Oregon Department of Transportation

Oregon Department of Transportation

Operational Greenhouse Gas Reductions: Best Practices & Recommendations

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Executive Summary

The Oregon Department of Transportation (ODOT) is committed to reducing greenhouse gas (GHG) emissions. Toward that end, ODOT conducted a multi-year GHG inventory to better understand the agency's baseline emissions and, in parallel, explored the market availability, costs and operational feasibility of various best practices to reduce GHG emissions.

Below are the key findings of ODOT's GHG Inventory, FY16-19 (see Figure ES1 for details):

- ODOT's largest source of "owned" GHGs (Scope 1 + Scope 2) is diesel and gasoline use by heavy trucks (56%) and pickup trucks (22%) for highway maintenance and operation, followed by electricity use in ODOT's buildings and highway system operations (e.g., streetlights). Other fuels (e.g., natural gas, propane) are a small share of emissions.
- The production of asphalt concrete pavement and concrete and cement products along with the fuels used by contractors working on ODOT's behalf represent important sources of upstream, Scope 3 emissions. Scope 3 emissions can be challenging to address because they are "shared" sources of emissions between ODOT and contractors.

ODOT has already began to reduce sources of both owned and shared emissions. Use of renewable diesel increased from 3% of total diesel use in FY 19 to 23% in FY20. Reclaimed asphalt pavement (RAP) is substituted for higher impact, virgin materials in asphalt concrete pavement. ODOT also maximizes its use of lower-impact materials substitutes for higher-impact Portland cement. And the agency has long followed a strategic energy management plan to implement energy efficiency upgrades to buildings and roadway lighting to reduce overall energy needs while also developing solar electricity generation.

The largest reduction opportunities for ODOT's "owned" Scope 1 and Scope 2 emissions in order of priority and recommended sequence are listed below. These actions offer large-scale reductions at a relatively low cost, except for electric vehicles (EVs) where cost can vary dramatically depending on circumstances.

1. Continued purchase of renewable diesel (R99) toward a 100% substitution for fossil diesel.
2. Purchase of 100% renewable electricity within Pacific Power and Portland General Electric (PGE) service territories.
3. Replace fossil gasoline vehicles with battery electric or hybrid vehicles.
4. Purchase carbon offsets equal to the amount of natural gas used.

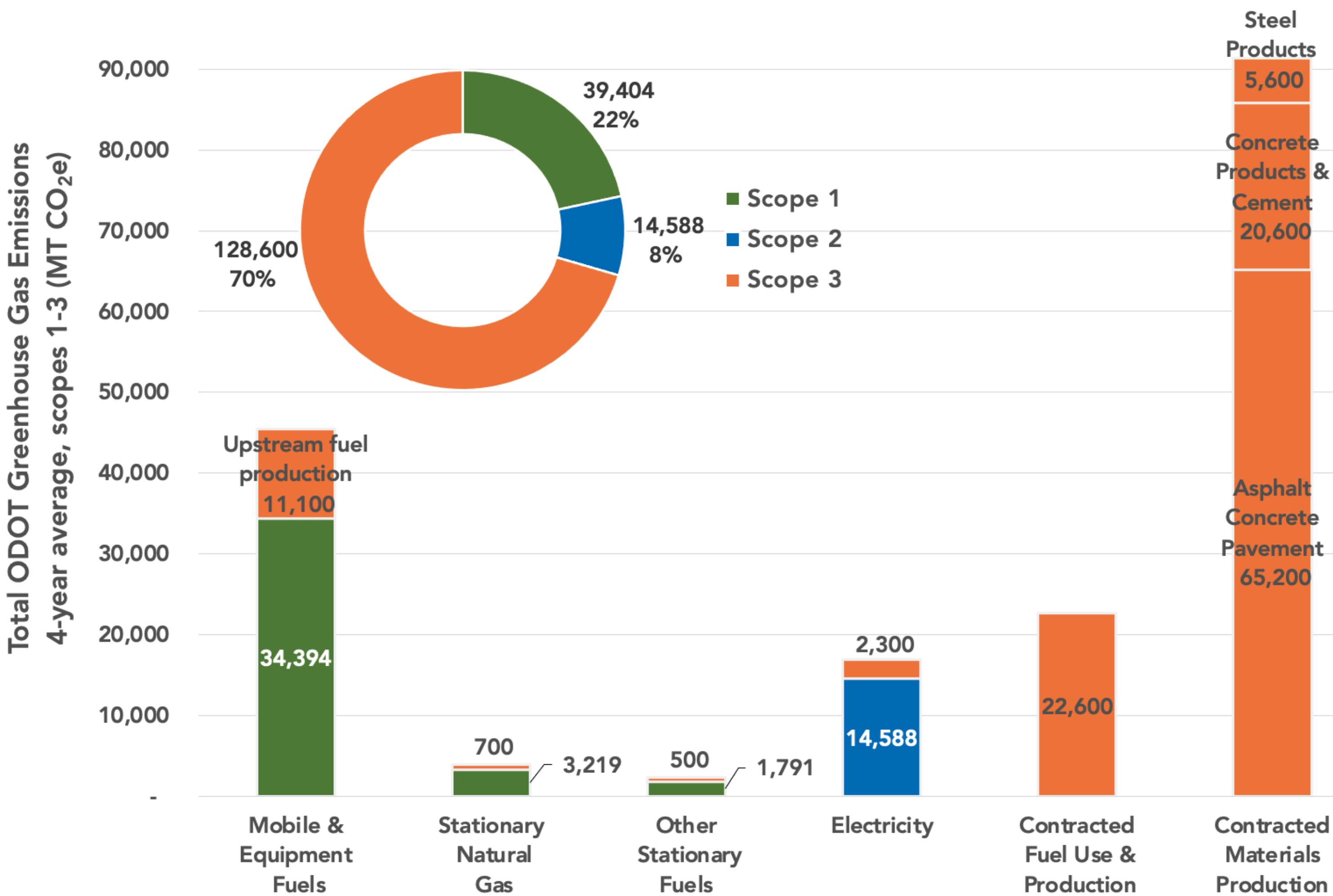
For Scope 3 sources, what ODOT "shares" with contractors that build infrastructure and procure materials on behalf of the agency, the following represent opportunities to reduce emissions – again in order of priority and sequence based on reduction potential and costs:

1. Develop and implement a program that utilizes environmental product declarations (EPD) to set GHG impact thresholds, by material type, and improve internal data systems for monitoring and reporting on progress.
2. Support ODOT contractors' transition to renewable diesel by supporting development of public and private fueling infrastructure (e.g., new tanks, private card lock R99 availability, etc.).

3. Continue to maximize use of alternative cements and encouraging industrial EnergyStar certifications for material vendors.
4. Encourage Oregon asphalt plants to participate in the Environmental Protection Agency's EnergyStar Challenge for Industry. This practice offers fewer GHG reductions than other best practices, but at a lower cost.
5. Substitute renewable fuels for fossil fuels in industry plants. This practice represents significant potential emissions reductions, but would come at a much higher cost compared to other best practice actions.

Figure ES2 presents estimates of potential emissions reductions; comparison of reductions to ODOT baseline emissions; estimated annual costs (for year 1); and the unit cost for each reduction (marginal cost increase vs. conventional ($) / GHGs reduced by the action). Figure ES2 also includes potential implementation timing for each action based on availability and compares the emissions reduction benefits and costs to provide a high-level comparison of opportunities to illustrate what actions to prioritize.

Figure ES1: Total GHG emissions across all analyzed sources of emissions (4-year average FY16-19)



Scope 1: *Direct GHGs from equipment and facilities owned or operated by ODOT.*

Scope 2: *Indirect GHGs from electricity purchased for equipment and facilities owned or operated by ODOT.*

Scope 3: *All other indirect emissions sources that result from ODOT's activities but occur from sources owned or controlled by ODOT Tier 1 contractors and other downstream supply chain vendors (e.g., asphalt and concrete plants and concrete and cement manufacturers).*

Figure ES2: Summary of best practice emissions reduction potential by GHG scope category

Scope	Action Description	Emissions Reduction	Reduction vs. Baseline	Estimated Annual Cost Range (year 1)	Unit Cost of Reductions	Implementation Timing
		MT CO_2e	% of Baseline	$ / year 1	$ / 1 MT CO_2e	year
1	ODOT Renewable Diesel Supply (100% of fossil diesel)	24,000	99%	$0 to $470k *(from $0 premium to $0.20 per gallon)*	$0 - $20	ongoing
1	Carbon Offsets / Renewable Natural Gas (100% of fossil gas)	3,200	100%	$7 - $50k *($2 to $21 per offset depending on project and location)*	$2 - $21	ongoing (until RNG is offered)
1	Electric Vehicles (100% of sedans, pickups, and SUVs)	5,500	100%	$250 - $350k (annual marginal increase over ICE vehicles)	$0 to $37	ongoing - 2035
2	Renewable Energy Purchases (100% for high-impact utilities)	14,000	96%	$80k - $100k (dependent Community Solar project availability and cost savings)	(-$12) to $12	2022 - 2040
3	Contractor Renewable Diesel Supply (100% of fossil diesel)	16,000	99%	$0 - $425k ($0 to $0.20 per gallon premium)	$0 - $20	ongoing
3	EPD Program and Reduction Targets	TBD	TBD	To be determined (program design dependent)		2022 - 2025
3	Alternative Cements (30% - 50% substitution for all Portland cement)	2,000 - 5,000	10 - 30%	Not available (anti-trust concerns about sharing costs between vendors)		ongoing
3	Asphalt Plants - EnergyStar Certification (10% reduction in baseline energy use)	1,000 - 3,000	5 - 15%	To be determined (plant and action dependent)	(-$20) - $20	2022 - 2025
3	Asphalt Plants - Renewable Fuels (100% substitution of fossil fuels)	20,000 - 26,000	15 - 25%	Significant additional cost for renewables not under Clean Fuels Program	$200 - $520	2022 - 2030
	Scope 1 (ODOT "owned" direct emissions)	**32,700**	**83%**	**$250 - $1,000k**	**$0 - $37**	
	Scope 2 (ODOT "owned" indirect emissions)	**14,000**	**96%**	**$80k - $100k**	**(-$12) - $12**	
	Scope 3 (Contractor "shared" indirect emissions)	**TBD**	**TBD**	To be determined (additional stakeholder process required)		

Project Introduction

Overview

ODOT constructs and maintains hundreds of bridges and thousands of highway lane miles throughout the state. In total, large amounts of materials go into construction and maintenance projects and significant amounts of fuel and electricity are used every day to maintain roadways and manage projects. While the agency tracks quantity, costs and other material specifications, as of February 2021, ODOT did not have a baseline inventory of GHG emissions related to agency operations nor did it have a clear set of actions to take to reduce emissions.

The Oregon Transportation Commission adopted a Strategic Action Plan (SAP) for ODOT in 2020 to articulate priorities for the agency to meet current and future demands. The plan revolves around three priorities: equity, modern transportation system, sufficient and reliable funding. These priorities set the overall direction for the agency, and include underlying goals that focus the agency's work. Climate action is listed as a high priority with specific outcomes, including:

- By the end of 2023, begin to reduce GHG emissions from ODOT activities.

ODOT's Climate Office responded to this task by initiating a greenhouse gas inventory of ODOT operations and maintenance practices with the intention to make more informed decisions to help the agency meet its climate goals detailed in the SAP.[1]

Project Overview

ODOT's Climate Office, with consultant support from Good Company, initiated the greenhouse gas inventory (hereinafter referred to as the "GHG Inventory") in February 2021 to develop a recommendations report (hereinafter referred to as the "Recommendations Report") based on an assessment of GHG emission reduction best practices, a review of related market conditions, and a forecast of GHG reduction potential from the practices. The project included three phases:

Phase 1 – GHG Inventory

The project started with a GHG emissions inventory of ODOT maintenance and construction operations, addressing fuel use during work performed and materials purchased by the agency. The tasks included in Phase 1 were: 1) selection of suitable topics (i.e., emissions sources) for the inventory; 2) identification of data sources; 3) data collection; and 4) analysis of the data. Inventory topics were selected based on prevalence, emissions impact and data availability.

Phase 2 – GHG Emissions Reduction Best Practices and Market Research

Phase 2 work included interviews with ODOT subject matter experts (SMEs) and three project advisory group meetings for related implementation opportunities, challenges, product availability, costs and other market conditions. The project advisory group included ODOT staff, industry representatives, and university professors.

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[1]ODOT's Strategic Action Plan is available here: https://www.oregon.gov/odot/SAPDocs/Strategic-Action-Plan.pdf.

Phase 3 – Recommendations Report

Phase 3 involved the development of recommended GHG reduction actions, scaling of the mitigation potential for each recommended action, and documentation of the findings and recommendations in a final report and education papers on key areas where the agency can focus efforts to reduced GHG emissions.

Advisory Group Meetings

ODOT's Climate Office hosted three (3) advisory group meetings, facilitated by Good Company, to share initial results and receive feedback on next steps, best practices, feasibility, and market dynamics. See previous section for AG group membership.

Summary of Findings

ODOT's first GHG inventory uses fiscal year (FY) 2016 through FY 2019 data. Multiple years of data was collected to better understand and account the year-over-year variability for a baseline operational inventory. Data was collected based on an operational control approach for agency-wide operations, with a focus on two ODOT program areas: Construction and Maintenance & Operations (M&O). The geographic boundary for the inventory was all ODOT operations located in the state of Oregon.

Table 1, on the next page, describes the emissions sources included in the inventory. Notable exclusions include fugitive refrigerants, employee commute, solid waste disposal, business travel, and production of concrete and steel products for use in maintenance projects. The primary reason for exclusion was a lack of an available, centralized data set.

Again, Figure ES1, above, shows ODOT's GHG emissions in metric tons of carbon dioxide equivalent (MT CO_2e).

Table 1: Sources of ODOT Emissions with Scope and Source Descriptions

SCOPE	EMISSIONS SOURCE	EMISSIONS SOURCE DESCRIPTION
Scope 1 (Direct Emissions)	**Owned Vehicles & Mobile Equipment**	Fuels include gasoline and ethanol blends (E10, E85); diesel, biodiesel, and renewable diesel blends (diesel, B2, B5, B20, B40, R20, R99); compressed natural gas (CNG); and propane. These fuels are used in a variety of equipment detailed later in the report. Scope 1 represent the tailpipe emissions for these fuels.
Scope 1 (Direct Emissions)	**Stationary - Natural Gas**	Natural gas is primarily used for air and water heating at ODOT facilities; some cooking use may also be included.
Scope 1 (Direct Emissions)	**Stationary Fuels - Other**	Other stationary fuels used by ODOT include diesel, fuel oil, and propane. Stationary diesel is used largely for diesel-powered electric generators. Santiam Pass Maintenance Facility in particular uses diesel as this facility is not connected to the electricity grid.
Scope 2 (Indirect)	**Purchased Electricity**	Electricity purchased for ODOT facility use and infrastructure, including streetlights. ODOT purchases electricity from 40 different Oregon, Washington and Idaho utilities, each with its own market-based emissions factor. Emissions area also calculated using a location-based emissions factor for the Northwest Power Pool region.
Scope 3 (Indirect Emissions)	**Asphalt Production**	Production and transportation of raw materials for asphalt concrete pavement (ACP) production for use in ODOT construction and maintenance projects. Materials are an indirect purchase from contractors for construction and maintenance projects.
Scope 3 (Indirect Emissions)	**Concrete Production**	Production and transportation of raw materials for Portland cement, ready-mix concrete, and precast products. Materials are often an indirect purchase from Tier 1 contractors for construction projects. Maintenance materials are not included due to data limitations.
Scope 3 (Indirect Emissions)	**Steel Production**	Production and transportation of raw materials for steel (including pipes, reinforcement, barriers, guardrail, etc.). Materials are often an indirect purchase from Tier 1 contractors for construction projects. Maintenance materials are not included due to data limitations.
Scope 3 (Indirect Emissions)	**Contractor Fuel Use (freight & construction)**	Fuel use by contractors for on- and off-road vehicles and equipment. Two primary categories are included: 1) Nonroad equipment used in construction and maintenance projects, and 2) On-road use for transport of asphalt, concrete, and steel products from plant to project site.
Scope 3 (Indirect Emissions)	**Upstream Fuels and Electricity Production**	All energy and fuel production, both stationary and mobile, have upstream energy and emissions associated with the production, refinement, and delivery of that fuel or energy.

Summary of Best Practice GHG Reductions and Cost Impacts

Figure ES2, above, presents high-level estimates of GHG reduction potential for a variety of climate action best practice areas. Details of these estimates may be found in the GHG Emission Reductions: Best Practices and Market Conditions section later in this document.

The largest reduction opportunities for ODOT's "owned" Scope 1 and Scope 2 emissions sources are listed in the bullet points below. These actions offer large-scale reduction opportunities at a relatively low cost, except for EVs where cost can vary dramatically depending on circumstances:

- Continued ODOT purchase of renewable diesel with a goal of 100% substitution for fossil diesel
- Purchase of 100% renewable electricity within Pacific Power and PGE service territories
- Replace fossil gasoline vehicles with battery electric or hybrid vehicles.
- Purchase carbon offsets equal to the amount of natural gas used in a year.

