Oregon.
- Lower gasoline prices since 2012, when the majority of work on the STS was completed.
- Resurging economy since 2012, when the majority of work on the STS was completed.
- Increases in Oregon's population and the number of people in the state traveling.

On the policy side, the timing of when current policies start to influence overall emissions trends is also an important consideration. In areas such as land use/urban design, emissions reduction effects will not be seen immediately but will be important in the intermediate and long-term future. And while ODOT is studying and preparing initial steps (e.g., submitting an application to the Federal Highway Administration) toward congestion pricing in the Portland area, the reality is that it will be a number of years before tolling would be implemented in the Portland area.

ODOT's 2018 STS Monitoring Report concluded that assumptions around certain legislative actions will need to hold true in order to get back on track with the STS vision. These include extended Federal Corporate Average Fuel Economy (CAFE) standards and extension of the Zero Emissions Vehicle Program (both discussed in the following section), as well as an extension of Oregon's Clean Fuels Program and the initiation of mechanism(s) for true-cost pricing. As will be discussed in the section on federal deregulation trends, sustained implementation of current policies is not always guaranteed.

Regarding fuels, the federal Renewable Fuel Standard,[43] the Oregon Renewable Fuels Standard,[44] and the Oregon Clean Fuels Program[45] have increased the amount of cleaner alternative fuels used in Oregon's transportation mix from less than 2% in 2005 to 7.4% in 2017 on an energy-equivalent basis (ODOE, 2018). The Oregon Clean Fuels Program is responsible for the introduction of new low-carbon fuels, including renewable natural gas from wastewater treatment plants and landfills, and renewable diesel sourced from a by-product of ethanol production. Some of these fuels are, or can be, produced in Oregon. The program is currently on track to meet its goal of reducing the carbon intensity of transportation fuels, though continued progress depends on factors including production and adoption rates for electric vehicles, biodiesel, and other alternative fuels.

Regarding true-cost pricing, those involved in the STS development process have recognized and emphasized the importance of sending a price signal about the impact of driving and thus incentivizing the adoption of other, less carbon-intensive, modal options. ODOT (2018) found that few of the fees called for in the STS have been imposed, although many are being considered, like congestion (value pricing), and per-mile (OReGO) charges. An economy-wide cap on greenhouse gas emissions, expected to be considered by the Oregon Legislature in 2019, would reinforce the message of these programmatic incentives to use cleaner vehicles and fuels.

ODOT (2018) indicated that continued and increased investments or work in the areas such as fuels and systems and operations are also needed to address light-duty vehicle emissions. ODOT identified a separate set of strategies to address some of the unique aspects of freight and heavy-duty vehicle emissions. Both sets of strategies will be needed to get the state on an effective pathway to achieving the STS vision and should be designed to be robust in the face of continuing changes in the policy and economic/consumer landscape.

The Oregon Clean Fuels Program is responsible for the introduction of new low-carbon fuels, including renewable natural gas from wastewater treatment plants and landfills, and renewable diesel sourced from a by-product of ethanol production.

[43] Congress passed the RFS program in 2005 and amended it in 2007 to increase the required amount of renewable fuels that must be included in the nation's fuel mix, as well as set requirements for the fuels' carbon content.

[44] The Oregon Renewable Fuels Standard passed in 2007 also sets standards for the amount of renewable, low-carbon fuels to be included in most transportation fuels sold in the state. The standard requires Oregon diesel fuel to contain 5% biodiesel and gasoline to contain 10% ethanol.

[45] The Oregon Clean Fuels Program was established by the State Legislature in 2009, with the goal of reducing GHG emissions from Oregon's transportation fuels by 10% over a 10-year period. The program sets the carbon intensity for individual fuels, creates annual baselines for regulated parties to meet, and establishes a market for clean fuels credits. The program has been fully operational since 2016.

Light-Duty Vehicle Emissions

Vehicles and fuels

Cleaner low- or no-emission vehicles and fuels. Cleaner vehicles and fuels are essential, representing 50–60% of the remaining gap between goals and implementation actions for light-duty vehicles in the STS. Immediate attention is needed to get cleaner vehicles on the road to reduce the carbon footprint of those who continue to drive.

- Today's vehicle mix includes more older, larger, and less fuel-efficient vehicles than when the STS was completed, and certainly more than what the STS envisions by 2020 and beyond. This, combined with no reductions in overall vehicle miles traveled, has led to increased emissions from transportation.
- A fleet shift to electric vehicles must be combined with a utilities shift to a decarbonized electricity supply for these vehicles.
- The electric vehicle industry must accelerate progress toward vehicles with less costly and more durable batteries, longer ranges between charges, and faster charging "fillups." State and local governments must work with the private sector to ensure that adequate charging infrastructure is available to meet the travel needs of Oregonians.

Public transportation

Promoting buses, light rail, passenger rail, and similar services. These types of strategies make up about 13–15% of the gap in implementation actions for light-duty vehicles in the STS. While continued investments in transportation options like biking and walking and public transportation are essential, mode shift is likely to be slow.

- Although recent funding from the 2017 Keep Oregon Moving Act helps progress in the direction of the STS, the levels envisioned in the STS call for exponentially more investment in transit service, along with converting bus fleets — public transit and school buses — to electricity as older buses are replaced.
- Continued investments and actions are needed to maintain gains in biking and walking and control of land uses. Investments in transportation options such as park-and-ride, vanpools, and other efforts to manage demand are also essential.

Systems and operations

Technologies that smooth traffic and help reduce idling. These types of strategies make up about 20–25% of the gap in implementation actions for light-duty vehicles in the STS.

- These types of investments are important because they reduce idling for vehicles on the road. The stop-start movement of traffic jams burns fuel at a higher rate than steady travel.
- Without such strategies, emissions are likely to continue to increase. These strategies will be most effective in the short term until significant vehicle turnover (to cleaner vehicles) occurs.