The State of Oregon has established climate goals (EO 20-04, 2020):

45% below 1990 levels by 2035 and 80% below 1990 levels by 2050

These goals translate to holding global warming to no more than 2°C above preindustrial levels.

Because reliable and complete agency data related to GHG emissions are not available back to 1990, for the purpose of this guidance document, Oregon's existing goals are adjusted to fit with a more recent emissions baseline. The adjusted 2°C Goal roughly equate to:

50% below 2015-2020 baselines by 2035 and 82% below by 2050

Oregon's existing goal is aligned with keeping global average temperatures below a 2°C increase compared to the start of the industrial revolution. This is understood to be the *minimum* guardrail needed to avoid a feedback loop of increased temperatures causing droughts, wildfires, floods, and other impacts that will become more severe and more frequent as we approach or exceed the goal.

Example Pathway for ODOT to Reach Oregon's Goal

For ODOT owned (Scope 1 + Scope 2) emissions – 90% renewable electricity by 2035; 50% renewable diesel; and use of 100% EVs for sedans and 25% for SUVs and pickup trucks is one possible scenario to achieve the State of Oregon's 2035 climate goal.

To address Scope 3 emissions, shared with contractors, reduction actions include:

- Support ODOT contractors' transition to renewable fuels by supporting development of public and private infrastructure.
- Continue to maximize use of alternative cements and encourage industrial EnergyStar certifications for material vendors. This practice offers fewer GHG reductions than other best practices, but at a lower cost.
- Substitute renewable fuels for fossil fuels in industry plants. This practice represents significant reductions, but would come at a much higher cost as these fuels are not under Oregon Clean Fuels Program and are not eligible for related financial incentives.

A contractor reporting program, informed by EPDs, has the potential to offer significant GHG emissions reductions, but the scale of reductions is wholly dependent on the rate of reduction specified by the program and specific to the material type. Use of alternative cements, industrial energy efficiency, and substitution of renewable fuels are all actions that may be leveraged by industry to meet requirements of an EPD program with GHG thresholds and targets for material production.

ODOT has already begun many of the best practices to address sources of owned emissions, such as increasing supply and use of renewable diesel and bringing battery electric and hybrid sedans into the fleet. The implementation timing on Figure ES2 is speculative and will need ODOT refinement but offers a rough outline of potential timing based on already ongoing activities, requirements of existing Oregon policy, and reasonable program development timelines based on examples and lessons learned from existing programs.

Summary of Recommendations

The following sections summarize:

- Project recommendations, by best practice area, based on the findings of the GHG inventory;
- Interviews and research for best climate action practices and regional market conditions with the project advisory group and other subject matter experts; and
- The scale of GHG reduction potential associated with the actions.

See the following sections in this report for a comprehensive description and additional details for each best practice. The recommended order of implementation, based on ODOT owned emissions first (Scope 1 + Scope 2), reduction potential and costs is summarized in the list below and the order of recommendations in this section follows this order.

1. Continued purchase of renewable diesel toward a 100% substitution for fossil diesel.
2. Purchase of 100% renewable electricity within Pacific Power and PGE service territories.
3. Substitution of battery electric or hybrid vehicles for fossil gasoline vehicles.
4. Purchase carbon offsets as needed to meet agency emissions reduction goals.
5. Develop and implement a program that utilizes EPD to set GHG impact thresholds, by material type, and improve internal data systems for monitoring and reporting on progress.
6. Support ODOT contractors' transition to renewable fuels by supporting development of public and private fueling infrastructure (e.g., new tanks, private card lock renewable diesel availability).
7. Continue to maximize use of alternative cements and encouraging industrial EnergyStar certifications for material vendors. This practice offers fewer GHG reductions than other best practices, but at a lower cost.
8. Encourage Oregon asphalt plants to participate in EPA's Industrial EnergyStar Challenge.
9. Substitute renewable fuels for fossil fuels in industry plants. This practice represents significant potential emissions reductions, but comes at a much higher cost compared to other best practice actions.

The following recommendations consider best practice actions ODOT has already taken to reduce GHG emissions and are accounted for in ODOT's FY16-19 baseline GHG inventory. For example, best-practices already implemented by ODOT include significant use of RAP and use of Portland cement alternatives. ODOT SMEs shared these practices are being maximized in ODOT's contracted materials and that any increased use of these substitutes risks reducing lifespan. ODOT pavement engineers regularly consider the balance between pavement lifecycle design and maximizing use of lower-impact substitutes. Low-carbon substitutions are the simplest way to reduce material production emissions within ODOT's control. However, such substitutions can lead to a decreased lifespan which increases net emissions. Beyond substitutions, material production emissions can be reduced by: 1) greater efficiency or renewable fuel use at the material production plant; 2) more efficient transportation to job site; 3) more efficient equipment use during installation. These types of best practices are high-lighted in the following text and may be captured within a Buy Clean program using EPDs to monitor progress.

Renewable Diesel

a. Develop partnerships with contractors and vendors to maximize market leverage for Oregon. ODOT should seek 100% renewable diesel as soon as possible for its owned equipment and support its contractors and vendors to achieve equal access and pricing for renewable diesel purchases.
b. Join existing public agency efforts, like the Greater Oregon Fleet Cooperative, to increase Oregon's renewable diesel purchasing power and to contract for the largest possible fuel volume as soon as possible.
c. Develop owned and shared fuel storage infrastructure as needed to allow for greatest distribution of renewable fuels at the lowest costs.
d. Work with private Oregon fuel distributors to develop access to renewable diesel blends at fuel supply/card-lock facilities for ODOT owned equipment as well as vendors and contractor equipment.
e. Communicate with US Department of Agriculture to position the agency to be ready for the next funding cycle of the Higher Blends Infrastructure Incentive Program, which can help offset the costs associated with renewable diesel infrastructure.

Renewable Electricity

a. Continue implementation of cost-effective energy efficiency and conservation projects to maintain, or ideally decrease, existing load. This precursor action will reduce total energy need and costs for energy and additional premiums for renewable electricity products.
b. Subscribe to community solar programs as much and as quickly as possible. Bill credits are likely to be less lucrative in the future.
c. Prepare application for PGE's next Green Future Impacts offering. This program is only offered during defined enrollment periods (next offering likely to be mid-2022).
d. Participate in Pacific Power's BlueSky program and transition to supporting 100% renewable electricity. Adjust purchases over time to account for existing renewables in retail products, the benefits of Oregon's existing Renewable Portfolio Standard (RPS) and the requirements of HB 2021 (i.e., decrease purchases over time as renewable mix on grid increases).

e. Participate in PGE's Enterprise Choice program as soon as the program opens for new enrollment. Adjust purchases over time, as described above.
f. Identify ODOT-owned facilities and land that present economically feasible opportunities for onsite solar photovoltaic (PV) development.

Electric Vehicles

a. Develop a fleet electrification and charging infrastructure plan with dedicated staff and funding for implementation.
b. Regarding implementation of Executive Order 17-21 and HB 2027 (2021), focus on passenger sedans in the near-term and rapidly adopt EVs in the pickup and SUV categories as models become available that meet the service needs of the agency.
c. Plan for and install EV charging infrastructure at ODOT facilities.
d. Engage with ODEQ Clean Fuels Program to get advance payments on vehicles.
e. Partner with the state's investor-owned utilities (i.e., Pacific Power and PGE) to procure 100% renewable electricity to ensure maximum GHG reduction benefits of EVs.
f. Develop a policy requiring the use of EVs before any other vehicle type. Track progress using vehicle miles traveled reporting, by vehicle class, in Oregon Department of Administrative Services (ODAS) biennial report on Fleet and Parking Services. Track vehicle miles traveled, by ODOT vehicle types to track progress toward maximizing use of EVs and minimizing use of conventional gasoline powered vehicles. Complimentary tracking could include the percent of renewable electricity purchased to power the vehicles.
g. Partner with DAS to regularly update statewide price agreement to ensure new BEVs and PHEVs are available for purchase.

Purchased Carbon Offsets

a. Participate in Oregon natural gas programs (as they become available) that substitute renewable natural gas (RNG) for fossil natural gas. Northwest Natural Gas (NWN) anticipates having a RNG product available in 2022.
b. Purchase carbon offsets from Bonneville Environmental Foundation (BEF) at the lowest cost to offset 100% of ODOT's natural gas emissions. Research found BEF to be a regional service provider with a range of project types and costs.
c. In conjunction or as an alternative to the recommendations above, participate in NWN's SmartEnergy program (run by The Climate Trust). SmartEnergy carbon offsets cost significantly more than other options, however, they offer significant co-benefits including regionally-based projects focused on developing RNG-production capacity.

EPD Program Development

Develop and pilot a "Buy Clean" policy as soon as possible:

Program Development

a. Require and track EPDs on specific projects or in certain regions (Portland-area vendors are more likely to have EPDs in response to the City of Portland's EPD requirement).

b. Research past projects (within one to two years) to match mix data with EPDs available on the market (using the EC3 tool). Develop an understanding of the status quo (i.e., range of emissions from current and recently completed projects).
c. Define material reporting categories and set a predictable and adequate timeline for EPD reporting from contractors / material producers.
d. Include accommodations for smaller businesses and provide access to financial incentives and technical support.
e. Design and implement new internal material tracking systems that align with EPD reporting units (AASHTOWare[2] is one example). The system at a minimum should be capable of tracking material quantities (weights or volumes depending on the EPD and material type) at the bid-item level; retaining a copy of the EPD; and the global warming potential value taken from the EPD. This system set up will allow for simple annual reporting of material quantities, average global warming potential by material type, and total annual GHGs.
f. Learn from the Carbon Leadership Forum. Follow the progress of Colorado's recently passed Buy Clean legislation and specifically how they develop the EPD tracking system for asphalt concrete pavement.

Implementation

a. Run pilot projects to experiment with low-carbon applications. This can happen concurrently - during program development - and does not need to wait for any policies. Reference the City of Portland's "Low Carbon Concrete Sidewalk Pilot" project.[3]
b. Review EPDs over time to see where there are common hotspots and work with material vendors to mitigate where possible (e.g., moisture management, cement alternatives, renewable fuels).
c. Require EPDs for projects, starting small and become more inclusive as availability of EPDs increases.
d. Set emission limits by region, material type, and/or specific to a project.
e. Lower emission limits over time at appropriate levels, sensitive to market and available technologies, as well as the need for climate action (i.e., net-zero emissions by 2050).

Alternative Cement

a. Determine if the allowable SCM levels in ACI301 are applicable for all ODOT applications. If not, research if there is room for increasing tolerances.
b. Develop long term sources of SCMs for ODOT and other local agencies.
c. Support vendors (as needed) to identify financial support from US Environmental Protection Agency (EPA), USDOE, etc. and state resources (Oregon Department of Energy, Oregon Department of Environmental Quality and Biz Oregon) for new capital equipment or conversion costs to install infrastructure that enable maximizing SCM availability.
d. Support research on SCMs and their viability on ODOT projects - specifically for materials with local or regional supply such as soda-lime glass.

[2] For details visit https://www.aashtoware.org
[3] https://www.portland.gov/sites/default/files/2020/concretecasestudy_copsidewalks_final.pdf

e. Update data tracking system to monitor climate impacts from material production.

Asphalt Plant Energy Efficiency

a. Promote and encourage ODOT contractors to voluntarily participate in the EnergyStar Challenge for Industry with a primary focus on moisture reduction.
b. Work with Energy Trust of Oregon (ETO) for technical support and incentives.
c. Seek financial support from EPA, USDOE, etc. and state resources (Department of Energy, Department of Environmental Quality and Biz Oregon) for conversion costs through low interest loans, grants, or bond issuance.

Asphalt Plant Renewable Fuels and Energy

a. Partner with industry and Oregon Department of Environmental Quality to develop an incentive program tailored to the asphalt pavement production industry that fairly incentivizes fuels that result in fewer GHG emissions.
b. Partner with trade associations to better understand (e.g., survey) which plants use fossil fuels and who might consider switching to renewable fuels.
c. Create a working group of plant operators and fuel providers to discuss transitioning fuels on a managed schedule and procurement of carbon offsets. Develop a pilot program as appropriate.
d. Consider incorporating the increased cost of renewable fuels into ODOT contracts to support fuel switching.
e. Substitute RNG and or renewable hydrogen for fossil natural gas, as it becomes available. (NWN anticipates offering RNG as early as 2022.)

GHG Emission Reduction Best Practices and Market Conditions

The following text offer details on best practices considered in during ODOT's GHG Inventory. Each topic includes:

- Action Description and Real-World Examples
- Current Conditions at ODOT
- Other Alternatives
- Market Study – Availability and Access, Costs, Incentives, and/or Making the Transition
- Lifecycle Considerations
- GHG Benefits and Cost Scaling
- Co-Benefits

Renewable Diesel

Substitution of lower-lifecycle climate impact fuels (specifically renewable diesel and biodiesel products) for fossil diesel represents a significant opportunity to reduce the climate impact of diesel equipment without negatively affecting operations or the quality of services provided. Biodiesel and renewable diesel reduce tailpipe GHG emissions by using plant-based feedstock to produce the fuel instead of fossil petroleum. The carbon contained in these materials is part of the living carbon cycle and therefore has a much lower climate impact than fuels produced with fossil carbon that has been stored in the earth for millions of years.

Biodiesel has been available for many years as a lower-GHG impact substitute for fossil diesel. In recognition of this benefit, the State of Oregon mandated the use of 5% biodiesel in all diesel products sold in Oregon beginning in 2011. Many organizations, including ODOT at times, exceed that minimum and use a B20 product (20% biodiesel / 80% fossil diesel) year-round. However, renewable diesel has emerged as the preferred fossil diesel substitute that can be used at much higher blend rates (99% renewable) than biodiesel without additional maintenance or warranty issues that some experience with biodiesel. Renewable diesel (also referred to as "R99", reflecting the blend rate: 99% renewable with 1% fossil diesel) is a drop-in fuel, meaning no equipment or storage tank modifications are necessary because the fuel can operate at the same cold temperatures as petroleum diesel, without the gelling problems experienced with biodiesel.

Real World Examples

Many public entities throughout Oregon are increasing their use of biodiesel or renewable diesel:

- ODOT is already using renewable and biodiesel fuels as fossil diesel replacements through a statewide price agreement. In 2020, renewable and biodiesel fuel use increased to 23% from 3% of diesel fuel in 2019.

- Lane County and others purchase R99 through a price agreement negotiated by the ***Greater Oregon Fleet Cooperative***[4] (GOFC).
- The Port of Portland is using R99 exclusively for owned operations. This policy is planned for expansion to marine vehicles and the Port's vendors. The Port is also in the process of procuring renewable natural gas to fuel its fleet of shuttle buses.

Current Conditions

Diesel fuel use by ODOT vehicles and equipment is critical to support the construction, operation, and maintenance of the state highway system. Between FY 2016-2019, ODOT consumed between 2.3 and 2.8 million gallons of diesel fuels annually in owned vehicles and equipment. Fossil diesel is commonly blended with either biodiesel (2% - 20% blends) or renewable diesel (between 20% - 99% blends). On average, between FY 2016-2019, ODOT used 91% fossil diesel, 7% biodiesel, and 2% renewable diesel of all diesel fuels consumed. ODOT's tailpipe GHG emissions from diesel fuel combustion in owned vehicles and equipment, between FY 2016-19, averaged 24,200 MT CO2e (range of 22,000 – 27,000 MT CO_2e). Beyond tailpipe emissions, another 6,000 – 9,000 MT CO2e were emitted during the production of ODOT's diesel fuel use.

Beyond direct fuel use in ODOT owned equipment, "shared" diesel fuel used by ODOT contractors was estimated between 1.5 – 2.0 million gallons over the period for on-road freight and off-road construction uses. Nonroad construction equipment fuel use is estimated using ODOT fuel volumes for nonroad use as reported in ODEQ's Non-road Diesel Equipment Survey and Emissions Inventory (for nonroad equipment). On road material freight transport is estimated using ODOT material quantities and fuel use and emissions factors reported in FHWA's Infrastructure Carbon Estimator Guidebook. As a best practice, renewable diesel may be utilized by ODOT contractors as well to reduce sources of ODOT "shared" emissions. For contracted construction equipment and materials delivery work, the emissions were found to be between 22,000 – 25,000 MT CO2e over the period from tailpipe and fuel production. In total, GHG emissions from ODOT direct and indirect fuel use average over 50,000 MT CO_2e annually.

Other Alternatives

Actions to compliment use of alternative diesel products include increasing fuel economy. Other renewable fuels are also available but are not drop-in like renewable diesel and may require capital upgrades or operational change. Examples of these alternative actions include:

- Use of anti-idle technology[5]
- Procurement of newer vehicles and/or hybrid technology to increase fuel efficiency
- Use of telematics to inform logistics planning and driver performance

[4] GOFC is a purchasing group comprised of different government agencies throughout Oregon and was formed to leverage public resources to reduce costs. Participants of the cooperative include: school districts, cities, counties, park districts, transit districts, utilities, colleges and universities. For more information visit https://greateroregonfleetcooperative.org
[5] Approximately 225 ODOT trucks use anti-idling technology, or, 24% of on-road fleet. ODOT's Sustainability Plan has a goal to increase this amount to 30%.

Other currently available lower-carbon fuel alternatives include:

- Propane (renewable or fossil)
- Natural gas-based fuels (renewable or fossil)

Other, "on the horizon" lower-carbon fuels include:[6]

- Battery electric
- Green/renewable hydrogen

Market Study

Availability and Access

According to the US Department of Energy, there are currently five plants that produce renewable diesel in or for the United States, with a combined capacity of nearly 400 million gallons per year. Renewable diesel availability is expected to grow significantly over the next five years as new plants are constructed. Large domestic and international renewable diesel producers include Green Diamond and Neste. New plants are anticipated to come online over the next two to five years in California and Oregon. In Oregon, those facilities are in Lakeview and Clatskanie.

The challenge with renewable diesel (as of this writing) is that supply is low and is not consistently available throughout Oregon to meet current demand for public fuel contracts. Further, renewable diesel is not available at card lock fuel stations used by ODOT and its contractors. Many of these stations are franchised, individually-owned and will likely need to install new tanks to regularly provide other fuels like renewable diesel.[7] Supplying this fuel via card locks would allow for greater access for smaller jurisdictions and other smalls-scale private business use. To improve distribution, a minimum annual purchase volume (100,000 gallons annually) is typically required to support card lock operators investing in the addition capital infrastructure.

During project interviews, representatives from smaller jurisdictions noted it would be helpful and appreciated if the State of Oregon would accelerate the availability and use of renewable diesel through regulation and/or distribution infrastructure. This could happen through a new State price agreement or through an organization like GOFC. Distributing renewable diesel at retail stations is not without precedent:

- California's Propel Fuels operates 32 public fueling stations that offer renewable diesel at a competitive price to conventional diesel.[8]
- VP Racing Fuels recently began selling renewable diesel in Bend, Oregon.[9]

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[6] Such fuels may become best practice in 5 - 15 years, but no near-term solution currently exists.
[7] Commercial fuel vendors are unlikely to fill their tanks with renewable diesel without more confirmed supply, better understanding of product (by vendor and customer), and overall reduced risks.
[8] For details visit https://www2.propelfuels.com/dieselhprlaunch/
[9] https://www.bendbulletin.com/business/renewable-disel-pump-added-at-the-quickway-market-in-bend/article_122eacae-2dee-11ec-93a2-878ea9cab6f9.html

Costs

Fuel Costs

Between FY 2016-19, ODOT paid the following price per gallon for the various diesel fuels used by fleet operations:

- $1.64 - $2.34 for B5 (conventional diesel fuel used in Oregon)
- $1.98 – $2.48 for B20
- $2.40 - $2.58 for R20
- $1.96 - $4.33 for R99

In FY21, the average R99 price per gallon was $1.95, versus $2.16 for B5 (a $0.21 savings per gallon for R99). Note: fuel costs include a markup for delivery; R99 delivery costs can be greater than for B5 due to delivery distances from Portland. Most fuel suppliers do not currently have storage capacity for R99 at their satellite locations and need to pick it up in Portland for delivery. ODOT's fleet and fuel experts believe this will change in the next few years. In Eastern Oregon, per gallon delivery costs are between $0.20 (truck and trailer delivery) to $0.39 (tank wagon delivery). ODOT would likely pay the higher end of the cost range in more rural areas due to limited tank size, which do not support bulk delivery via a truck and trailer. With the higher delivery cost, net cost for R99 can be greater than B5; without the delivery charges, R99 is cost neutral to B5.

Infrastructure Costs

ODOT-owned fueling sites typically have one dedicated tank for diesel fuel. The type of diesel in each tank depends on price, location and any specific needs of the district. It is unlikely ODOT would install additional tanks to have multiple diesel types at one site. ODOT is on track to use R99 exclusively when there is sufficient supply at a competitive price. Because R99 is a drop-in fuel, there are no anticipated additional infrastructure costs for ODOT.

Fuel suppliers, retailers and card lock operators may need to invest additional funds for extra storage tanks to have the ability to carry multiple diesel types to meet the needs of their customers. It was made clear during project interviews the current demand for R99 is not significant enough to warrant conversion of a fossil diesel tank to renewable diesel. Thus, expanded tank infrastructure may be needed to supply ODOT and, potentially, the agency's contractors with R99. Market research indicated a new 1,000-gallon tank costs approximately $13,000 and a 2,000-gallon tank is approximately $26,000. These costs do not include installation, electrical, and other development and permitting costs which can vary greatly by location and circumstances.

Grants / Incentives

The Internal Revenue Service (IRS) currently provides a 30% tax credit (up to $30,000) for the cost of installing alternative fuel pumps (Alternative Fuel Vehicle Conversion and Infrastructure Tax Credit). There was previously a federal grant program (Higher Blends Infrastructure Incentive Program[10]) allotting $100 million to aid in the creation of renewable diesel infrastructure (funding to install

[10] For program details visit https://www.rd.usda.gov/hbiip

renewable diesel pumps). The program closed in January 2021 but the program officer at the US Department of Agriculture indicates there is discussion about having another $100 million grant cycle.

In Oregon, the Department of Environmental Quality launched the Clean Fuels Program in 2016 to help reduce the health and climate impacts from diesel emissions. The program provides financial incentives from sale of credits to fuel distributors and others who participate in the program. These funds may be used to lower costs for preferred fuels, vehicles or infrastructure.

A few of the Clean Fuel Program efforts include:

- Alternative Fuel loans;[11]
- Biofuels Production Property Tax Exemption[12] (rural properties used to produce biofuels can receive a tax incentive);
- Phase out for registration of older heavy-duty engines to remove them from the roads starting in 2023.
- Diesel Emissions Reduction Task Force to address equity, incentives, and strategies to accelerate the transition away from fossil diesel.[13]

Making the Transition

The US Department of Energy states renewable diesel is a biomass-derived transportation fuel suitable for use in diesel engines and meets the ASTM D975 specification for petroleum in the United States. Oregon fuel distributor, Star Oil, states renewable diesel can be used by any diesel fleet without equipment conversion concerns.[14] This is confirmed by a variety of fleet managers around Oregon, including those at ODOT. Renewable diesel has virtually eliminated previous concerns of biodiesel use related to additional maintenance, cold weather performance, and warranty concerns. The most challenging aspects reported for renewable diesel are:

- Not having enough supply to meet demand;
- Inability to access the fuel at privately-owned card lock stations; and
- Higher delivery costs compared to conventional fuels.

Lifecycle Considerations

Greenhouse gas pollution from tailpipes is often the focus when considering emissions from vehicles. However, there are also GHG emissions from the production of fuels (i.e., embodied carbon). Biofuels offer significant GHG reductions at the tailpipe, but commonly have greater impacts than fossil fuels during production. This is because the most common feedstock for biofuels are agricultural crops, such as soybeans. And, therefore, impacts associated with growing and harvesting crops also need to be considered. Fertilizer production and application-process emissions, on-farm fuel use, land use change (deforestation), fossil energy for refining, and fossil fuels used in distribution to market all create climate impacts. ODEQ considers lifecycle fuel emissions factors in the Clean Fuels Program accounting because

[11] For program details visit https://www.oregon.gov/energy/incentives/pages/energy-loan-program.aspx
[12] For program details visit https://www.oregon4biz.com/Oregon-Business/Tax-Incentives/Renewable-Energy/
[13] For program details visit https://afdc.energy.gov/laws/all?state=OR
[14] For program details visit https://www.staroilco.net/renewable-diesel-portland-or/

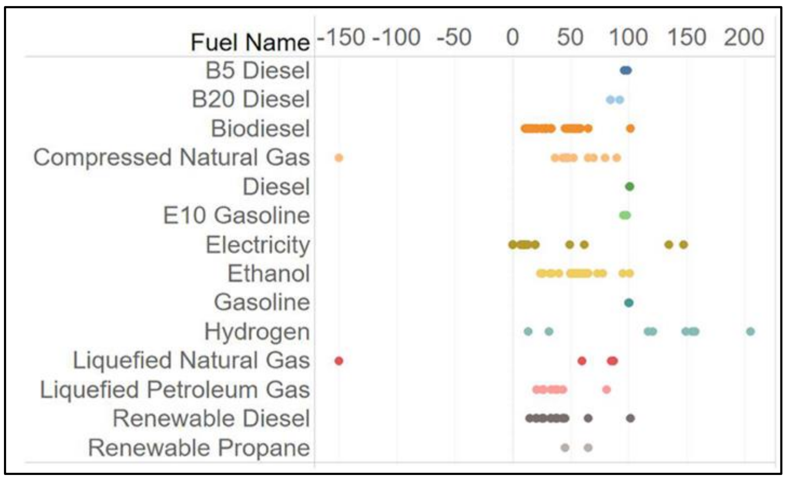
of the upstream and downstream emissions associated with biofuels. ODEQ's emissions factors were used in ODOT's FY16 – 19 GHG Inventory and accounted for in the Scope 3, upstream fuel production emissions. ODEQ reports - on a lifecycle basis - renewable diesel reduced emissions from conventional fossil fuels by 50 -70%. From an end-user perspective, a first order of business is to switch to renewable fuels that emit biogenic carbon dioxide for those emitting fossil CO_2. As the renewable fuel market evolves, end-users will also need to work with suppliers on sources of Scope 3 production emissions.

Ideally, biofuels are produced to the largest extent possible with "waste" materials such as used cooking oil or tallow. Use of waste material feedstock for renewable diesel offers some of the lowest-impact fuels available on the market. Unfortunately, waste materials are not available in quantities required to produce the volumes of diesel fuels currently consumed, which is why crop feedstocks are also used for production.

GHG Benefits and Cost

GHG Benefits

Figure 1: Climate impact of various fuels and production pathways



Measured at the tailpipe, using renewable diesel exclusively offers a roughly 99% reduction in ODOT's owned, Scope 1 GHG emissions. When production emissions are included (lifecycle GHG emissions), R99 still offers a 50-75% lifecycle GHG reduction (Scope 1 (tailpipe) + Scope 3 (upstream production)) compared to conventional B5 diesel.[15] Figure 1 is provided by ODEQ and compares the climate impact of various fuels and production pathways for various fuel types.[16] Each circle on the graph represents the climate impact from a single pathway. These impacts vary depending on the fuel production raw materials and energy inputs used by the fuel producer. As can be seen in Figure 1, there can be a wide range in impacts depending on these factors. Significant negative values have been found for fuels that use biomethane from dairies, which can be seen for CNG.[17]

[15] Voluntary GHG inventory protocol accounts for the benefits differently than Oregon Department of Environmental Quality (ODEQ) does in the Clean Fuels Program. GHG protocol – for Scope 1 tailpipe – allows for exclusion of all biogenic carbon dioxide emissions at the tailpipe. For R99 this equates to about a 99% reduction of Scope 1 GHGs. ODEQ looks at Scope 1 and Scope 3 together in its accounting – from that perspective total lifecycle emissions are reduced by about 70% compared to conventional diesel.

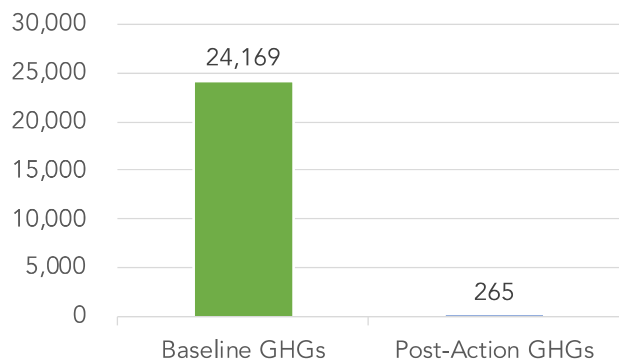
[16] Image Source: https://www.oregon.gov/deq/ghgp/Documents/cfpCarbonIntensityValues.pdf. Image Note: The carbon intensity values for the program are expressed in grams of carbon dioxide equivalents per megajoule of energy (gCO_2e/MJ). B5 diesel and E10 gasoline are the minimum standards required in Oregon.

[17] Dairy bio-methane can be converted to CNG and LNG and are represented as negative carbon intensity because they prevent fugitive loss of methane to the atmosphere in addition to the production of a biogenic fuel.

Because renewable diesel can be used at high blend volumes as a substitute for fossil diesel there are dramatic results in tailpipe (Scope 1) emissions reductions. Biodiesel offers similar per gallon reductions, but because it cannot be blended at high volumes, the opportunity for Scope 1 reduction is lower than for renewable diesel.

Figure 2 compares baseline GHGs for diesel fuel use with potential reductions associated with 100% use of soybean-based renewable diesel. If ODOT were to replace 100% of the agency's B5 diesel fuel use with renewable diesel, Scope 1 tailpipe emissions could decrease by about 23,900 MT CO2e annually, or about 99%. Assuming renewable diesel supply is soybean based (most common in Oregon), lifecycle emissions (Scope 1 (tailpipe) + Scope 3 (upstream production) are reduced by about 70% (reduced from 30,000 to 9,000 MT CO2e annually) compared to B5. If used cooking oil is used as the feedstock lifecycle emissions are reduced by about 80% compared to B5.[18]

Figure 2: Tailpipe GHGs from B5 compared to R99



Cost Scaling

Fuel costs for R99 were lower than conventional B5 diesel in FY20, FY21, and, to date, in FY22. That said, delivery charges for R99 are greater than for B5, bringing the total cost to equal or a slight premium for the climate benefit of renewable diesel. Table 2, below, compares annual costs and per metric ton (MT) cost of CO2e reduction for two premium levels. A $0.10 per gallon premium per one MT CO2e reduced is about $10 per ton while a premium of $0.20 per gallons premium is about $20 per ton. For a benchmark, regulatory grade carbon offsets currently sell for $20 per MT CO_2e.

Table 2: Comparison of fuel use, costs, and tailpipe emissions reductions for R99

Category	Fuel Use, 2016-19 average (millions of gallons)	Annual Cost, $0.10 premium	Annual Cost, $0.20 premium	Baseline Scope 1 Emissions (FY16-19 annual average)	Annual Scope 1 Reductions	Cost per MT CO2e reduced, $0.10 premium	Cost per MT CO2e reduced, $0.20 premium
Owned Fleet	2,335,000	$233,500	$467,000	24,196	23,900	$9.75	$19.50

[18] See Oregon Clean Fuels Program website for more information and a downloadable spreadsheet that summarizes the carbon intensity for all fuels used in Oregon. Visit Image Source: https://www.oregon.gov/deq/ghgp/Documents/cfpCarbonIntensityValues.pdf

Co-Benefits

In addition to the GHG benefits, renewable diesel also offers the following co-benefits:

- Reduction in criteria air pollutants. The Federal Highway Administration (FHWA) and ODOT report nitrogen oxides, particulate matter, carbon monoxide, and total hydrocarbons emissions for renewable diesel are all lower than conventional ultra-low sulfur diesel.[19]
- Green job creation in the U.S.[20] Future supply will likely be produced from domestic feedstocks and production.

Purchased Carbon Offsets

Carbon offsets are a voluntary method of mitigating GHG emissions. An organization calculates its emissions over a time period - usually a year - and then purchases the equivalent number of offsets in metric tons of carbon dioxide equivalent (MT CO_2e) to balance the GHG impact of those activities. Carbon offsets can come from a variety of project types including forestry, land use (e.g., avoided deforestation, reforestation, avoided grassland conversion) and waste disposal, among others. Carbon offset projects must follow strict project development, accounting, and verification protocols, and depending on the requirements vary in quality and cost. The baseline quality of offsets is set to the Verified Carbon Standard (VCS), while Climate Action Reserve (CAR) and Gold Standard are an even higher level of third-party certification.

Carbon offsets may be used to counteract the climate impacts of any source of GHG emissions. That said, for the purposes of this report, the need is framed around addressing ODOT's use of natural gas. Because natural gas does not yet have a market-ready, lower-impact substitute that can scale to offset ODOT's total use, carbon offsets are one option to reduce emissions.

Carbon offsets may be purchased from a variety of vendors. Arguably the simplest option in Oregon, from an administrative standpoint, is NWN's SmartEnergy program.[21] This program allows for direct, on-bill purchase of offsets equal to the annual quantity of natural gas purchased from a well-established Oregon provider – The Climate Trust, which develops projects to capture and utilize renewable methane from dairy farms. This program may be used to offset ODOT natural gas purchases from NWN; additional carbon offsets will be needed to offset the agency's natural gas purchases from other utilities. Other reputable vendors include Bonneville Environmental Foundation (BEF), Native Energy, Renewable Choice Energy, and 3Degrees.