Freight Truck Emissions

Both the STS and the 2018 STS Monitoring Report acknowledge the challenges associated with reducing GHG emissions from freight transportation, mostly from heavy-duty trucks. For example, freight mode choice is primarily driven by the type of goods being shipped, which can limit opportunities for mode shift to other, less GHG emissions-intensive, forms of freight transport. The 2018 STS Monitoring Report identifies a number of ongoing ODOT actions that contribute to reducing medium- and heavy-duty truck GHG emissions. Their investments to reduce roadway congestion have emissions benefits in terms of reduced engine idling and reduced stops and starts, all of which help to minimize fuel consumption. Similarly, ODOT's Green Light truck preclearance system allows for weighing participating trucks at highway speeds using a combination of high-speed weigh-in-motion scales, transponders, and computer systems, which avoids stops and engine idling at weigh-in stations. The Connect Oregon program provides funding for projects supporting development of intermodal freight facilities to transfer goods between truck and rail (a less GHG emissions-intensive mode).

Although cleaner trucks and fuels will need private sector commercialization, progress could be facilitated by public sector efforts in areas such as investments in electric truck charging stations.

In addition to continuing and expanding implementation of current actions, more public and private sector efforts are needed to advance other freight truck emissions strategies. Both the STS and a recent review of the peer-reviewed literature on this topic (Oliveria et al., 2017) point to urban consolidation centers as a more efficient and less GHG emissions-intensive approach to freight deliveries to final destinations in urban areas (also referred to as "last mile" deliveries). These are distribution centers on the periphery of urban areas where large freight trucks can be unloaded, and then smaller commercial fleets can deliver the products within city centers. This keeps most heavy-duty trucks on main highways at higher, more fuel-efficient speeds. It also allows smaller commercial vehicles to chain trips to multiple businesses and thus reduce total vehicle miles traveled. The use of existing and emerging electric vehicle technologies in last mile deliveries can achieve additional emissions reduction benefits (Oliveria et al., 2017).

Other emerging strategies will depend on advancements in alternative fuels and autonomous vehicle technologies. These include:

Cleaner trucks and fuels

Less carbon-intensive trucks and fuels for both the medium- and heavy-duty fleet (e.g., Tong et al., 2015; Sen et al., 2017). Although cleaner trucks and fuels will need private sector commercialization, progress could be facilitated by public sector efforts in areas such as investments in electric truck charging stations.

Platooning

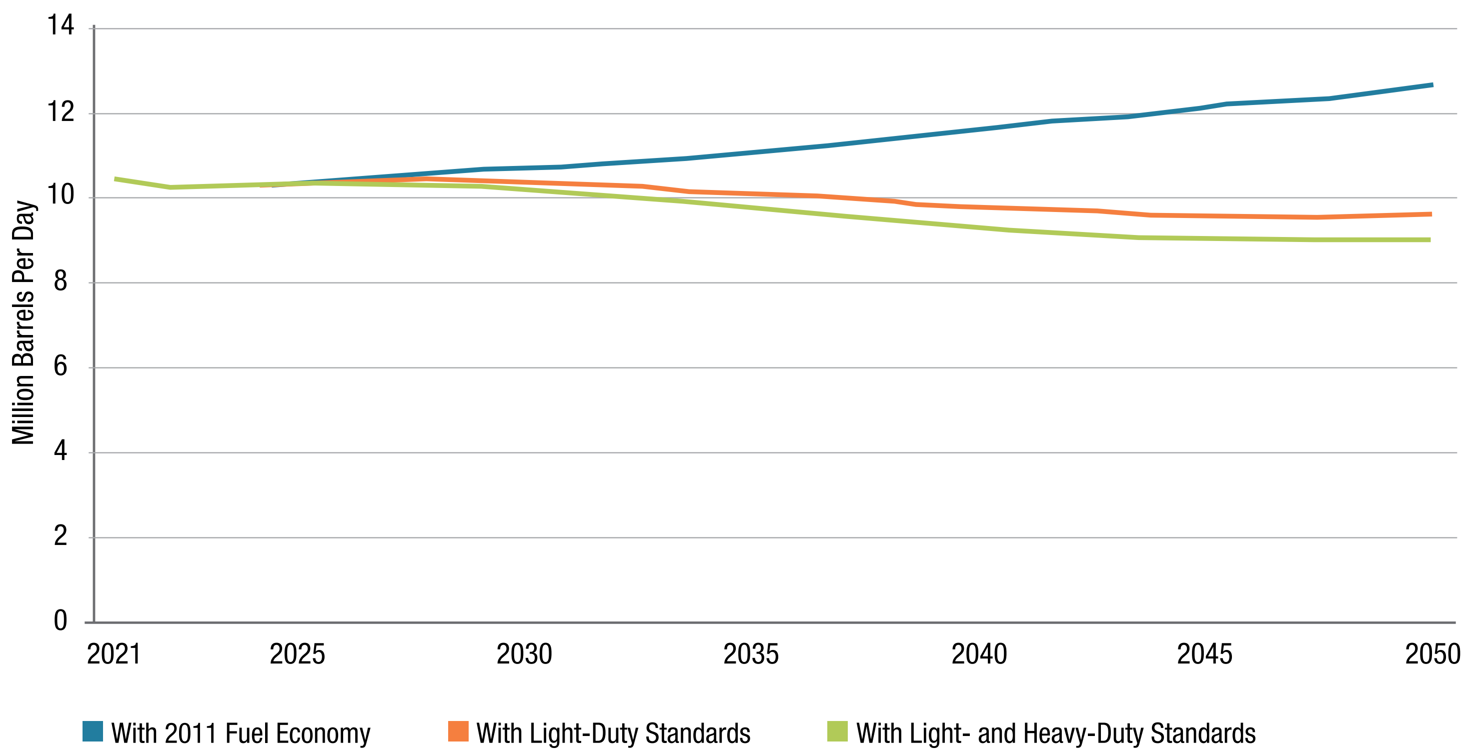
Automated trucks that allow drivers to travel closely behind another truck and thus reduce drag, improve fuel efficiency, and lead to overall emission reductions (e.g., Alam et al., 2015; Lammert et al., 2014). This strategy will also need private sector commercialization of products and technologies, though progress could be facilitated by public sector policies to allow platooning and testing of such fleets.

How Important are Federal Deregulation Trends for Meeting Oregon's Transportation Emissions Goals?

The Oregon Department of Transportation (2018) has stated that extended federal Corporate Average Fuel Economy standards and zero-emissions vehicles II requirements are needed for the STS vision to be realized. The CAFE standards are the primary pathway for reducing fuel use. Established by Congress in 1975, these standards set fuel efficiency goals that automobile manufacturers must achieve in the development of new vehicle models. Congress granted California a special waiver to allow the state to set its own, more stringent, standards to help better manage high levels of air pollution in its major cities. California's new goals, which covered both fuel efficiency and GHG emissions through 2025, were subsequently adopted by the federal government in 2009.

Oregon, along with 12 other states, signed on with California and agreed to follow their fuel efficiency standards. As the standards are updated, new targets are established for vehicle manufacturers to meet. However, on August 2, 2018, the EPA and National Highway Traffic Safety Administration submitted a proposed rule to freeze the standards to 2020 levels, making them less stringent on fuel efficiency and carbon emissions for years 2021 through 2026. The proposed rule would also revoke California's waiver and establish a single nationwide standard with weaker fuel economy goals than the current standard.

Figure 23. Car and truck fuel consumption with and without recent fuel economy standards



Source: American Council for an Energy-Efficiency Economy, 2013.

Fuel efficiency standards create benefits that continue throughout the lifetime of a vehicle, including decreasing petroleum consumption, saving money, and reducing harmful emissions. For example, if fuel efficiency standards had remained the same since 2011, rather than vehicles becoming more efficient based on CAFE standards set for 2016 and 2020, the U.S. would see increasing petroleum consumption. Figure 23 shows projected fuel consumption through 2035 for the 2011 standards (blue line) and the current efficiency standards (red and green lines). The standards are projected to save more than 3 million barrels a day by 2035, which is a key contributor to reducing GHG emissions.

The EPA/National Highway Traffic Safety Administration proposal to freeze the vehicle fuel efficiency standards also includes revoking California's authority to set rules for their Zero Emission Vehicle Program. Nine states, including Oregon, participate in the California ZEV Program, which requires most vehicle manufacturers to deliver a certain number of zero-emission vehicles, such as battery electric and fuel cell vehicles, plug-in hybrids, other hybrids, and gasoline vehicles with near-zero tailpipe emissions. This program is widely credited for the development of today's generation of electric cars on the market.

Conclusion

Oregon and the nation are off track in curbing vehicle greenhouse gas emissions and straying further away from the necessary pace every day. While electric vehicle sales are ramping up, new gasoline-fueled SUVs are entering the national fleet in far greater numbers. Even California, considered by many to be at the forefront of GHG reduction efforts, is seeing transportation emissions headed upward.

The federal government sets fuel economy standards and overall vehicle efficiency and emissions standards. Under the Trump administration the gains and directions set by previous administrations are now going in reverse. The states that have adopted California standards, including Oregon, are suing the administration, under the terms of the Clean Air Act, over its challenge to California's standards and our right to set our own climate-sensitive fuel economy standards.

Oregon and other states can enable progress on transportation emissions reduction with policies that incentivize low-carbon choices: electric vehicles, bicycle and pedestrian travel, and better urban design, to name a few. The states can reshape their electricity system to deliver clean, low-carbon electricity to a growing electric vehicle fleet. But states also face a difficult next several years trying to encourage sufficient market pull on manufacturers to maintain the necessary progress toward a clean vehicle fleet.

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Appendix

Appendix A. Oregon Greenhouse Gas Statewide Sector-based Inventory 1990-2015 and preliminary 2016 data

Emission estimates are based on the most current available data from Oregon's greenhouse gas reporting program and the U.S. EPA's State Inventory Tool.[1] All data are expressed in Million Metric Tons of Carbon Dioxide Equivalent (MMTCO2e) and use 100-year Global Warming Potentials from the IPCC's Fourth Assessment Report. High Global Warming Potential Gases (HGWP) include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6).

Total Oregon Gross GHG Emissions (With Emissions from the Use of Electricity) 1990-2003

1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
56	58	58	63	64	65	68	68	70	72	70	67	67	67

Total Oregon Gross GHG Emissions (With Emissions from the Use of Electricity) 2004-2016

2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	
68	66	68	70	68	65	64	62	61	61	60	63	62	

Emissions by Key Sectors 1990-2003

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Transportation	21.0	22.5	22.7	22.0	22.8	22.5	23.4	23.7	24.7	25.0	24.3	23.2	23.6	23.5
Electricity use (without transportation)	16.6	16.8	16.5	20.6	20.8	21.2	22.0	22.0	20.8	22.0	23.3	22.7	21.3	21.7
Natural gas use	5.0	5.6	5.5	6.3	6.3	6.5	8.0	8.2	8.9	9.7	7.7	7.3	7.4	6.9
Residential & Commercial	3.5	3.4	3.1	3.3	3.2	3.3	3.3	3.3	3.4	3.4	3.6	3.9	3.9	3.8
Industrial	5.2	5.1	5.7	5.6	5.5	5.8	5.5	5.6	6.3	6.8	6.3	5.1	5.1	4.8
Agriculture	4.9	4.9	4.9	4.9	5.2	5.5	5.6	5.6	5.5	5.2	4.9	4.9	5.5	5.8