Real World Examples

- **City of Eugene, Oregon:** Carbon offsets are purchased to meet the requirements of the City's Climate Recovery Ordinance.[22]

[19] https://altfueltoolkit.org/wp-content/uploads/2017/11/Renewable-Diesel-Fact-Sheet.pdf
[20] U.S. Department of Energy reports "*Five plants produce renewable diesel in the United States, with a combined capacity of nearly 400 million gallons per year. Production is expected to grow in the coming years due to expansions at existing plants and the construction of new plants.*" For details visit https://afdc.energy.gov/fuels/emerging_hydrocarbon.html.
[21] SmartEnergy details available online at https://www.nwnatural.com/about-us/carbon-offset-program/about-smart-energy
[22] https://www.eugene-or.gov/3210/Climate-Recovery-Ordinance

Other Alternatives (to address fossil natural gas emissions)

- **Energy efficiency and conservation** is a complement to purchased offsets. Reducing natural gas use will save costs for the fuel itself as well as additional costs for carbon offsets.
- **Renewable natural gas (RNG)** is an alternative to offsets to address emissions from fossil natural gas. While most methane/natural gas is produced from fossil sources, RNG can be utilized for energy when gaseous byproducts of solid waste decomposition, from cattle farms and wastewater treatment, are collected. RNG is shown to have significantly lower climate impacts compared to fossil gas, particularly when it is collected from dairy operations.[23] See EPAs report on RNG from biogas.[24] RNG from dairies is beneficial as it captures a currently uncontrolled source of methane and utilizes the captured methane to displace fossil energy sources. California Air Resource Board and Oregon's Clean Fuels Program have issued carbon intensity values for dairy RNG as less than zero.[25] It is important to note RNG cannot fully replace natural gas at current rates of use. At its maximum technical potential, RNG is estimated to replace 10 – 20% of baseline use across Oregon's natural gas system.[26]
- **Renewable hydrogen** offers an alternative to offsets for gas when produced using renewable electricity to split water molecules (electrolysis). Hydrogen produced from natural gas is most common but provides much less - if any - climate benefit compared to green hydrogen. This technology is in the early phases and has yet to achieve large-scale production. Based on recent modeling done for the Clean Fuels Program, hydrogen is anticipated to enter the Oregon fuel mix in 2030.[27]
- **Building electrification** (e.g., trading gas furnaces for electric heat pumps) also provides an alternative to purchasing offsets for natural gas. However, electrification is not an option for all building types, sizes, and configurations. American Council for an Energy Efficient Economy (ACEEE) released a report in 2020 detailing the greatest opportunities in the commercial building space.[28]

Current Conditions

During FY 2016-19, ODOT purchased an average of 600,000 therms of natural gas to heat office spaces and maintenance district crew rooms, thaw maintenance trucks during inclement weather, and maintain specific temperatures in material laboratories. This represents an average of 3,200 MT CO_2e per year. Natural gas is purchased from three natural gas utilities in Oregon: Avista, Cascade, and NWN. The only utility to currently offer the purchase of carbon offsets directly is NWN and they also plan to offer the ability to purchase 4% of gas from renewable sources beginning in 2022.

Market Study

Availability and Access

As previously mentioned, NWN provides on bill purchasing of carbon offsets. The offset projects are managed by The Climate Trust, located in Portland, and focus on dairy farm methane capture projects

[23] Dairy operations, depending on manure management, can represent a large direct source of methane emissions.
[24] For details visit https://www.epa.gov/sites/default/files/2020-07/documents/lmop_rng_document.pdf.
[25] See ODEQ CFP website for more details https://www.oregon.gov/deq/ghgp/cfp/Pages/Clean-Fuel-Pathways.aspx
[26] See Oregon Department of Energy report for more details https://www.oregon.gov/energy/Data-and-Reports/Documents/2018-RNG-Inventory-Report.pdf
[27] For details see Scenario C https://www.oregon.gov/deq/rulemaking/Documents/cfp2021icf.pdf
[28] See ACEEE's report for details https://www.aceee.org/research-report/b2004

for use as RNG. One-year contracts are a minimum with longer terms available for bulk pricing. Other vendors (BEF, Native Energy, Renewable Choice Energy, and 3Degrees) offer a variety of project types. Offsets may be purchased annually, but longer-term contracts are also available (up to 25 years) and typically come at a reduced cost. See the next section for additional details by vendor on project offerings and costs.

Costs

Project types differ in cost widely from under $2 per MT (for low-cost voluntary market)[29] to upward of $21 per MT (NWN SmartEnergy Program and California's compliance market).[30] Project pricing varies and is impacted by quality, market supply and demand, as described below:

- Supply: Certain types of projects and technologies are not as widely available. Landfill gas projects are abundant, whereas dairy farm projects in the U.S. are less available.
- Vintage: The age of offsets varies by project. Some projects are attributed to the current year, whereas others are related to projects generated within the last few years. There are also credits for projects yet to be built. Generally, older projects will be less expensive, while current or future projects will cost more.
- Regulatory quality: Offsets that are required for certain compliance markets, or follow compliance market protocols, are typically priced higher.
- Co-benefits and cultural alignment: A key difference between offsets is the proximity to the operational and supply chain emissions sources. Generally, offsets that are more closely aligned (i.e., within the same state or region of emissions source) will cost more, particularly projects originating in the exact region of interest. Projects that offer significant additional co-benefits, a more compelling story, or tie into core operations or customer-shared value generally draw a higher price point.

Table 3: Overview of Carbon Offset Projects

Company	Description and Costs (price per 1 MT CO2e)
NWN - SmartEnergy Program	• Dairy biodigesters in PNW ($20 with 1-year contract) • Dairy biodigesters in PNW ($12–16 with 3-year contract)
NativeEnergy	• **Landfill gas in U.S. ($2-5)** • Forestry / land use projects ($5) • Clean water or cookstove projects in Haiti ($6-12) • Avoided deforestation in Tanzania ($11) • Avoided grassland conversion ($12-14) • Dairy composting project ($16)

[29] Ecosystem Marketplace – State of the Voluntary Carbon Markets 2020. Report online at https://app.hubspot.com/documents/3298623/view/101893633?accessId=bf5d12
[30] CA Carbon Allowance Prices (2021). Report online at https://ww2.arb.ca.gov/sites/default/files/classic/cc/capandtrade/carbonallowanceprices.pdf

Company	Description and Costs (price per 1 MT CO2e)
The Climate Trust	• **Landfill gas to energy ($2-$3)** • Forestry and grasslands ($6-$8) • Dairy biodigester (The Climate Trust manages NWN's SmartEnergy program)
Bonneville Environmental Foundation (BEF)	• **Landfill gas-to-energy in North Carolina ($2)** • Landfill gas-to-energy in Utah ($6) • Waste heat recovery in Montana ($7) • Clean energy career training program for PNW Students ($8) • Organic waste composting in Washington ($7-9) • Avoided grassland conversion in Oregon ($12) • Dairy biodigester in Idaho ($12) • Forestry project in Washington ($12) • Forestry project in California ($13) • Prairie conservation in South Dakota ($15)

GHG Benefits and Cost

Table 4, below, provides program costs in two groupings: 1) Northwest Natural (NWN), and 2) all others (Avista and Cascade). To offset remaining gas purchased from other natural gas utilities in Oregon (Avista, Cascade), prices from BEF are used because they sell offsets produced within the NW region for a variety of relevant project types and costs.

Table 4: Annual and per MT costs of offsets from different providers and projects

Carbon Offset Vendor	Project Type	Average Annual Use (therms)	Average Annual Cost ($)	Annual GHG Reductions (MT CO2e)	Price per MT of Reduction
Northwest Natural – SmartEnergy (1-year contract)	Dairy biodigester in PNW	323,000 (NWN use only)	$35,460	1,718 (scaled for Northwest Natural only)	$20.66
Northwest Natural – SmartEnergy (3-year contract)	Dairy biodigester in PNW	323,000 (NWN use only)	$20,600 - $27,500	1,718 (scaled for Northwest Natural only)	$12 - $16
Bonneville Environmental Foundation (BEF)	Dairy biodigester in Idaho	277,000 (Avista and Cascade use)	$17,000	1,482 (scaled for Avista/Cascade gas only)	$11.50

Carbon Offset Vendor	Project Type	Average Annual Use (therms)	Average Annual Cost ($)	Annual GHG Reductions (MT CO2e)	Price per MT of Reduction
BEF	Tree planting on west coast	277,000 (Avista and Cascade use)	$11,900	1,482 (scaled for Avista/Cascade gas only)	$8
BEF	Grassland restoration in Oregon	277,000 (Avista and Cascade use)	$17,800	1,482 (scaled for Avista/Cascade gas only)	$12
BEF	Landfill gas to energy in North Carolina	277,000 (Avista and Cascade use)	$3,000	1,482 (scaled for Avista/Cascade gas only)	$2
BEF	Landfill gas to energy in North Carolina	277,000 (Avista and Cascade use)	$6,400	3,200 (scaled for total (all utility) gas)	$2

Combining costs for NWN's SmartEnergy program (3-year contract) for dairy biodigesters with BEF offsets from tree planting would cost ODOT approximately $35,000 annually to offset 100% of natural gas emissions (3,200 MT CO_2e). These costs could be dramatically reduced if ODOT were to purchase BEF offsets for landfill gas to energy in North Carolina: annual costs would total $6,400.

Renewable Electricity

Procurement of renewable electricity from sources like wind and solar offers an immediate and significant opportunity to reduce GHG emissions from ODOT's retail electricity purchases. Like renewable diesel, renewable electricity is a drop-in energy source, meaning it does not require any capital or operational upgrades to access the benefits. Procurement of renewable electricity and thus supporting the rapid development of renewable energy generation is a "super action", a foundational step and necessary precursor to achieving climate goals through mobile and stationary equipment electrification. Furthermore, purchasing renewables supports Oregon utilities as they evolve to comply with Oregon HB2021[31] which requires the transition to 100% renewable electricity by 2040. There are various options in the marketplace to procure renewable electricity supply, including:

- Development of on-site renewable generation (e.g., PV solar)
- Participation in a community solar program

[31] https://olis.oregonlegislature.gov/liz/2021R1/Downloads/MeasureDocument/HB2021/Enrolled

- Participation in local utility green power programs
- Power purchase agreements directly with the power generators (direct access)
- Contract with an independent broker to purchase unbundled renewable energy certificates/credits (RECs)

On Site Renewables

ODOT led the nation in innovative on-site renewable generation through Oregon's Solar Highway Program, which utilizes highway right-of-way space for installation of solar PV arrays. Installation of owned-renewable electricity generation requires an appropriate area – either roof space or open land area – and the economics favor installing as large of a system as possible. On-site solar installments can carry large upfront costs and require additional maintenance costs, which can be a barrier for many. While these installations generate GHG-free electricity for ODOT, significant developments would be needed to match ODOT's electricity consumption.[32] If considered, project locations should focus on PGE and Pacific Power territories since these investor-owned utilities continue to offer net metering agreements that are limited in consumer-owned utility districts.

Community Solar

Several ODOT maintenance districts are pursuing a program referred to as Community Solar, which offers customers of PGE, Pacific Power and Idaho Power the option to subscribe to an off-site solar energy project and receive clean energy credits on their utility bill. ODOT is a unique customer in that there are various subscription rates assigned to different meters, and unfortunately, not all rates can subscribe to a community solar project. Program fees vary based on the project; initial inquiries indicate a cost-neutral or even reduced costs for ODOT to participate.

Green Power Programs

Participation in Oregon utility green power programs (e.g., Pacific Power's BlueSky program) offer a relatively simple way to procure large quantities of renewable electricity without the cost and labor burden of owning and maintaining onsite generation. As stated above, these programs also enhance and financially support Oregon utilities as they make the transition to 100% renewable electricity. Depending on total annual load and related plans for renewable purchases, the additional cost for renewable power may be discounted for bulk purchases. See the following sections for more details on costs and program administration.

Direct Power Purchase Agreements

Utility customers may also contract with developers for power purchase agreements to supply dedicated renewable power transmitted and distributed via local utilities. This approach can be challenging to develop and administer, particularly for a geographically distributed organization like ODOT. These agreements are common between generators and industrial or commercial facilities with large, consistent electricity loads in a common geography. The benefit of these types of agreements is access to large supplies of renewable power potentially at below commercial or meter rates.

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[32] ODOT's existing onsite solar arrays only represent an estimated 5% of the agency's annual electricity use.

Purchase of RECs

RECs may also be purchased "unbundled" from a variety of brokers operating in the Northwest (e.g., 3Degrees or Native Energy). Purchase of these products transfer ownership of the environmental benefit to the buyer but may not originate from a local project, and, therefore, may not support Oregon's transition to renewable electricity as directly as participation in a utility sponsored program. The benefit of this approach is potentially lower costs for the renewable environmental attribute. If this approach is taken, it is highly recommended that unbundled REC purchases be required to originate from Oregon-based projects and carry the Center for Resource Solutions' Green-e Energy certification.

Real World Examples

The EPA's Green Power Partnership is a program that helps organizations, businesses, and governments purchase lower-carbon power. The program lends credibility to green power purchases, provides resources for communicating the benefits of green power to stakeholders, and publicly recognizes organizations for participation. The program also grows the green energy market in the US, ensuring a steady supply of power and continuous investment in lower carbon energy. The Green Power Partnership's Top 30 Local Government[33] rankings as of April 2021 include two Oregon communities:

- City of Portland operations (81% renewable and ranked 12th in the nation)
- City of Hillsboro (93% renewable and ranked 30th)

Outside of Oregon, examples include Port of Vancouver, Massachusetts Bay Transportation Authority, and Dallas Fort Worth International Airport.[34]

There are state governments involved in the program as well:

- Delaware (50% renewable). Delaware purchases its energy on the open market through brokers, leveraging its large demand to secure attractive rates for supplying its owned buildings with renewables.
- Pennsylvania (40% renewables for government operations).
- Connecticut (13% renewable for government operations).
- California (13% renewable for government operations). California powers its vast array of government services (from jails to administrative buildings) with purchased green power and from onsite generation.
- New Hampshire (12% for government operations).
- Wisconsin (9% for government operations).

Several federal agencies also purchase renewable energy - all purchase between 9 - 13% renewables to power their buildings:

- General Services Administration
- Centers for Disease Control
- Drug Enforcement Administration
- Department of Agriculture

[33] https://www.epa.gov/greenpower/green-power-partnership-top-30-local-government
[34] https://www.epa.gov/greenpower/green-power-partnership-100-green-power-users

Current Conditions

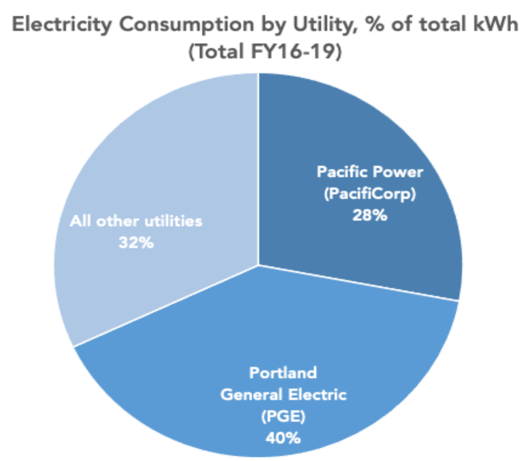
During FY 2016-19, ODOT purchased an average of 41,000 MWh of electricity annually from over 40 different electric utilities. Electricity is used by ODOT to power buildings as well as highway system equipment (i.e., street lighting, ramp meters, traffic signals, radio towers, bridges). ODOT's electricity consumption trended downward between FY16-19, decreasing by about 9% between those years.

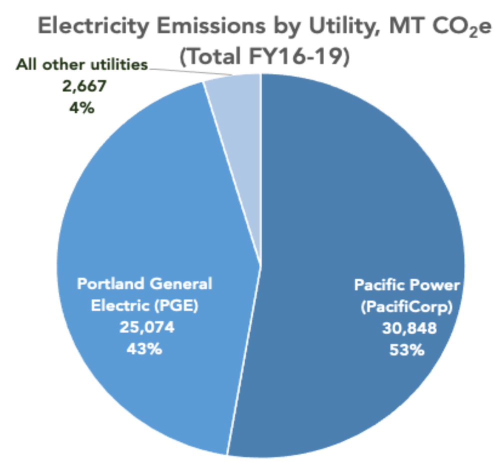
ODOT currently practices strategic energy management in its largest facilities by monitoring energy use and upgrading equipment for efficiency. One project of note is the upgrade of highway lighting in ODOT Region 1 (greater Portland area). This project converted 9,500 lights to efficient LEDs and is estimated to reduce energy consumption by 7,000 MWh per year.[35]

ODOT also generates about 2.1 MWh annually[36] from onsite PV solar generation from two sites located on ODOT-owned land (Baldock rest area solar array, I-205 / I-5 interchange). ODOT also has solar arrays installed on facilities throughout the state (East Salem Compound, Building Q; Transportation Building, Salem; SE Portland DMV; Lawnfield Bridge Building; Region 4 Headquarters; Pendleton Maintenance Station). Unlike the Baldock and interstate interchange sites, these solar arrays are net metered meaning the local utility reduces the agency's bill equivalent to the amount of electricity added to the grid. These solar arrays are equal to roughly 5% of ODOT's average annual electricity consumption.[37]

Two utilities supply almost 70% of ODOT's electricity: PGE is ODOT's largest electricity supplier (40%), followed by Pacific Power (28%). Figure 3 depicts two circle graphs: the left graphic shows the percent of ODOT's total electricity consumption, while the graph on the right show's utility-specific consumption and associated GHG emissions for the two main utilities compared to all others.