Emissions by Key Sectors 2004-2016

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	
Transportation	24.2	24.7	25.2	25.6	23.8	23.8	23.3	22.4	22.4	21.2	21.4	23.0	24.2	
Electricity use (without transportation)	21.5	20.2	20.9	23.0	22.3	20.7	20.3	18.1	17.3	18.3	17.9	18.7	16.2	
Natural gas use	7.2	7.5	7.6	7.6	7.8	7.1	7.8	8.0	7.6	8.2	7.6	7.3	7.3	
Residential & Commercial	3.6	3.6	3.6	3.6	3.9	4.1	4.1	4.1	3.7	3.7	3.8	4.1	4.2	
Industrial	5.1	4.8	5.4	5.1	5.0	4.4	3.6	4.0	4.0	3.7	4.1	4.3	4.3	
Agriculture	5.9	5.7	5.6	5.5	5.5	5.1	5.3	5.7	5.7	5.6	5.6	5.7	5.7	

[1] The 2016 data utilizes 2016 emissions data reported to DEQ's Greenhouse Gas Reporting Program and 2015 modeled data from EPA's State Inventory Tool. It is considered to be preliminary and is subject to change. Please contact the Oregon DEQ Greenhouse Gas Reporting Program for the latest information and for the full data set at GHGReport@deq.state.or.us.

Transportation 1990-2003															
		1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
CO2	Motor Gasoline	11.610	11.782	11.705	12.112	12.372	12.400	12.801	12.208	13.114	13.257	13.061	12.957	13.133	13.004
	Distillate Fuel	4.533	4.849	4.935	4.661	4.876	4.572	4.902	5.069	4.889	5.495	5.523	5.144	5.509	5.370
	Jet Fuel, Kerosene	1.254	1.393	1.515	1.661	1.866	2.053	2.143	2.343	2.403	2.636	2.571	2.137	2.120	2.289
	Natural Gas	0.489	0.482	0.376	0.271	0.323	0.404	0.442	0.707	0.746	0.579	0.647	0.604	0.500	0.384
	Residual Fuel	1.723	2.665	2.697	1.758	1.808	1.489	1.415	1.509	1.706	1.119	0.588	0.548	0.565	0.710
	Lubricants	0.222	0.198	0.202	0.206	0.215	0.212	0.205	0.217	0.227	0.229	0.226	0.207	0.205	0.189
	Aviation Gasoline	0.042	0.044	0.045	0.038	0.054	0.050	0.067	0.061	0.052	0.056	0.048	0.079	0.054	0.047
	LPG	0.043	0.037	0.035	0.034	0.052	0.026	0.023	0.016	0.000	0.006	0.015	0.005	0.006	0.022
	Light Rail Electricity Use - Other	0.004	0.004	0.004	0.005	0.005	0.006	0.005	0.005	0.006	0.015	0.016	0.017	0.017	0.007
	Jet Fuel, Naphtha	0.082	0.113	0.098	0.072	0.004	0.003	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
CH4	Passenger & Light Vehicles	0.095	0.088	0.092	0.094	0.089	0.085	0.080	0.079	0.076	0.071	0.066	0.062	0.053	0.049
	Non-Road Vehicles & Equipment	0.008	0.009	0.009	0.007	0.008	0.008	0.008	0.009	0.009	0.008	0.008	0.008	0.008	0.008
	Heavy-Duty Vehicles	0.007	0.007	0.007	0.007	0.007	0.006	0.006	0.006	0.005	0.005	0.005	0.004	0.004	0.003
	Natural Gas Distribution (sector share)	0.041	0.052	0.041	0.027	0.030	0.038	0.034	0.054	0.046	0.033	0.043	0.040	0.036	0.030
N2O	Passenger & Light Vehicles	0.758	0.760	0.849	0.924	0.922	0.936	0.934	0.977	0.985	0.971	0.935	0.862	0.773	0.711
	Non-Road Vehicles & Equipment	0.034	0.039	0.040	0.036	0.039	0.040	0.041	0.046	0.047	0.045	0.043	0.039	0.040	0.043
	Heavy-Duty Vehicles	0.019	0.020	0.022	0.023	0.024	0.025	0.026	0.029	0.031	0.032	0.031	0.026	0.027	0.027
HGWP	Refrigerants, A/C, Fire Protection Use	0.002	0.003	0.010	0.035	0.081	0.185	0.258	0.330	0.374	0.425	0.469	0.510	0.542	0.564
Transportation Sub-total		20.97	22.55	22.68	21.97	22.77	22.54	23.39	23.67	24.72	24.98	24.29	23.25	23.59	23.46