Figure 3: Electricity Consumption and GHGs





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35 Email exchange with Ameresco staff 3/2021

36 120,000 kwh from the I-5 and I-205 interchange (number from US Federal Highway Administration https://www.fhwa.dot.gov/publications/publicroads/12novdec/04.cfm) and 1.97 million kwh from the Baldock Solar Station (from ODOT's webpage https://www.oregon.gov/odot/Programs/Pages/Solar-Baldock.aspx)

37 From G3C, average annual usage = 141,024 MMBTU ≈ 41.3 million kwh. 2.03/41.3 ≈ 4.9%

PGE and Pacific Power are investor-owned utilities and have significantly higher market-based emissions factors (GHGs/kWh) than other Oregon electric utilities.[38] While ODOT purchases about 70% of its total electricity from these two utilities, they make up 95% of ODOT's "owned" GHG emissions from electricity. Both utilities offer 100% renewable purchase options that could quickly reduce this significant source of operational emissions.

Other Alternatives

- Strategic energy management is already practiced by ODOT and provides a significant precursor action to purchases of renewable electricity. Because renewable electricity may require a premium for purchase in the near-to-midterm, reducing overall electricity consumption and particularly reducing peak electricity demands will reduce energy cost, and, therefore, reduce the premium required for renewable electricity.
- Partner with the ODAS to pursue Direct Access through a price agreement.[39] Identifying a large-scale renewable generator to supply ODOT with 100% renewable electricity and administering that program across the State of Oregon may be better suited to an agency like ODAS, which focuses on procurement across state agencies.
- Design new buildings to be fully electric and retrofit existing buildings with electric heating (air and water); converting natural gas buildings to electricity allow for 100% of renewable power. Based on interviews with Oregon Department of Energy, electric heat pumps (including water heating) for smaller commercial/public building spaces (e.g., 5,000 square feet or smaller) are viable options now. No technologies are readily available to convert ODOT's existing large commercial spaces that are using natural gas boilers. Fully electric maintenance stations are also not feasible due to operational needs (e.g., quickly melting snow or ice off equipment). Where conversion to electric is not a viable option, focus should be on equipment efficiency upgrades like advanced controls and procurement of RNG.[40]

Market Study

Availability and Access

Participation in existing utility green power programs offers a near-term option to purchase a renewable electricity supply. These programs are available to commercial customers like ODOT. The following section focuses on costs for participation in PGE and Pacific Power's existing renewable electricity programs since their power generation represents the largest source of ODOT's electricity GHG emissions.

[38] See Oregon Dept. of Environmental Quality, 2010-2019 – Greenhouse Gas Emissions from Electricity Use. Utility-specific factors found online at https://www.oregon.gov/deq/aq/programs/Pages/GHG-Emissions.aspx.

[39] From the Public Utility Commission website: "Under Oregon's Electric Restructuring law, all nonresidential consumers can purchase electricity from a Public Utility Commission-certified electricity service supplier (ESS) other than their current utility, which is known as Direct Access. Under a Direct Access agreement, the local service provider is responsible for distribution of services, while an electricity service supplier (ESS) would be responsible for the generation and transmission services. More info available here: https://www.oregon.gov/puc/utilities/Pages/Direct-Access.aspx

[40] Barlow School Office Building in Portland switched from a natural gas steam to hydronic boiler system to zonal ductless heat pumps with a high-efficiency heat recovery ventilator. The building was one of the highest natural gas users for office spaces in ODOT's portfolio and now uses no natural gas (overall building energy use intensity is down).

Portland General Electric

- ***Green Future Enterprise*** – This option is supported by RECs generated in the Northwest and other wind power sources from the U.S. This option offers flexibility in the scale and duration of participation. The program is typically available for enrollment at any time, but is currently suspended through November 2021 due to lack of REC supply, high demand and volatile prices in the marketplace.
- ***Green Future Impact*** – This option is a green tariff that directly funds development of new Northwest wind and solar facilities. This option requires a long-term power purchase agreement between 10 – 20 years. Longer terms can reduce costs. This program has specific enrollment periods and has sold out quickly in the past.

Pacific Power

- ***BlueSky Renewable Energy*** – The BlueSky program is also supported by RECs. The program can be aligned with 100% of electricity usage or purchased in 200 kWh blocks. The usage program uses a 50:50 mix of wind and solar, while the block program is 92:5:2:1 of wind, solar, biomass, and geothermal. Pacific Power does not offer a green tariff program like PGE.

Oregon Community Solar Program[41]

Customers of Pacific Power, PGE, and Idaho Power can participate in community solar programs within Oregon. These programs generate solar energy from a central location and share electricity credits amongst multiple owners or subscribers, which offers customers the benefits of solar without installing panels themselves. New subscribers can sign a contract to initiate a new project and then receive credits as soon as the project is connected to the grid.

Costs

The following section focuses on costs for renewable electricity programs.

Portland General Electric

- ***Green Future Enterprise/Choice*** - PGE staff report customer interest in RECs has significantly increased recently, which is creating unprecedented price and supply volatility in the REC market. As a result, prices being paid in the market are regularly exceeding the standard prices for commercial customers ($0.003 per kWh). Given the circumstances of PGE paying more than what customers are being charged, PGE requested regulators temporarily suspend their program for 90 days (as of September 1, 2021). This means PGE will not be enrolling any new customers in its Green Futures Enterprise program until the suspension is lifted. At the time of writing this report, PGE was unable to provide specific costs for ODOT's participation in the program. However, high-level estimates range from $75,000 - $120,000 per year to offset roughly 1.5 MW across 10,000 eligible ODOT meters.[42]
- ***Green Future Impact*** - Participation in the Green Future Impact program requires a long-term contract and ensures the purchased renewable energy is from a regional solar or wind project in

[41] More information about the Oregon Community Solar Project can be found here: https://www.oregoncsp.org/about/
[42] Not all subscription rates are eligible to participate in a REC program like Green Futures Enterprise/Choice.

Oregon. The initial offering of this program sold out quickly and is not currently available. PGE anticipates opening this program again soon (mid-2022) and foresees sign-up opportunities to go quickly. Cost to participate in the initial offering was $0.001 / kWh for a 15-year contract, in addition to standard rates. There is a 10-year minimum contract period, and up to a 20-year contract to get the best rates. PGE did not share estimates for the anticipated next round of the program.

Pacific Power

- ***BlueSky Renewable Energy -*** Pacific Power's program is open and available for enrollment. Prices range between $0.0071 – 0.0075 per kWh. The lower end of the range is the bulk price, if ODOT were to purchase 100% renewables. The higher-end of the range is for a purchase equal to 25% of annual use.

Oregon Community Solar Program

- Community solar is unique in that it does not cost extra to subscribe. The program is partially funded through utility rate-payers, which reduces costs for subscribers. At the time of writing, ODOT was quoted a bill savings of approximately 8%. While the savings is not guaranteed, an increase in costs is not possible from simply subscribing to the program. There are cancellation fees ($40 per account), which may be waived if advanced notice is given (more than 30 days).

Making the Transition

Participating in one of the renewable electricity programs described above:

- Offers a relatively simple climate action to transition to a low-to-zero carbon energy source without the need to upgrade existing equipment.
- Allows the user to procure up to 100% renewable electricity without large-scale, onsite development of renewable electricity generation equipment and capacity.

Staff time is required:

- To prepare and understand current usage and renewable electricity goals prior to negotiating a price with local electric utilities.
- To administer and maintain the program. That said, electric utilities sometimes provide technical support for program design and annual accounting support and summaries.

Recommendations to better position ODOT for future opportunities:

- Prepare for PGE's next Green Future Impact offering; the last round sold out within one day. Better understand the application requirements and have an application prepared well ahead of time to maximize the chance of success.
- Work with the utilities to have specific utility staff assigned to ODOT's account to support future data collection and organization toward climate action.

Lifecycle Considerations

Greenhouse gas pollution from tailpipes is often the focus when considering emissions from vehicles. But there are also GHG emissions associated with the production of fuels used to generate electricity (e.g., natural gas, coal, etc.). As power supplies move toward renewables like wind and solar, upstream production emissions are also significantly reduced.

GHG Benefit and Cost Scaling

GHG Impacts

This section focuses on participation in existing investor-owned utility or Oregon Community Solar programs. Other options are available, such as development of owned-solar or direct access, but these options require feasibility studies outside the scope of this project to evaluate potential benefits and costs. One-hundred percent (100%) participation in Pacific Power's Blue Sky and/or Oregon Community Solar programs would reduce ODOT's electricity emissions by 51% (7,500 MT CO_2e), which is 14% of ODOT's "owned" Scope 1 and Scope 2 emissions (55,000 MT CO_2e total). Full participation in one of PGE's programs would add another 43% reduction, for a total decrease of 26% of owned emissions.

Cost Scaling

Table 5: Additional Cost Programs

Program	Unit Price	Average Annual Use (MWh)	Average Annual Cost ($)	Annual GHG Reductions (MT CO2e)	Price per MT of Reduction
Portland General Electric – Green Enterprise	$0.003 per kWh[43]	16,500	$49,500	6,270	$7.90
Portland General Electric – Green Future Impact	$0.001 per kWh	16,500	$16,500	6,270	$2.60
Pacific Power – BlueSky	$0.0071 - $0.0075 per kWh[44]	11,600 (100% of use); 2,900 (25% of use)	$82,360 (100%); $21,750 (25%)	7,710 (100%); 1,930 (25%)	$10.70 (100%); $11.30 (25%)

Note: ODOT's electric meters are on various rate schedules and not all are eligible to participate in the programs identified above.

43 Price information provided by PGE staff with the acknowledgement this program is currently suspended, and prices may increase due to current increased market demand and related price volatility for renewable power.
44 Price information provided by Pacific Power staff. Lower end of the cost range is for purchase equal to 100% of total use and the higher cost is for 25% of use.

Table 6: Community Solar Overview

Program	Unit Price	Average Annual Use (MWh)	Average Annual Savings ($)	Annual GHG Reductions (MT CO2e)	Price per MT of Reduction
Community solar	$0.08951 per kWh (subscription rate) $-0.0977 per kWh (bill credit) ***Estimated savings of 8%**	2,000 MWh (about 18% of total PAC purchase in FY2019, 10,900 MWh)	$16,492 (annual savings from Pacific Power bill)	1,388	-$12 (negative values indicates a financial savings in addition to GHG reduction)

Note: Due to the subscription model of community solar, participating in the program fully (matching 100% of electric load) is not an option. The rates and available amounts provided are estimates received November 2021.

Direct Access Power Purchase Agreements

Oregon allows all non-residential customers to purchase electricity from a Public Utility Commission certified electricity service provider (ESS) other than their current utility. This option was researched as part of the project, but is complex and beyond the project scope. Initial research found that while direct access could provide cost savings for ODOT, there is also risk that costs would increase, depending on the terms of the agreement and daily flux in market prices. This option would require significant ODOT staff time to evaluate and select an ESS provider(s), negotiate purchase agreement terms, and manage the contract over time. This option may be considered over the mid-term, but in the near-term existing utility program and participation in Oregon's Community Solar program are preferable in that they will require less staff time and program risk.

Co-Benefits

- Maximizes GHG benefits from related actions (e.g., electrification of vehicles and buildings).
- Does not require new equipment or retrofits.
- Creation of regional green jobs to support development of renewable generation.
- Enhanced organizational image for support of this important climate action and energy system transition.

Electric Vehicles

Electric-propulsion technology is rapidly replacing combustion engines for clean, efficient transportation. Electric vehicles (EVs) reduce harmful air pollution, GHG emissions and noise. Battery electric vehicles (BEVs) use no liquid fuel, relying on an all-electric drive train, and are refueled by plugging into an external electricity source. Plug-in hybrid EVs (PHEVs) can fully operate on a battery pack for a limited range before an on-board internal combustion engine (ICE) powers the drivetrain. PHEV batteries are recharged by plugging into an external electric power source. Hybrid electric vehicles (HEVs) combine an internal combustion engine with an electric drivetrain. HEVs are not recharged from an external electric power source like PHEVs; they rely on an electric generator to recharge the vehicle's batteries.

All versions of EVs offer reduced emissions compared to ICE vehicles, even when the source of electricity is not renewable (see Table 7). That said, BEVs offer the added opportunity to substitute 100% renewable electricity for fossil fuel gasoline, which maximizes the GHG-benefits of EVs. It is important to note battery electric technology to replace diesel vehicles and equipment is not currently available. Therefore, this recommendation focuses on the GHG reduction potential from replacing light-duty gasoline powered vehicles with BEVs.

Table 7: Comparison of EV climate impacts based on electricity source

Electricity source	Well-To-Wheels EV Miles Per Gallon Equivalent (mpg_{ghg})
Coal	30
Oil	32
Natural Gas	54
Solar	500
Nuclear	2,000
Wind	3,900
Hydro	5,800
Geothermal	7,600

Emissions Reduction Potential

BEVs supplied with 100% renewable electricity is one of the largest GHG reduction opportunities currently available to address fossil gasoline emissions from ICE vehicles. EV technology is market-ready and cost competitive (especially from a life-cycle basis) for mid-sized sedans and similarly expected for the light-duty pick up and SUV market by 2025. Note: "market-ready" does not imply readily available for procurement, particularly given the supply chain issues present at the time of writing. Depending on the timing and need for vehicle purchase, HEV or PHEV may also provide significant benefit compared to ICE vehicles powered by fossil gasoline.

The United States Environmental Protection Agency reports the following advantages for EVs compared to gasoline vehicles:[45]

- **Energy efficient.** EVs convert over 77% of the electrical energy from the grid to power at the wheels. Conventional gasoline vehicles only convert about 12%–30% of the energy stored in gasoline to power at the wheels.
- **Performance benefits.** Electric motors provide quiet, smooth operation and stronger acceleration and require less maintenance than ICE.
- **Reduced energy dependence**. Electricity is a domestic energy source.

[45] https://www.fueleconomy.gov/feg/evtech.shtml

- **Environmentally friendly.** EVs emit no tailpipe pollutants, although the power plant producing the electricity may emit them. Electricity from nuclear-, hydro-, solar-, or wind-powered plants create no air pollutants

Current downsides and barriers to implementation for BEVs include:

- **First costs** of vehicles is greater compared to conventional fossil gasoline vehicles.
- **Range** of EVs and available charging infrastructure can be limited and may not always align with ODOT operational needs. It is important to note that vocational use of vehicles is different than general public use. For example:
  - Tools and gear are commonly transported in ODOT vehicles that add significant weight.
  - Onsite power may be needed from ODOT vehicles.
  - ODOT vehicles need to operate under adverse weather conditions.

  All of these factors reduce range and could increase fuel cost per mile if commercial charging is required.
- **Vehicle types** currently available are non-existent or severely limited for the SUV and pickup truck vehicle types.
- As of this writing, **supply chain issues** are prevalent in automobile manufacturing which limit purchasing options.

Relationship to other Best Practices

Purchase or production of 100% renewable electricity maximizes the climate benefits of EVs. Renewable electricity procurement should be prioritized to support and enhance vehicle and equipment electrification. However, the Union of Concerned Scientists found powering EVs with fossil fuel electricity sources still leads to overall improved efficiency. Even in states that use fossil fuels to generate electricity, average EV MPGs are still greater than average on road fossil fuel powered fuel economy.[46] Table 8, above, compares electricity generated from various sources and shows, even using coal, the average MPG equivalent is still 35% greater than the average fuel economy of an on-road light-duty vehicles in the U.S. (i.e., 22.2 MPG in 2019 according to the U.S. Bureau of Transportation Services).[47]

Real World Examples

Many public fleets around Oregon are transitioning to EV passenger sedans:

- City of Eugene – Developed purchasing policy requiring the purchase and use of EVs before all other types of vehicles. Exemptions are available for emergency and others on an as-needed basis but require review and defense in front of a fleet management board. This policy was put in place to comply with the City of Eugene's Climate Recovery Ordinance that required carbon neutral operations by 2020 via operational change and the purchase of carbon offsets for remaining emissions.