Transportation 2004-2016														
		2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
CO2	Motor Gasoline	13.055	13.197	13.350	13.257	12.361	12.380	12.111	11.657	11.636	11.108	11.281	12.489	13.197
	Distillate Fuel	6.103	6.358	6.691	6.902	6.523	6.463	6.726	6.636	6.723	6.339	6.513	6.505	6.873
	Jet Fuel, Kerosene	2.088	2.212	2.361	2.306	2.238	2.672	1.750	1.835	1.863	1.784	1.801	2.040	2.156
	Natural Gas	0.525	0.410	0.463	0.532	0.410	0.449	0.416	0.315	0.278	0.263	0.235	0.296	0.297
	Residual Fuel	0.801	0.878	0.689	1.018	0.693	0.358	0.728	0.428	0.379	0.269	0.046	0.120	0.127
	Lubricants	0.192	0.191	0.186	0.192	0.178	0.160	0.178	0.169	0.155	0.164	0.171	0.187	0.187
	Aviation Gasoline	0.044	0.050	0.071	0.070	0.065	0.047	0.048	0.045	0.044	0.033	0.030	0.037	0.039
	LPG	0.019	0.041	0.034	0.025	0.051	0.038	0.039	0.043	0.039	0.049	0.054	0.052	0.052
	Light Rail Electricity Use - Other	0.007	0.007	0.008	0.009	0.009	0.010	0.011	0.010	0.009	0.009	0.009	0.010	0.008
	Jet Fuel, Naphtha	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CH4	Passenger & Light Vehicles	0.045	0.041	0.038	0.034	0.030	0.028	0.026	0.024	0.023	0.021	0.021	0.024	0.025
	Non-Road Vehicles & Equipment	0.008	0.008	0.009	0.009	0.008	0.008	0.008	0.009	0.009	0.008	0.007	0.006	0.007
	Heavy-Duty Vehicles	0.003	0.003	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.003
	Natural Gas Distribution (sector share)	0.034	0.029	0.034	0.035	0.026	0.030	0.025	0.024	0.020	0.016	0.016	0.018	0.018
N2O	Passenger & Light Vehicles	0.648	0.577	0.518	0.442	0.370	0.310	0.273	0.228	0.200	0.159	0.147	0.147	0.155
	Non-Road Vehicles & Equipment	0.040	0.042	0.043	0.045	0.042	0.045	0.040	0.042	0.041	0.042	0.037	0.034	0.036
	Heavy-Duty Vehicles	0.027	0.024	0.013	0.012	0.012	0.016	0.014	0.011	0.011	0.009	0.009	0.009	0.010
HGWP	Refrigerants, A/C, Fire Protection Use	0.584	0.611	0.657	0.708	0.765	0.825	0.876	0.902	0.933	0.960	1.005	1.057	1.057
Transportation Sub-total		24.22	24.68	25.17	25.60	23.78	23.84	23.27	22.38	22.36	21.24	21.38	23.03	24.25

Residential and Commercial 1990-2003															
		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
CO2	Residential Electricity Use	5.930	6.150	5.862	7.725	7.617	7.549	7.841	7.795	7.792	8.355	8.426	8.654	8.281	8.528
	Commercial Electricity Use	4.662	4.779	4.848	5.950	6.212	6.273	6.389	6.567	6.545	7.101	7.278	7.547	7.251	7.445
	Residential Natural Gas Combustion	1.269	1.440	1.273	1.644	1.601	1.555	1.840	1.813	1.917	2.169	2.117	2.089	2.114	1.993
	Commercial Natural Gas Combustion	1.110	1.221	1.078	1.328	1.275	1.242	1.417	1.419	1.448	1.604	1.564	1.522	1.508	1.395
	Commercial Petroleum Combustion	0.788	0.658	0.593	0.492	0.458	0.561	0.501	0.489	0.543	0.455	0.537	0.647	0.578	0.368
	Residential Petroleum Combustion	0.762	0.734	0.613	0.760	0.738	0.651	0.622	0.549	0.529	0.604	0.617	0.655	0.617	0.583
	Waste Incineration	0.076	0.076	0.073	0.078	0.079	0.078	0.084	0.090	0.094	0.098	0.085	0.086	0.087	0.088
	Residential Coal Combustion	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Commercial Coal Combustion	0.003	0.002	0.002	0.004	0.002	0.002	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000
CH4	Municipal Solid Waste Landfills	1.155	1.159	1.096	1.082	1.057	1.015	1.073	1.135	1.173	1.181	1.215	1.269	1.299	1.367
	Natural Gas Distribution (sector share)	0.200	0.288	0.258	0.294	0.267	0.263	0.251	0.245	0.209	0.215	0.243	0.236	0.263	0.266
	Municipal Wastewater	0.229	0.234	0.238	0.243	0.247	0.252	0.256	0.260	0.263	0.266	0.275	0.278	0.282	0.284
	Residential Combustion Byproducts	0.061	0.064	0.066	0.081	0.077	0.076	0.080	0.068	0.062	0.064	0.068	0.107	0.109	0.114
	Commercial Combustion Byproducts	0.019	0.019	0.017	0.021	0.014	0.014	0.015	0.015	0.014	0.015	0.016	0.023	0.023	0.023
	Waste Incineration	0.003	0.003	0.003	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	Compost	0.004	0.004	0.004	0.012	0.016	0.016	0.020	0.022	0.022	0.018	0.024	0.025	0.032	0.031
N2O	Fertilization of Landscaped Areas	0.060	0.058	0.061	0.060	0.066	0.065	0.070	0.076	0.075	0.057	0.042	0.059	0.079	0.090
	Residential Combustion Byproducts	0.011	0.012	0.012	0.015	0.014	0.014	0.014	0.012	0.011	0.012	0.012	0.019	0.019	0.020
	Waste Incineration	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.010	0.010	0.010	0.010	0.010	0.011
	Compost	0.004	0.004	0.004	0.011	0.014	0.014	0.018	0.019	0.020	0.016	0.021	0.023	0.029	0.028
	Commercial Combustion Byproducts	0.005	0.005	0.004	0.004	0.003	0.004	0.004	0.004	0.004	0.003	0.004	0.005	0.005	0.005
	Municipal Wastewater	0.084	0.086	0.088	0.090	0.093	0.094	0.097	0.097	0.099	0.102	0.105	0.105	0.107	0.109
HGWP	Refrigerants, Aerosols, Fire Protection Use	0.001	0.002	0.007	0.024	0.057	0.129	0.181	0.231	0.262	0.298	0.328	0.357	0.379	0.395
Residential & Commercial Sub-total		16.45	17.01	16.21	19.93	19.92	19.88	20.78	20.92	21.09	22.65	22.99	23.72	23.08	23.14

Residential and Commercial 1990-2003														
		2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
CO2	Residential Electricity Use	8.492	7.986	8.264	9.140	9.031	8.624	8.324	7.460	7.005	7.412	7.056	7.244	6.255
	Commercial Electricity Use	7.391	6.697	7.004	7.636	7.400	6.958	6.828	6.049	5.871	6.167	6.079	6.353	5.485
	Residential Natural Gas Combustion	2.062	2.188	2.255	2.350	2.450	2.439	2.584	2.827	2.565	2.856	2.502	2.326	2.332
	Commercial Natural Gas Combustion	1.403	1.519	1.530	1.590	1.655	1.618	1.725	1.841	1.705	1.888	1.724	1.611	1.615
	Commercial Petroleum Combustion	0.346	0.343	0.323	0.292	0.375	0.429	0.417	0.330	0.238	0.195	0.221	0.564	0.596
	Residential Petroleum Combustion	0.440	0.461	0.424	0.361	0.441	0.442	0.349	0.342	0.287	0.288	0.269	0.257	0.272
	Waste Incineration	0.086	0.086	0.088	0.089	0.091	0.092	0.096	0.090	0.098	0.099	0.104	0.100	0.100
	Residential Coal Combustion	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Commercial Coal Combustion	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CH4	Municipal Solid Waste Landfills	1.395	1.382	1.341	1.412	1.534	1.543	1.575	1.571	1.343	1.373	1.405	1.449	1.449
	Natural Gas Distribution (sector share)	0.225	0.261	0.282	0.262	0.260	0.274	0.262	0.360	0.312	0.298	0.288	0.243	0.245
	Municipal Wastewater	0.286	0.290	0.294	0.299	0.303	0.306	0.307	0.310	0.312	0.314	0.318	0.322	0.322
	Residential Combustion Byproducts	0.116	0.077	0.069	0.076	0.084	0.120	0.106	0.109	0.101	0.138	0.139	0.105	0.104
	Commercial Combustion Byproducts	0.023	0.016	0.015	0.016	0.017	0.021	0.021	0.021	0.018	0.020	0.021	0.023	0.022
	Waste Incineration	0.004	0.004	0.004	0.004	0.004	0.004	0.003	0.003	0.003	0.003	0.003	0.003	0.003
	Compost	0.037	0.035	0.034	0.040	0.036	0.039	0.041	0.040	0.043	0.041	0.050	0.045	0.045
N2O	Fertilization of Landscaped Areas	0.087	0.077	0.075	0.081	0.072	0.064	0.077	0.082	0.083	0.087	0.087	0.087	0.087
	Residential Combustion Byproducts	0.020	0.014	0.012	0.013	0.015	0.020	0.018	0.018	0.017	0.023	0.023	0.018	0.017
	Waste Incineration	0.011	0.011	0.011	0.011	0.011	0.011	0.009	0.009	0.009	0.009	0.009	0.009	0.009
	Compost	0.033	0.031	0.030	0.036	0.032	0.035	0.037	0.035	0.038	0.037	0.045	0.040	0.040
	Commercial Combustion Byproducts	0.004	0.003	0.003	0.003	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.005	0.005
	Municipal Wastewater	0.111	0.110	0.113	0.113	0.113	0.114	0.114	0.118	0.119	0.120	0.121	0.123	0.123
HGWP	Refrigerants, Aerosols, Fire Protection Use	0.409	0.428	0.460	0.495	0.536	0.578	0.613	0.631	0.653	0.672	0.703	0.740	0.740
Residential & Commercial Sub-total		22.98	22.02	22.63	24.32	24.46	23.74	23.51	22.25	20.82	22.04	21.17	21.67	19.87

Industrial 1990-2003															
		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
CO2	Industrial Electricity Use	5.976	5.898	5.831	6.946	6.974	7.329	7.724	7.657	6.508	6.527	7.567	6.469	5.801	5.751
	Natural Gas Combustion	2.603	2.956	3.163	3.286	3.405	3.739	4.751	4.925	5.583	5.918	4.066	3.709	3.737	3.524
	Petroleum Combustion	2.620	2.374	2.824	2.634	2.398	2.504	2.028	1.972	2.503	3.035	2.598	1.844	2.011	1.524
	Cement Manufacture	0.216	0.139	0.173	0.193	0.214	0.207	0.359	0.379	0.397	0.457	0.445	0.428	0.429	0.370
	Coal Combustion	0.137	0.180	0.221	0.214	0.272	0.270	0.185	0.188	0.072	0.000	0.000	0.000	0.104	0.139
	Ammonia Production	0.069	0.068	0.071	0.065	0.068	0.071	0.072	0.070	0.071	0.072	0.067	0.047	0.058	0.047
	Urea Consumption	0.008	0.008	0.008	0.008	0.009	0.009	0.010	0.010	0.011	0.009	0.007	0.010	0.017	0.019
	Waste Incineration	0.065	0.065	0.065	0.060	0.064	0.105	0.047	0.028	0.025	0.015	0.019	0.013	0.009	0.009
	Iron & Steel Production	0.704	0.704	0.704	0.704	0.704	0.704	0.704	0.811	0.747	0.640	0.750	0.573	0.440	0.429
	Soda Ash Production & Consumption	0.031	0.030	0.030	0.031	0.031	0.032	0.032	0.033	0.033	0.032	0.032	0.032	0.033	0.032
	Limestone and Dolomite Use	0.009	0.009	0.009	0.009	0.007	0.011	0.005	0.011	0.011	0.013	0.008	0.006	0.008	0.005
	Lime Manufacture	0.085	0.108	0.125	0.140	0.147	0.157	0.172	0.156	0.171	0.160	0.145	0.098	0.074	0.077
	Pulp & Paper including wastewater	0.186	0.186	0.186	0.186	0.186	0.186	0.186	0.186	0.186	0.186	0.186	0.186	0.186	0.186
CH4	Natural Gas Distribution & Production	0.257	0.392	0.438	0.423	0.455	0.456	0.481	0.477	0.530	0.496	0.521	0.542	0.496	0.598
	Industrial Landfills	0.070	0.071	0.073	0.074	0.077	0.081	0.086	0.092	0.097	0.102	0.109	0.114	0.118	0.124
	Combustion Byproducts	0.032	0.031	0.025	0.022	0.023	0.023	0.027	0.029	0.025	0.023	0.025	0.024	0.020	0.016
	Food Processing Wastewater	0.012	0.011	0.011	0.011	0.012	0.012	0.012	0.012	0.012	0.012	0.009	0.008	0.008	0.008
	Waste Incineration	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.003	0.003	0.003	0.004	0.004	0.005
N2O	Combustion Byproducts	0.053	0.050	0.041	0.036	0.038	0.038	0.044	0.046	0.041	0.037	0.040	0.038	0.033	0.025
	Waste Incineration	0.002	0.002	0.002	0.002	0.002	0.002	0.004	0.004	0.005	0.005	0.005	0.006	0.006	0.007
	Nitric Acid Production	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
HGWP	Semiconductor Manufacturing	0.357	0.357	0.357	0.446	0.490	0.619	0.688	0.727	0.963	1.057	0.957	0.735	0.821	0.922
	Refrigerant, Foam, Solvent, Aerosol Use	0.000	0.001	0.003	0.010	0.024	0.055	0.078	0.099	0.112	0.128	0.141	0.153	0.163	0.169
	Aluminum Production	0.313	0.316	0.307	0.281	0.250	0.256	0.270	0.272	0.279	0.280	0.272	0.191	0.084	0.084
Industrial Sub-total		13.81	13.96	14.67	15.78	15.85	16.87	17.97	18.19	18.39	19.21	17.97	15.23	14.66	14.07