[46] For details see https://blog.ucsusa.org/dave-reichmuth/plug-in-or-gas-up-why-driving-on-electricity-is-better-than-gasoline/
[47] For details visit https://www.bts.gov/content/average-fuel-efficiency-us-light-duty-vehicles

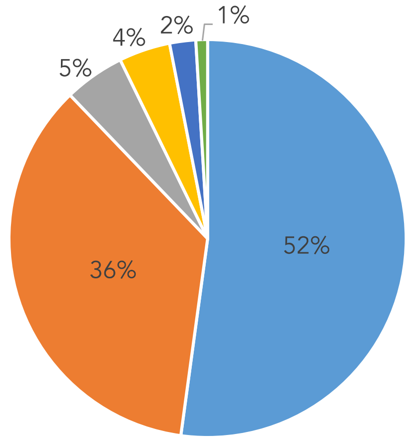
- State of Oregon – House Bill 2027 (passed in the 2021 Legislative Session) requires state agencies to purchase light-duty, zero-emission vehicles by 2025, unless the agency finds it is not feasible for the specific use the vehicle is intended.[48]
- City of Portland – Developed an electric vehicle strategy for City operations.[49]

Current Conditions

Fuel use by ODOT vehicles and equipment is critical to support the construction, operation and maintenance of Oregon's state highway system. In FY 2016-19, ODOT used an average of one million gallons of fossil gasoline annually. This translates to about 10,000 MT CO_2e of GHG emissions per year. About 5,700 MT CO2e of this total are from light-duty sedans, pickup trucks, and SUVs.

As is shown in Figure 4, fossil gasoline is used predominately by ODOT's fleet of light-duty pickup trucks (<1 ton) and medium-duty trucks with smaller quantities used by light-duty SUVs and passenger sedans.

Figure 4: Comparison of gasoline use by vehicle category



ODOT's fleet, as of FY20, includes five BEV sedans; six PHEVs; ten HEVs; and 135 conventional ICE vehicles for a total of 146 sedans. Electric sedans were driven 80,000 total miles in FY 20, compared to ICE sedans at almost 1,000,000 miles. Beyond sedans, gasoline-powered pickup trucks and SUVs were driven an additional 12,000,000 miles during the same time-period. These usage patterns indicate providing access to EVs may not be enough. The range of BEVs currently owned by ODOT is limited, which naturally limits their use. However, range limitations do not explain why available HEVs and PHEVs are not being used before ICE sedans. A combination of EV-first policies and more funding to develop training and outreach programs may be necessary to increase use.

Table 8: ODOT FY2020 fleet data and mileage

FY2020	Vehicle Count	Annual Vehicle Miles	Ave Miles per Vehicle
Cargo Van (fossil gasoline)	51	481,941	9,450
EV's (Full Battery Electric)	5	1,906	381
PHEV's (Plug-in Hybrid Electric Vehicle)	6	31,851	5,309
LEV's (Hybrids or over 40 MPG efficiency)	10	46,603	4,660
Passenger Van (fossil gasoline)	50	362,470	7,249
Pickup (fossil gasoline)	794	10,108,054	12,731
Sedans (fossil gasoline)	135	982,341	7,277
SUV (fossil gasoline)	197	1,673,292	8,494

[48] A zero-emission vehicle means a battery electric vehicle, a plug-in hybrid vehicle or a hydrogen fuel cell vehicle or any type of vehicle defined by the State Department of Energy or the Environmental Quality Commission by rule as a "zero-emission vehicle". The adopted bill can be found here: https://olis.oregonlegislature.gov/liz/2021R1/Downloads/MeasureDocument/HB2027/Enrolled

[49] https://www.portland.gov/sites/default/files/2019-07/final_electric-vehicle_report2016_web.pdf

Market Study

Availability and Access

Currently available EVs already provide a cost-effective substitute for gasoline passenger sedans with ranges over 250 miles (such as the Hyundai Kona and Chevy Bolt). Within the next five-years it is widely anticipated many cost-effective EV pickups and SUVs will be commercially available. Table 9, below, summarizes known products with cost, range and anticipated availability.[50] Particularly of interest, given ODOT's use of pickup trucks, are the Ford Lightning and Chevy Silverado which have relatively long-range batteries at a price point greater than, but comparable to conventional pickup truck prices. Other vehicles included are to illustrate product offering, but are not intended to imply all these vehicles would align with ODOT's operational needs (e.g. GMC Hummer EV). A compressive list of new & upcoming vehicles is available at https://www.fueleconomy.gov/feg/evnews.shtml.

Table 9: Summary of near-term pickup and SUV EV products and costs

Name	Price	Range	Availability
Trucks			
Ford F-150 Lightning[i]	$40,000	230-300 Miles	2022
Rivian R1T[ii]	$67,500	300-400 miles	2022
Chevy Silverado EV[iii]	$50,000+	400+ Miles	2024
GMC Hummer EV[iv]	$80,000-$112,595	350 Miles	2024
SUVs[v]			
Chevy Bolt EUV[vi]	$37,500	247+ miles	Currently available
Kia Niro EV[vii]	$40,000	239 Miles	Currently available
Volvo Recharge[viii]	$55,300	223 Miles	Currently Available
Rivian R1S[ix]	$75,000	316 Miles	2022
GMC Hummer EUV[x]	$80,000-$112,595	350 Miles	2024

[i] https://www.cnet.com/roadshow/news/2022-ford-f-150-lightning-electric-pickup-truck-specs-pricing/
[ii] https://rivian.com/r1t
[iii] https://www.chevrolet.com/electric/upcoming-all-electric-silverado
[iv] https://gmauthority.com/blog/gm/gmc/gmc-hummer-ev/
[v] https://insideevs.com/car-lists/electric-suvs/
[vi] https://www.chevrolet.com/electric/bolt-euv
[vii] https://www.kia.com/us/en/niro-ev
[viii] https://www.volvocars.com/us/v/cars/xc40-electric
[ix] https://rivian.com/r1s

EV availability for purchase by public agencies is a significant issue as of this writing due to supply chain issues resulting from the pandemic and combined with a still developing EV battery supply chain and related production capacity. These issues are anticipated to significantly impact new EV vehicle production in the near-term (one to three years). This supply issue will likely have negative impacts on the pace of implementation for electric vehicle transition, particularly for public fleets with existing price agreements.

Two important notes that impact ODOT's ability to purchase EVs:

1. ODOT is limited to procure vehicles listed on the State of Oregon price agreement (not all of the vehicles listed in Table 9 are on this list).[51]
2. Market availability does not equate to available for public agencies like ODOT. For example, at the time of this writing, ODOT is not able to purchase a Toyota Prius because suppliers are focused on selling their top-end models over previously-negotiated, lower-profit government vehicles. This situation could last several years.

Costs

EVs often have greater initial costs versus comparable ICE vehicles. Costs can vary widely depending on brands and models selected for comparison. For the purpose of this report, it is assumed the marginal premium for light-duty EVs is $20,000 per vehicle (over the next 10-15 years).[52] While these premiums are appropriate based on current pricing, it is widely anticipated light-duty EVs will reach cost parity with ICE vehicles within five years without the help of incentives.[53]

There are also additional costs for EV chargers and related electrical upgrades depending on facility location and operational demands. Costs vary depending on type of charger and other upgrades that may be needed to support charger installation. ODOT reports the following for infrastructure costs:[54]

- An average cost of $3,500 per charging head
- Installation costs of $5,532 per charging head
- Annual service fees of $240 per charger head
- Additional, site-specific costs for upgrading power, trenching, ADA compliance, signage, etc.

[50] Note: The "Range" column in Table 9 is the estimated range per the manufacturer. ODOT uses vehicles differently than the general public (e.g., working an incident scene with overhead flashing lights running, operation in extreme weather conditions, frequent and extended idle times, etc.). Therefore, the actual vehicle range experienced by ODOT are likely to be vastly different than the manufacturer's expectations.

[51] https://www.oregon.gov/das/Procurement/SiteAssets/Lists/PriceAgreements/EditForm/FleetPricing.docx

[52] Calculated from information provided by Oregon Department of Administrative Services – Fleet Department.

[53] See https://www.bloomberg.com/news/newsletters/2021-05-25/hyperdrive-daily-the-ev-price-gap-narrows.

[54] Per DAS 2020 ORS 276.255 report.

While initial purchase and infrastructure costs for EVs can be greater, fuel and maintenance costs are significantly lower than ICE vehicles. Table 10 shows per mile fuel costs for a variety of vehicle types in the ODOT fleet based on historic fleet data. Average light-duty ICE fuel cost is roughly $0.16 and BEV fuel costs are approximately $0.01 per mile. Note: EV fuel costs may be significantly greater (two to four times) for use of commercial chargers, depending on charger type and service provider. Maintenance costs for EVs are also anticipated to be significantly lower than conventional ICE vehicles due to reduced need for fluid changes and brake work. Default assumptions from Argonne National Laboratory's Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool indicate an average per mile maintenance & repair charge for light-duty gasoline-powered vehicles is $0.15 per mile compared to a BEV at $0.09 per mile.[55]

Table 10: Comparison of vehicle type fuel conomcy and available data on fuel costs

Vehicle Type	Fuel Economy (MPG)	Fuel Cost per Mile
Cab-Chassis	11	$0.24
Cargo Van	14	$0.19
Battery Electric Sedan	110	$0.01
Plug-in Hybrid Electric Sedan	110 (electric) 42 (hybrid)	$0.06
Hybrid Electric Sedan	40	$0.07
Passenger Van	15	$0.17
Pickup (<1 ton)	13	$0.19
Sedans	22	$0.12
Station Wagon	18	$0.15
SUV	20	$0.13

To reduce the initial costs of EVs, a variety of financial incentives are available that further improve the lifecycle cost comparison for EVs:

- **Oregon Clean Fuels Program Advanced Crediting**. Public fleets that have a plan to convert to an all-electric fleet within 15 years are eligible and may apply to receive the up to six years of the financial values of Clean Fuels Program credits.[56] For a fleet that travels 15,000 miles per year, the value of the advanced credits is estimated to be almost $26,000. It is important to note: funds generated from the Clean Fuels Program typically go into a general fund and are not always dedicated to fleet budgets.
- The **Oregon Clean Vehicle Rebate Program** provides up to $2,500 standard rebate.[57] State fleet vehicles are limited to ten vehicle rebates per year.

Making the Transition

Oregon public-agency fleet managers offered the following lessons and guidance:

- Utilize Clean Fuels Program financial incentives to help transition to an EV fleet.
- Plan for charging infrastructure and related electrical service to support EV transition. Maximize use of ODOT-owned chargers for lowest fuel costs, and minimize use of commercial chargers with higher rates.

[55] https://greet.es.anl.gov/afleet
[56] For more details visit https://www.oregon.gov/deq/ghgp/cfp/Pages/Advance-Crediting.aspx.
[57] https://www.oregon.gov/deq/FilterDocs/evrebateapplication.pdf

- Create a vehicle purchasing policy that requires EVs as the default, except where the duty cycle excludes the operational abilities of an EV. (Many reported this policy as being a critical component to avoid challenges and biased preferences in the purchasing process.)
- Create a policy requiring the use of EVs before ICE vehicles when available and when it fits the activity need.
- Adequately fund fleet programs to:
  - Cover costs of necessary infrastructure upgrades and increased initial costs of EVs.
  - Enable adequate education and outreach to promote and instill a positive culture toward EVs.
- Consider the trade-offs between procuring early versions of EVs with minimal range versus waiting for EVs that have the range needed for ODOT operations.

Lifecycle Considerations

Upstream production GHGs for EVs are greater compared to ICE. However, the Union of Concerned Scientists found upstream production emissions are quickly offset by emission reductions during the use of EVs.[58] And, again, while the best case scenario is to fuel an EV with 100% renewable power, EVs powered by ODOT existing mix of energy sources means less overall emissions than ICE vehicles.

End of life battery management at present also represents a lifecycle issue for EVs. As of this writing no standard physical or chemical specifications in the marketplace exist for recycling the cells, modules or battery systems. Many public agencies and private companies are working to improve battery design which speeds performance improvements and lowers production costs, but currently makes recycling labor intensive with limited opportunity for mechanization and makes the value of recovery inconsistent. Overtime design choices and specification will likely converge allowing recycling systems an easier path to economies of scale and economic viability, but at present recycling poses economic challenges. See the Department ReCell Advanced Battery Recycling for more information.[59]

Until a national recycling strategy is well understood, best practice for lifecycle battery management include policies to maximize battery life using appropriate charging and operational practices, such as:

- Battery takeback in vehicle contracting;
- Work with private partners to reuse battery pack at the end of useful vehicle life (e.g., stationary energy storage);
- Support ODEQ to establish Oregon producer takeback programs.

GHG Benefits and Cost Scaling

GHG Benefits

ODEQ reports 100% renewable electricity from wind and solar produces zero tailpipe and lifecycle GHG emissions (MT CO_2e / kWh). Thus, electrification of ODOT's light-duty fleet, paired with 100% renewable electricity, has the potential to reduce 100% of ODOT's owned sources of light-duty vehicle GHG

[58] For details visit [58] For details see https://blog.ucsusa.org/dave-reichmuth/plug-in-or-gas-up-why-driving-on-electricity-is-better-than-gasoline/
[59] Dor details visit https://recellcenter.org.

emissions by about 7,000 MT CO2e per year. Table 11 summarizes ODOT's fleet vehicle types that use gasoline and are first in line to have market-ready products available within two years.

Table 11: Summary of ODOT's vehicles, baseline vehicle miles, and GHG emissions

Vehicle Type	Vehicle Count	Baseline 2019 Vehicle Miles Traveled	Baseline 2019 Emissions (MT CO2e)	Emissions per Vehicle (MT CO2e / vehicle)
Light-Duty Gasoline (E10) Powered Vehicles	1,257	14,000,000	7,000	5.6

Cost Scaling

The marginal cost benefits or impacts of EV ownership versus conventional ICE vehicles varies significantly depending on several factors, including:

- Vehicle initial costs.
- Available financial incentives.
- EV charging and related infrastructure needs.

ODAS Fleet anticipates a premium of $32,600 per EV:

- $20,000 per vehicle for incremental costs
- $9,000 per vehicle for charger and installation
- $3,600 per vehicle over 15-years for charger subscription services

The marginal cost to transition ODOT's light-duty fleet to EVs over the next 15 years is roughly $41 million with an annual cost of $2.7 million over those 15 years. These costs assume no Federal or State financial incentives for vehicles or chargers. EV cost savings for reduced fuel and maintenance savings are estimated at (-$37 million over 15 years) or about -$2.5 million per year. Thus, the net costs to transition to EVs is estimated to be $3.9 million over 15 years (in 2019 dollars).

Using this net value and 15-year emissions reductions of 105,000 MT CO_2e[60] the cost of carbon reduction is estimated at $37 per one (1) MT CO_2e. If average EV electricity costs are decreased from $0.04 to $0.03 per mile, the cost of carbon reduction is reduced from $37 to $10 per one (1) MT CO_2e. The fuel cost used in this financial analysis is 4x greater than existing ODAS data. This increase assumption is included to be conservative around unknown factors related to vehicle fuel economy and actual charging costs, particularly for commercially-owned Level 3, DC-Fast Chargers. That said, it is conceivable these costs assumptions will decrease in the future. This could be accomplished by strategic installation of ODOT-owned chargers that fit operational needs to limit use of commercial chargers. Similarly, if Oregon's EV rebate were available to 100% of state agency EVs purchases each year, it would reduce the first cost for light-duty vehicles ($2,500 per vehicle) which have the effect of reducing the net lifecycle cost of carbon reduction to $0 per one (1) MT CO_2e.

[60] 7,000 MT CO_2e / year * 15 years = 105k MT CO_2e

See the following bullet points and tables for the assumptions and sources used to generate the analysis presented above.

Cost Impact Assumptions:

- EV vehicles average a 15-year lifespan.
- EV marginal cost: $20k per light-duty ICE vehicle substitution (average price over next 10-15 years). Source: ODAS DAS 2020 ORS 276.255 report.
- Charger installation costs: $9k per ICE vehicle substitution ($3,500 for equipment and $5,500 for installation). Source: ODAS DAS 2020 ORS 276.255 report.
- Annual charger subscription: $240 per charger per year, or $3,600 total per EV over average 15-year vehicle lifespan. Source: ODAS DAS 2020 ORS 276.255 report.
- State financial incentives: $0. These incentives are limited - if available at all - to state fleets per interviews with subject matter experts. The state rebate is limited to ten vehicles per year and advanced Clean Fuels Programs credits revenue typically goes to general fund, not fleet department budgets.
- Light-duty ICE fuel cost (per VMT): $0.16 per mile
- Light-duty EV fuel cost (per VMT): $0.04 per mile (adjusted upward by 4x to address concerns related to usage of commercial chargers and lower efficiencies of vocational use of EVs).
- Light-duty ICE maintenance and repair costs (per VMT): $0.15 per mile (source: AFLEET).
- Light-Duty EV maintenance and repair costs (per VMT): $0.09 per mile (Source: AFLEET).
- A 10% premium is added to the per mile fuel cost for EVs to account for additional costs incurred by ODOT for the purchase of 100% renewable electricity from utilities.