Industrial 2004-2016														
		2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
CO2	Industrial Electricity Use	5.639	5.523	5.657	6.188	5.872	5.122	5.173	4.593	4.460	4.682	4.796	5.135	4.434
	Natural Gas Combustion	3.757	3.749	3.781	3.704	3.674	3.062	3.453	3.380	3.333	3.471	3.365	3.361	3.369
	Petroleum Combustion	1.675	1.432	1.575	1.372	1.486	1.381	1.319	1.643	1.573	1.377	1.410	1.619	1.711
	Cement Manufacture	0.422	0.443	0.454	0.451	0.320	0.314	0.455	0.461	0.452	0.490	0.694	0.713	0.571
	Coal Combustion	0.131	0.019	0.248	0.216	0.157	0.180	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Ammonia Production	0.057	0.056	0.062	0.061	0.057	0.058	0.113	0.130	0.115	0.129	0.130	0.101	0.110
	Urea Consumption	0.016	0.015	0.016	0.017	0.015	0.013	0.016	0.017	0.016	0.017	0.017	0.017	0.017
	Waste Incineration	0.010	0.012	0.012	0.012	0.016	0.018	0.019	0.022	0.009	0.013	0.006	0.004	0.004
	Iron & Steel Production	0.429	0.340	0.364	0.369	0.365	0.234	0.030	0.031	0.030	0.035	0.033	0.038	0.027
	Soda Ash Production & Consumption	0.032	0.032	0.031	0.031	0.029	0.026	0.027	0.026	0.026	0.026	0.027	0.026	0.026
	Limestone and Dolomite Use	0.007	0.009	0.006	0.000	0.000	0.000	0.000	0.000	0.014	0.015	0.018	0.018	0.018
	Lime Manufacture	0.097	0.095	0.083	0.072	0.060	0.050	0.051	0.052	0.052	0.054	0.055	0.055	0.055
	Pulp & Paper including wastewater	0.186	0.186	0.186	0.186	0.186	0.186	0.186	0.192	0.180	0.138	0.139	0.140	0.133
CH4	Natural Gas Distribution & Production	0.560	0.603	0.589	0.621	0.640	0.613	0.643	0.550	0.603	0.627	0.607	0.655	0.659
	Industrial Landfills	0.128	0.134	0.140	0.145	0.151	0.156	0.161	0.166	0.171	0.176	0.181	0.184	0.184
	Combustion Byproducts	0.022	0.021	0.023	0.023	0.020	0.019	0.019	0.019	0.023	0.025	0.025	0.028	0.025
	Food Processing Wastewater	0.008	0.008	0.008	0.009	0.008	0.009	0.008	0.009	0.009	0.009	0.009	0.009	0.009
	Waste Incineration	0.005	0.006	0.007	0.006	0.005	0.004	0.004	0.004	0.004	0.004	0.004	0.005	0.005
N2O	Combustion Byproducts	0.035	0.034	0.036	0.037	0.032	0.031	0.031	0.031	0.038	0.041	0.040	0.045	0.040
	Waste Incineration	0.008	0.009	0.011	0.009	0.008	0.006	0.006	0.006	0.006	0.006	0.006	0.008	0.008
	Nitric Acid Production	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
HGWP	Semiconductor Manufacturing	1.001	1.064	1.297	1.299	1.222	0.902	0.356	0.548	0.588	0.449	0.608	0.540	0.571
	Refrigerant, Foam, Solvent, Aerosol Use	0.175	0.183	0.197	0.212	0.230	0.248	0.145	0.101	0.126	0.114	0.106	0.126	0.125
	Aluminum Production	0.087	0.087	0.087	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Industrial Sub-total		14.49	14.06	14.87	15.04	14.56	12.63	12.22	11.98	11.83	11.90	12.28	12.83	12.10