Table 12: Summary of EV marginal costs and savings

Summary of EV Marginal Vehicle & Charger Costs						
Metric	Activity Unit (ODOT 2019 Light-Duty Vehicle Count)	EV Vehicle Marginal Cost (Average for Light-Duty)	EV Charger Marginal Cost	EV Charger Subscription Costs	Financial Incentives (Available to State Fleets for Vehicles and Chargers)	Total EV Marginal Costs
Per Vehicle	1	$ 20,000	$ 9,000	$ 240	$ -	$ 32,600
Annual Cost	84	$ 1,676,000	$ 754,200	$ 20,112	$ -	$ 2,731,880
15-Year Total	1257	$ 25,140,000	$ 11,313,000	$ 4,525,200	$ -	$ 40,978,200
Summary of Fuel, Maintenance & Repair Costs						
Metric	Activity Unit (ODOT 2019 Vehicle Miles Traveled)	ICE Baseline Fuel Costs	EV Fuel Cost	ICE Baseline Maintenance & Repair Costs	EV Maintenance & Repair Costs	Total EV Marginal Savings
Per Vehicle Mile	1	$ 0.16	$ 0.04	$ 0.15	$ 0.09	$ (0.18)
Per Vehicle	167,601	$ 26,816.23	$ 7,374.46	$ 25,140.21	$ 15,084.13	$ (29,498)
Annual Cost	14,045,000	$ 2,247,200	$ 617,980	$ 2,106,750	$ 1,264,050	$ (2,471,920)
15-Year Total	210,675,000	$ 33,708,000	$ 9,269,700	$ 31,601,250	$ 18,960,750	$ (37,078,800)
					Per EV Net Cost	**$ 3,102**
					Annual EV Net Cost	**$ 259,960**
					15-Year EV Net Total	**$ 3,899,400**

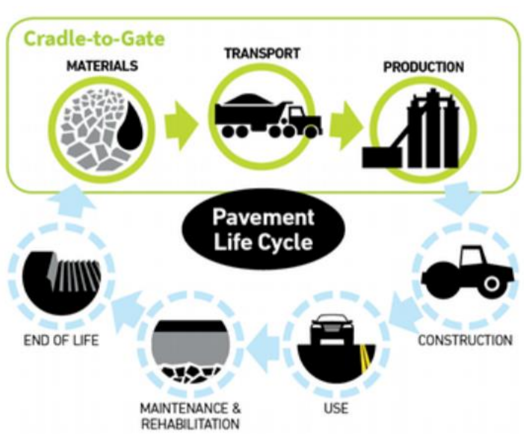
EPD Program Development

Environmental Product Declarations (EPDs) are a rapidly emerging platform being used by the construction industry to convey vendor, plant, and product-specific climate impacts from material production. Public agencies and private customers are beginning to use EPDs as a tool to measure the carbon footprint of infrastructure projects. Furthermore, EPDs can be factored into product selection to comply with previously-set emission reduction targets. By requiring and tracking EPDs, ODOT could better understand the climate impacts of product selection while still optimizing the use phase for smoothness and durability. The agency could go even further and require contractors to install materials that are below a set emission threshold, which would move certain materials toward lower carbon alternatives on a prescribed schedule.

EPD Description

EPDs are produced by material vendors, commonly with consultant assistance and/or dedicated software packages (e.g., National Asphalt Pavement Association's Emerald Eco Label program) to measure climate impacts, along with other environmental impacts to air and water resources. EPDs focus on "upstream" impacts for material production, often referred to as "cradle to gate," and are highlighted in Figure 5. These include impacts associated with raw materials extraction; transport of raw materials to the plant; and plant energy use and emissions. EPD measurements typically stop at the plant gate. Other factors are needed to measure emissions from the full lifecycle of a product (such as material transport from plant to jobsite, construction, use, maintenance, and deconstruction or end of life).

Figure 5: EPD boundaries compared to the complete pavement lifecycle.



Source: Baker Rock Resources. EPD reports the impacts for Level 2 1/2" dense #JMAC 2016-1 w/RAS, a Superpave design asphalt mixture.

EPD results are presented based on a declared unit:

- Concrete EPDs commonly report climate impacts as kilograms of carbon dioxide equivalent (kg CO_2e) per cubic yard of material.
- Asphalt concrete pavement and steel products are commonly reported per short ton or another weight-based unit of the material.

EPD Programs

Several jurisdictions around the U.S. have started a program to develop baseline climate impacts of vendor mixes and are requiring EPDs to be submitted with material delivery. These programs include the City of Portland, OR; Caltrans (California Buy Clean); Sound Transit (WA), Colorado DOT; Minnesota DOT; Illinois Turnpike Authority; and Port Authority of New York and New Jersey (PANYNJ). Major material vendors in Oregon are concentrated in the Portland-metro area and are already producing concrete EPDs for the City of Portland.[61] In each program, the

[61] Oregon Department of Environmental Quality has worked with a variety of industry partners to establish and promote a system of voluntary greenhouse gas reporting, specifically for material production through EPDs.

agency and main specifier has made an EPD a term of doing business and established baselines that reflect reduction goals and regionally available materials. The best practice is to adopt a process that incorporates EPDs but work with *regionally specific baselines* and targets that meet the atmospheric limit reductions that are needed.[62] Regionally-specific baselines are important due to Oregon's diversity of aggregate quality, traffic use and weather conditions that shape the need and type of cements or asphaltic binders.

By establishing a material activity data tracking system that aligns purchased material quantities with the appropriate vendor, plant, and product-specific EPD, an accurate tracking system for climate impacts may be established for mixes delivered to ODOT's performance standards. EPDs may also be used to benchmark climate impacts across vendors for products produced in similar geographic regions that show the range and the mean of the available products on the market.

Real World Examples

- ***Port of New York and New Jersey* (PANYNJ)** initiated EPD requirements and is developing a baseline for standardized mixes in use for roadways, runways, highways, structures, and buildings.
- ***Buy Clean Colorado,*** signed into law in 2021, became the first EPD mandate in the nation requiring EPDs for asphalt mixtures. The Colorado Department of Transportation (CDOT) now requires contractors to submit EPDs for road, highway, or bridge projects that are advertised, starting July 1, 2022. CDOT will use EPDs to develop GHG emissions reduction policy that will take effect in 2025.
- ***Buy Clean California***, signed into law in 2017, includes EPD reporting for seven major building materials: steel rebar, structural steel, flat glass, mineral wool board insulation, concrete, asphalt, and aggregate.[63]
- ***Buy Clean and Buy Fair Washington Project,*** a partnership between the University of Washington's Carbon Leadership Forum and the Washington State Department of Commerce, received funding from the state legislature to collect data on certain projects (i.e., EPDs, quantities, other product-specific data) with the goal of reducing GHGs and identifying low-carbon materials.
- Other states considering similar legislation include Oregon[64] and Minnesota. ***BlueGreen Alliance***[65] is supporting these efforts by uniting labor unions and environmental organizations.
- ***City of Portland, Oregon's Low Carbon Concrete Initiative***[66] began requiring EPDs for all Portland Cement Concrete in January 2020 to inform where climate impact thresholds should be

[62] Appropriate emission reduction targets are aligned with the scientific consensus of not increasing global temperatures beyond 1.5 degrees C, which means emission reductions of 50% by 2030 and 100% by 2050.
[63] For details on Buy Clean California visit https://dot.ca.gov/programs/engineering-services/environmental-product-declarations
[64] HB 2688 was introduced in the 2021 Oregon legislative session but did not receive a formal vote. The bill would have required ODOT to track EPDs from contractors installing cement concrete, asphalt, and steel. More details can be found here: https://olis.oregonlegislature.gov/liz/2021R1/Downloads/MeasureDocument/HB2688/Introduced
[65] For details on BlueGreen Alliance's Buy Clean work visit https://www.bluegreenalliance.org/work-issue/buy-clean/
[66] For details on Portland's program design and pilot project results visit https://www.portland.gov/omf/brfs/procurement/sustainable-procurement-program/sp-initiatives

set for public purchases of concrete. Carbon limits per strength class of concrete are expected to be published in 2022.

High-level process steps used by City of Portland EPD program for concrete include:

- Phase 1: Environmental Product Declaration (EPD) Requirements
- Phase 2: Data Collection, including Lower Carbon Concrete Pilot Projects
- Phase 3: Establishing Global-Warming Potential (GWP) Thresholds

Current Conditions

Note: this discussion on EPDs focuses on the production phase of construction materials and does not include the use phase of the pavement, where smoothness and durability (life-cycle optimization) are a top priority.

ODOT purchases large quantities of construction materials including asphalt concrete pavement, concrete and cement products, and steel products that have climate change impacts. Upstream production of construction materials is outside the agency's direct control. However, ODOT could adjust material performance standards and project-level or regionally-specific outcomes. For example, ODOT has historically specified use of recycled materials (e.g., up to 30% reclaimed asphalt pavement (RAP)) and the allowance of substitute cementing materials (SCM), which now occurs in 85% of all concrete mixes used in ODOT projects. These policies demonstrate ODOT's leadership on lower material production impacts.

Furthermore, while ODOT tracks material activity data by type and between construction and maintenance programs, the agency does not track emission factors alongside specific, project-level material purchases. Two pieces of information are required to track climate impacts of material production:

1. ***Activity Data:*** Common reporting units include weight (e.g., short tons), volume (e.g., cubic yards), or in some cases, dollars spent. Ideally, the activity data collected will align with commonly-agreed-upon, published emission factor reporting units.
2. ***Emissions Factors (GHGs / activity unit):*** For construction materials, the current best data source are vendors who provide EPDs. Ideally, the emissions factor used to account for production impacts will be vendor and product specific. However, this information may not be available or may not align with available activity data, necessitating the use of industry average proxies.

ODOT tracks asphalt concrete pavement used in construction by weight and mix type which aligns well with EPDs. For the many concrete products used by ODOT, material weight or volume data by product are unavailable in a consistent form which does not align with EPDs. However, the agency does track information that lends itself to looking up EPDs for specific purchases of concrete products. Specifically, ODOT tracks information about vendor, mix number, and use of SCMs at the project level for specific bid items. Details about the data and process to calculate GHG emissions form concrete and steel are described in Appendix A of the GHG Inventory report.

GHG Inventory Results

Contracted material production and use represents the largest source (estimated to be 70%) of ODOT's annual emissions. The materials included in ODOT's GHG inventory represent large known quantities and have publicly available EPDs.

Market Study

Availability and Access

EPDs are public documents that provide consumers with information about the climate impact of the product they are buying. The National Ready Mix Concrete Association produces industry average EPDs of its membership on its website.[67] Specific vendors – like CRH and CalPortland – post EPDs for their mix designs from specific plants. And recently, Building Transparency, a 501c (3) nonprofit, released an international database of available EPDs for a variety of materials.[68] The database, known as EC3, allows the user to look up EPDs based on geographic location, vendor, and specific mix properties and qualities to allow for rapid review of available mixes that fit project need. Currently, most EPDs are available for ready-mix and other related cement and concrete products (about 1,400 ready-mix EPDs are publicly available for Oregon). Other materials do not have the same breadth and depth of EPD resources. For example, there are currently 17 EPDs for asphalt concrete pavement available from Oregon producers. There are only two available for steel products – for rebar only – in the Oregon marketplace.

Figure 6: EC3 database example

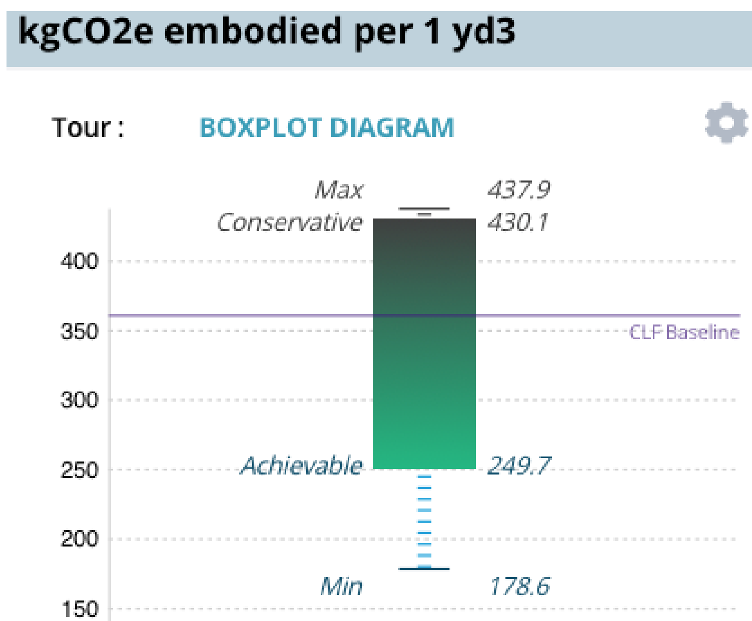


Figure 6, to the right, is an image taken from EC3 and illustrates the average GHG impact of Oregon concrete mixes with a compressive strength of 4,000 psi, as an example. The tool can be customized to isolate concrete specifications of interest, including compressive strength curing time, exposure class, slump, and more. It is designed to provide a range of emissions from known mixed designs (maximum and minimum) as well as an "achievable" mark (20% of EPDs reach this value).

EPD service providers and software packages are readily available in the marketplace. Athena Institute[69] and Climate Earth[70] are two well-known vendors in this space. These vendors aid with data collection and provide verification, impact

[67] https://www.nrmca.org/association-resources/sustainability/disclosing-environmental-impacts/
[68] https://www.buildingtransparency.org/
[69] http://www.athenasmi.org/
[70] https://www.climateearth.com/

calculations, and preparation of standard EPD reporting. Any material vendor may engage with such a firm for assistance in developing an EPD for a production plant. The services do come at a cost, which may be a bigger financial challenge for smaller "mom and pop" material contractors to provide the same EPD information as larger companies with greater resources and staff expertise.

On average, preparation of EPDs for a new plant takes approximately one to six months of calendar time from the beginning of data collection through reporting of results. The amount of time required depends on a company's existing data systems and staff expertise and availability to collect and organize the necessary data. Once the initial set up is complete, an automated EPD system can produce an EPD efficiently (15 minutes to four hours, depending on the number of changes).

Costs

Consultant companies, like the Athena Institute and Climate Earth, charge a set-up fee to develop software for a material vendor and then a subscription fee for the vendor to update EPDs or create new EPDs for a given plant. These fees range from $500 to $15,000 depending on the plant, materials and services requested. On the more involved end of services, one EPD developer quoted $15,000 to produce 30 EPDs from 4 plants (approximately $500 per mix). There are economies of scale in this work: per plant costs for EPD services is reduced as more plants are included in the project. Additional costs for vendors to develop EPDs include staff time, estimated to be one full-time employee for three months during initial data collection and production of an initial set of EPDs. No specific staff training costs were reported by vendors, but they did report a learning curve and the skills required can be self-taught. Costs for consultant services and dedicated staff time may be challenging for smaller vendors. Financial and technical support services may be available from ODEQ.[71]

It is unclear if fees borne by material vendors to develop an EPD would be passed along to the customer. Nonetheless, an EPD for a specific material is typically valid for five years and can be used repeatedly (i.e., initial costs to develop EPDs for a production plant will be amortized across many projects). Project interviews indicated it is unlikely ODOT would see an increase in material costs simply because of a requirement to provide an EPD.

Within ODOT's operations, staff time would be required to review and manage submitted EPDs. Program development, including setting baselines and climate goals, will take time and consideration to ensure alignment with existing data management. Investment in EPD-specific software may be necessary to adequately track EPDs and tie them to specific projects. However, this depends on the goals of the agency; simply tracking global warming potential - a single data point in an EPD - would be very informative for ODOT. A more robust program could require the assistance of a consultant or academic support.

Making the Transition

The following text summarizes concerns and suggestions from the project advisory group and individual stakeholder interviews regarding an EPD program at ODOT.

[71] For details visit ODEQ's website https://www.oregon.gov/deq/mm/production/Pages/Concrete.aspx.

- An emphasis needs to be placed on optimizing the lifecycle and smoothness of pavement. While EPDs are an important and useful tool to understand climate impacts, pavement lifecycle and efficiency factors like smoothness are not captured in a typical EPD. Smoothness reduces friction from tires rolling on the pavement which reduces fuel consumption from vehicles on the system. Durability of the pavement means less energy and materials are put into the pavement as the same materials sit in place for a longer period, thus reducing the need for more materials.
- ODOT should only require submittal of EPDs after contract award to ensure the performance specifications are met. This is heavily preferred over an open competition model in which a contractor is selected based, in part, on the lowest embodied emissions from their bid. It also allows for the entire industry to make the transition together and does not pick winners, which will most likely be the larger firms that can make the capital investments before the smaller independent and portable operations can. This is the route that CalTrans appears to be moving toward (establishing regional baselines and then mandating new thresholds for embodied GHGs).
- A set of emission thresholds need to be declared early on and need to reflect a schedule that allows the industry to plan for and execute a successful transition to utilizing EPDs to meet climate goals.
- Pilot and/or demonstration projects are encouraged to develop understanding and build confidence with EPDs.
- Special considerations should be made for smaller-scale vendors that may not have the financial or staff resources to produce EPDs.
- Where possible, reduce the number of mix specifications being requested by ODOT to simplify reporting within an EPD program. PANYNJ, for example, uses only 20 mixes total for all applications (airport runways, bridges, roadways, and structures).
- Trade organizations like the National Asphalt Pavement Association[72] or the National Ready Mix Concrete Association[73] provide technical support to their members.
- At least four regions are suggested for designing an EPD program for ODOT: Coast, Valley, High Mountains and Eastside. EPD requirements or climate impact thresholds informed by EPDs should also be specific to fixed plants (located in major metro areas) compared to mobile plants (used in more rural areas). The reason being there will be a large difference in the fuel types used for the production, in addition to available materials. For fixed plants, the heat source is typically natural gas, while portable plants are likely to use residual fuel oil (RFO).
- The Carbon Leadership Forum's Embodied Carbon Policy Toolkit[74] offers a wide variety of background information and factsheets on measurement of climate impacts for material production and disclosure, basics of Buy Clean Policies, and details related to development and implementation. It is recommended to reference this toolkit and consult the organization's staff if ODOT moves forward with creating an EPD program.