Agriculture 1990-2003															
		1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
CO2	Urea Fertilization	0.063	0.062	0.063	0.065	0.071	0.072	0.074	0.079	0.085	0.070	0.053	0.080	0.129	0.144
	Liming of Agricultural Soils	0.029	0.025	0.027	0.029	0.031	0.033	0.035	0.038	0.040	0.042	0.044	0.038	0.033	0.034
CH4	Enteric Fermentation	2.582	2.604	2.609	2.603	2.781	2.936	3.014	2.996	2.922	2.926	2.819	2.661	2.769	2.787
	Manure Management	0.298	0.301	0.309	0.296	0.316	0.319	0.314	0.315	0.320	0.339	0.353	0.363	0.429	0.486
	Agricultural Residue Burning	0.007	0.006	0.006	0.008	0.007	0.007	0.008	0.007	0.007	0.004	0.007	0.004	0.004	0.006
N2O	Agricultural Soil Management	1.795	1.765	1.710	1.804	1.802	1.944	2.026	2.016	1.998	1.707	1.487	1.618	1.963	2.217
	Manure Management	0.135	0.135	0.135	0.121	0.141	0.149	0.137	0.137	0.146	0.151	0.159	0.166	0.170	0.172
	Agricultural Residue Burning	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.001	0.001	0.002
Agriculture Sub-total		4.91	4.90	4.86	4.93	5.15	5.46	5.61	5.59	5.52	5.24	4.92	4.93	5.50	5.85

Agriculture 2004-2016															
		2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	
CO2	Urea Fertilization	0.120	0.117	0.122	0.128	0.113	0.098	0.121	0.130	0.129	0.134	0.134	0.134	0.134	
	Liming of Agricultural Soils	0.039	0.043	0.041	0.040	0.037	0.030	0.027	0.035	0.039	0.050	0.048	0.058	0.058	
CH4	Enteric Fermentation	2.946	2.971	2.936	2.751	2.878	2.703	2.681	2.803	2.816	2.718	2.684	2.711	2.711	
	Manure Management	0.481	0.491	0.490	0.481	0.494	0.511	0.501	0.544	0.568	0.568	0.594	0.586	0.586	
	Agricultural Residue Burning	0.006	0.005	0.006	0.007	0.006	0.006	0.007	0.009	0.007	0.006	0.005	0.005	0.005	
N2O	Agricultural Soil Management	2.084	1.914	1.886	1.968	1.819	1.634	1.839	1.997	2.003	1.946	2.009	2.012	2.012	
	Manure Management	0.180	0.156	0.162	0.158	0.155	0.145	0.145	0.143	0.146	0.143	0.147	0.147	0.147	
	Agricultural Residue Burning	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001	
Agriculture Sub-total		4.91	4.90	4.86	4.93	5.15	5.46	5.61	5.59	5.52	5.24	4.92	4.93	5.50	

ADJUSTMENT TO DERIVE PRODUCTION-BASED GROSS INVENTORY

(In-state direct emissions only — Uses in-state electricity generation emissions instead of emissions associated with the use of electricity within Oregon.)

In-State Electric Power Generation 1990-2003

		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
CO_2	OR Power Plant Natural Gas Combustion	0.402	0.623	0.792	0.928	1.436	1.046	1.425	1.303	2.859	2.678	3.749	4.470	3.013	4.031
	OR Power Plant Coal Combustion	1.369	2.978	3.713	3.359	4.014	1.674	1.769	1.389	3.308	3.539	3.548	3.976	3.358	3.977
	OR Power Plant Petroleum Combustion	0.024	0.010	0.008	0.024	0.005	0.005	0.004	0.010	0.025	0.007	0.045	0.078	0.006	0.043
CH_4	OR Power Plant Combustion Byproducts	0.004	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.006	0.005	0.006	0.006	0.005	0.006
N_2O	OR Power Plant Combustion Byproducts	0.013	0.019	0.022	0.021	0.024	0.014	0.015	0.013	0.023	0.023	0.024	0.027	0.022	0.027
HGWP	Transmission and Distribution Systems	0.366	0.350	0.343	0.334	0.309	0.282	0.265	0.241	0.191	0.195	0.187	0.163	0.143	0.128
In-State Electric Power Generation Sub-total		2.179	3.984	4.883	4.668	5.793	3.027	3.483	2.959	6.412	6.446	7.559	8.721	6.547	8.212
Remove Total of Electricity Use Emissions		(16.57)	(16.83)	(16.55)	(20.63)	(20.81)	(21.16)	(21.96)	(22.02)	(20.85)	(22.00)	(23.29)	(22.69)	(21.35)	(21.73)
Gross GhG Emissions, Production Basis		42	46	47	47	49	47	49	49	55	57	54	53	52	53

In-State Electric Power Generation 2004-2016

		2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	
CO_2	OR Power Plant Natural Gas Combustion	4.804	4.762	4.087	5.564	6.315	5.894	6.045	3.310	4.497	5.645	4.997	6.353	6.087	
	OR Power Plant Coal Combustion	3.214	3.247	2.221	3.955	3.642	2.862	4.045	3.323	2.650	3.648	3.102	2.296	1.825	
	OR Power Plant Petroleum Combustion	0.017	0.040	0.005	0.004	0.009	0.002	0.002	0.005	0.005	0.005	0.008	0.005	0.004	
CH_4	OR Power Plant Combustion Byproducts	0.003	0.008	0.007	0.007	0.006	0.006	0.016	0.012	0.010	0.015	0.013	0.011	0.010	
N_2O	OR Power Plant Combustion Byproducts	0.018	0.025	0.020	0.028	0.024	0.021	0.026	0.020	0.018	0.024	0.022	0.018	0.016	
HGWP	Transmission and Distribution Systems	0.117	0.105	0.091	0.081	0.080	0.079	0.072	0.075	0.061	0.059	0.061	0.052	0.052	
In-State Electric Power Generation Sub-total		8.172	8.187	6.431	9.638	10.076	8.865	10.207	6.745	7.240	9.396	8.203	8.735	7.995	
Remove Total of Electricity Use Emissions		(21.53)	(20.21)	(20.93)	(22.97)	(22.31)	(20.71)	(20.34)	(18.11)	(17.35)	(18.27)	(17.94)	(18.74)	(16.18)	
Gross GhG Emissions, Production Basis		54	54	54	57	56	53	54	51	51	52	51	53	54	

KeepOregonCool
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