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72 For details on NAPA's Emerald Eco-Label EPD program visit https://www.asphaltpavement.org/programs/napa-programs/emerald-eco-label

73 For details on NRMCA EDP program visit https://www.nrmca.org/association-resources/sustainability/epd-program/

74 For details on The Carbon Leadership Forums toolkit visit https://carbonleadershipforum.org/clf-policy-toolkit/

Lifecycle Considerations

- Embodied emissions should not be optimized at the expense of smoothness (reduced friction on vehicle wheels) or durability/longevity of the wearing surface (reduced need for maintenance materials over time) unless a complete lifecycle analysis is performed and proves otherwise.
- EPDs only capture a small set of the material lifecycle. Other impacts such as transportation to the job site, construction, maintenance and end of life steps are not included.
- Concrete has the potential to sequester significant quantities of carbon over its lifecycle and those benefits are not currently counted in EPDs. Cursory research for this project found there are a wide variety of estimates in private market claims and the academic literature. Additional research is required to better inform the scale of the carbonation benefit and how best to apply that benefit within ODOT's GHG Inventory.

GHG Benefits

EPDs do not mitigate GHG emissions on their own. EPDs are a tool - emission reductions are seen through their application. For example, material vendors may find inefficiencies in their operations by way of an EPD. Some experts believe simply requiring EPDs can lead to emission reductions because of this awareness. That said, an EPD can have the greatest GHG impact when used to show compliance with an emission performance standard (i.e., an installed product must be below a previously set carbon threshold).

Alternative Cement Substitution

Concrete is one of the most widely used construction materials in the world, and, therefore, the associated economic, human, and environmental benefits and impacts are significant. An estimated 7% of GHG emissions are associated with cement production.[75] Concrete is a mix of aggregate, water, hydraulic cement (blend of Portland cement, ground limestone, and/or supplementary cementing materials - "SCMs") and chemical admixtures that modify the behavior of fresh and hardened concrete to make it easier to place and to enhance strength or durability. The material cost and associated climate impact is largely dependent on the amount of Portland cement used in the concrete mix. Therefore, identifying ways to lower the impacts of Portland cement production or displace the need for production through use of alternative materials[76] rank high on the list of best practices to address the GHG emissions from the production of concrete.

Portland cement is manufactured by heating raw materials (mostly limestone) to about 2,500F (1,400C). Heating to this temperature requires significant amounts of fuel (sources include natural gas, coal, used tires, waste oils, solvents, etc.). Emissions from the combustion of these fuels represent about 40% of the GHG footprint of Portland cement. The remaining 60% of impacts are from production-related

[75] International Energy Agency (2018). Available online at https://www.iea.org/reports/technology-roadmap-low-carbon-transition-in-the-cement-industry.
[76] Throughout this report, alternative cements and SCMs are used interchangeably.

calcination process emissions, generated as raw materials are heated and decompose during production.[77]

SCMs can enhance concrete properties and reduce the need for production of Portland cement and the associated climate impacts. Examples of more-common alternative cements include fly ash (a byproduct of coal combustion), blast-furnace slag (a byproduct of iron production) and silica fume (a byproduct of silicon metal); others include ground limestone or other pozzolans (such as volcanic ash and glass). Fly ash can be substituted for Portland cement up to 30%. ODOT specifications allow slag substitution up to a maximum of 50%. The Slag Cement Association suggests that up to 80% may be used in specific applications with proper precautions.[78]

Cement substitutes provide a GHG reduction relative to the production of Portland cement, although it is important to note this benefit can be diminished or negated depending on material transport distances and freight mode. The benefit may also decrease if contractors increase the cementitious materials to comply with early-age strength tests needed for construction schedules. According to the National Ready Mix Concrete Association's U.S. average EPD, a 30-39% substitution of fly ash results in a 22% decrease in GHG emissions per unit of concrete compared to a Portland cement concrete mix, while a 50% substitution of slag results in a 39% reduction (for strength class 3001-4000 psi).[79] While alternative cements offer an opportunity to reduce climate impacts, there can be barriers to adoption including longer curing times to reach required compressive strengths, concerns about toxicity of the alternative materials, increased risk of salt scaling, and prohibitive transportation costs.

Real World Examples

Examples are too numerous to mention – this best practice is used by many organizations for a wide variety of end uses including ODOT.

Current Conditions

ODOT purchases large volumes of construction materials including ready-mix and precast concrete products, cement, aggregate, steel, etc.[80] While ODOT does control the life cycle of pavement in their system, the upstream climate impacts from production of these products is outside the agency's direct control. That said, ODOT does have the ability to request greater SCM content in their projects (toward the standard specification maximum in all applications) for better climate performance.

ODOT's specifications have included significant quantities of materials that lower GHG impacts, such as the substitution of alternative cements/SCMs for Portland cement and its use of reclaimed asphalt pavement (RAP) to substitute for virgin asphalt binder and aggregates. ODOT's baseline GHG emissions would be significantly larger without ODOT's use of these best practices. SCMs used on ODOT projects include fly ash, blast-furnace slag, and silica fume. ODOT's contractors have used 30% fly ash and 5%

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[77] Portland Cement Association (2020). Carbon Footprint of Cement. Online at https://www.cement.org/docs/default-source/th-paving-pdfs/sustainability/carbon-foot-print.pdf.

[78] Details online at https://www.slagcement.org/aboutslagcement/is-02.aspx

[79] NRMCA U.S. average EPDs found online at https://www.nrmca.org/wp-content/uploads/2020/02/NRMCA_EPD10294.pdf

[80] During the period, FY2016 – 19 ODOT used an estimated 250,000 cubic yards of concrete annually.

silica fume mixes, but are reportedly moving toward slag cement and away from fly ash in both ready mix and precast concrete products due to reduced fly ash supply in the region.

GHG Inventory Results

The production of concrete and cement products used in ODOT construction projects have an annual average climate impact of 20,000 MT CO_2e (for FY2016-19). These results account for use of alternative cements throughout the defined period. It is estimated concrete-related emissions would be 20 – 30% larger if not for ODOT's use of SCMs. ODOT keeps sound records of concrete and cement product purchases including detailed mix specifications,[81] quantities purchased and financial data. This record keeping has served ODOT's historic needs, but this system will require modification to cost-effectively and accurately monitor climate impacts to track progress toward goals.

Market Study

Availability and Access

- **Slag and Fly Ash**, the cement alternatives most used by ODOT, both arrive in Oregon at the Port of Portland. From there they are trucked elsewhere in the state. Blast furnace slag is produced in British Columbia, Canada and Asia. Fly ash is currently produced in Centralia, Washington (reportedly shutting down in or around 2025), and from sources in Wyoming and Canada. Fly ash can be transported from other parts of the country, but freight costs and associated GHG impact can become prohibitive if it is shipped from too far away.
- **Type 1L limestone cements**, where up to 15% of Portland cement is replaced with ground limestone, are available in the Pacific Northwest (per AASHTO M240 standard specification for blended hydraulic cement). This substitute provides about a 10-15% reduction of GHG emissions compared to conventional mixes and has more available supply versus other SCMs. It also can be blended with other SCMs to increase GHG reduction benefits. Interviews conducted for this project indicated additional market availability of Type 1L limestone in the Portland region in 2022. Reporting from Portland Cement Association and National Concrete Consortium indicates the cement industry is moving toward all Portland-limestone cement (AASHTO M240) soon to replace Type I/II (AASHTO M85).
- **Volcanic pozzolan** is another SCM that is currently available but at scale. Multiple industry and ODOT engineers spoke about the availability of this material in the state as an existing natural source of SCM. One of these products has already been approved (Lafarge TS100) which uses pumice from Kamloops, British Columbia. A report was completed in 2018 by the Oregon Institute of Technology evaluating this material for use and comparing its energy demands and associated GHGs.[82] The report found: with additional processing, Mount Mazama volcanic ash

[81] In a ODOT Excel-based report titled CDM Survey. This report captures details of mix specifications cross referenced with project and bid items. There is also information on Contractor and Contractor Mix Design Number, but this information is less consistent and unfortunately the Contractor Mix numbers do not always align with information on Environmental Product Disclosures.

[82] Sleep, Matthew and Masley, Morgan. The use of Mt. Mazama volcanic ash as natural pozzolans for sustainable soil and unpaved road improvement. NITC-SS-1075. Portland, OR: Transportation Research and Education Center (TREC), 2018. Downloaded online at

can be effective as a supplement to Portland cement for binding compacted gravel layers and reducing dust. It also found energy use and GHG emissions were comparable to fly ash as a SCM.

- **Ground glass** may be a used as a SCM as well, which was recently made easier by the release of a standard ASTM specification (*C1866, Recycled Ground-Glass Pozzolan for Use in Concrete*). The context for this new standard is summarized by subcommittee members in a report titled *Ground-Glass Pozzolan for Use in Concrete*.[83] The report lists three glass types suitable for use as pozzolan in in Portland cement concrete: container glass, plate glass, e-glass (by product of fiberglass manufacturing). Overall, the report found glass pozzolan has greater purity (uniform material free of hazards), widespread supply that is geographically distributed, with similar reactivity and performance compared to fly ash and slag, lower water demand, and similar environmental benefits as fly ash and slag. The report suggests container glass and plate glass may provide a 10-40% substitute for Portland cement, while e-glass may substitute for between 10-30%. The report references field validation testing taken place over the past ten years in concrete masonry units, pavers, precast concrete products, and sidewalks. The City of Montreal began testing post-consumer glass in sidewalks beginning in 2010. New York City has completed testing in 2016 in sidewalks and is included in Department of Design and Construction specifications. New York has tested up to 50% Portland cement replacement in high-rise construction. Two bridges are being constructed in Montreal, Canada using 10% Portland cement replacement.
    - The *Ground-Glass Report* is more optimistic about the prospects for glass pozzolan than ODOT and Oregon-based suppliers. ODOT reports these materials are not being produced on the West Coast - only soda-lime bottles may be used (per ASTM 1866 Type GE/GS) - and that fiberglass does not produce a quality pozzolan that can be used in ODOT projects. ODOT further reports no suppliers (as of this writing) have requested to get their products approved for use in Oregon. Early conversation with potential suppliers indicate the quantity of available soda-lime glass in Oregon is not enough to invest in viable, long-term production. While post-consumer glass is abundant in Oregon,[84] it is not clear how much of the available material is soda-lime glass. Another challenge for adoption is that a dedicated pozzolan production facility would need to be developed in Oregon to capture the material and process it to be ready for use as an SCM.

Costs

The City of Portland conducted a pilot study in early 2020 to evaluate lower-impact concrete mixes and report costs for alternative cements equal to or less than Portland cement. These findings may not be applicable in the post-pandemic market-place due to a variety of factors.

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https://ppms.trec.pdx.edu/media/project_files/NITC_SS_1075_Use_of_Mt_Mazama_Volcanic_Ash_as_Natural_Pozzolans_for_Sustainable_Soil_and_Unpaved_Road_Improvement_Accessible.pdf.

[83] Available for download online at https://www.concrete.org/publications/internationalconcreteabstractsportal.aspx?m=details&ID=51729296

[84] Oregon Department of Environmental Quality's 2017 Waste Composition Study found that over 70,000 short tons of glass was landfill disposed (35,000 short tons of containers; 14,000 tons of plate glass).

Interviews with suppliers shared pricing has recently changed for blended SCM-cement in the marketplace due to multiple factors including supply chain issues, transportation, and a growing awareness from suppliers of the increasing demand for these materials. Prices as of this writing are reported as neutral or up to a 25% increase compared to conventional Portland cement. Suppliers also report blended SCMs can require a change in grinding processes at plants. Many plants would require an additional silo, which costs an estimated $100,000 with additional site-specific costs for permitting and other infrastructure.

Making the Transition

- No single type of SCM fits all circumstances. Use of SCMs need to be well matched to environmental conditions, construction schedule, and availability.
- Alternative cements are not produced locally and therefore supply fluctuates. A long-term consistent supply needs to be identified to regularly utilize.
- Alternative cements requests are becoming more common and therefore costs may rise.
- Transportation distances and transportation mode must be considered when comparing GHG emission tradeoffs with Portland cement.
- Because additional capital equipment is needed, required use of alterative cements can hurt smaller suppliers unless they are supported in their transition to the new materials. ODOT reports most ready-mix facilities have silo space for at least one SCM. Some have more which would create a competitive advantage for those suppliers depending on ODOT material requirements.
- Typical cement content is higher than needed to ensure strength test are met, reducing risk for producers.
- Cure times can be longer for SCMs, which can have negative impacts on construction schedules. Thus, the use of SCMs should be focused on mixes that can have longer cure times without disruptions. Another option is to look at projects more holistically and define an appropriate amount of cure time and then develop construction schedules.
- Test maturity curves and compression at different days to see where the strengths are when piloting new mixes. Installing sensors within an installed mix can measure moisture and temperature and enables real-time data on curing status. This technique allows for other means to support curing (e.g., blankets).

Lifecycle Considerations

- All concrete mixes should be designed and specified for durability and smoothness first (e.g., reduced rolling resistance) before considering emissions from material production. An inefficient surface or significant additional maintenance over the life of the infrastructure could result in a net-emissions increase, even if emission reductions are made during material production.

- Concrete can sequester carbon over its life, which was recognized in research used for the most recent International Panel on Climate Change assessment report.[85, 86] However, EPDs do not currently account for this and an internationally agreed upon scale of emission reductions to adjust EPDs is not readily available.
- At the end-of-life, concrete may be used as a reclaimed substitute for virgin aggregate materials. Using this material in place of virgin aggregate for subgrades has become acceptable practice, but not so for use in mixes. The construction industry has not adopted this technology on a regular basis because the quantities used by ODOT (and potential GHG benefit) do not justify the risk to performance associated with the material substitution.

GHG Benefit and Cost Scaling

GHG Impacts

The GHG benefits from ODOT's current use of SCMs is included in the GHG baseline inventory calculated for FY2016-19. Figure 7, on the next page, compares baseline emissions to various scenarios including: a no-SCM scenario (illustrates emissions without ODOT's current use of SCMs); a 30% SCM scenario (illustrates if all concrete used 30% SCMs); and a 50% SCM scenario.

[85] Cao, Z., Myers, R. J., Lupton, R. C., Duan, H., Sacchi, R., Zhou, N., Reed Miller, T., Cullen, J. M., Ge, Q., & Liu, G. (2020). The sponge effect and carbon emission mitigation potentials of the global cement cycle. Nature Communications, 11(1), [3777]. https://doi.org/10.1038/s41467-020-17583-w
[86] Freidlingstein, P, et al.(2020). Global Carbon Budget 2020. Earth System Science Data, 12, 3269-2020. https://doi.org/10.5194/essd-12-3269-2020

Figure 7: Estimated annual concrete use and emissions from various SCM-usage scenarios

Strength Classification (psi) - % SCM - SCM Type description	Concrete Volume cubic yards	Baseline Emissions Factors kg CO2e / cuyd	Baseline FY16-19 Ave. Emissions MT CO2e	Low-SCM Emissions Factors kg CO2e / cuyd	Low-SME Scenario Emissions MT CO2e	30% SCM Emissions Factors kg CO2e / cuyd	All 30% SCM Scenario Emissions MT CO2e	50% SCM Emissions Factors kg CO2e / cuyd	All 50% SCM Scenario Emissions MT CO2e
2500-3000psi_0-19% FA/SL	50,324	264	13,294	264	13,294	204	10,283	164	8,253
2500-3000_30-39% FA	753	207	156	264	199	204	154	164	123
2501-3000_30-39% SL	879	204	180	264	232	204	180	164	144
3001-4000_0-19% FA/SL	73,077	326	23,826	326	23,826	251	18,307	200	14,615
3001-4000_20-29% FA	21,241	279	5,935	326	6,925	251	5,321	200	4,248
3001-4000_30-39% FA	14,850	254	3,773	326	4,842	251	3,720	200	2,970
3001-4000_30-39% SL	19,478	251	4,880	326	6,351	251	4,880	200	3,896
3001-4000_40-49% SL	1,958	225	441	326	638	225	441	200	392
4001-5000_0-19% FA/SL	257	400	103	400	103	305	79	242	62
4001-5000_30-39% FA	2,515	310	779	400	1,005	305	767	242	609
4001-5000_30-39% SL	2,673	305	815	400	1,068	305	815	242	647
4001-5000_40-49% SL	135	274	37	400	54	274	37	242	33
5001-6000_0-19% FA/SL	7,494	421	3,154	421	3,154	321	2,406	254	1,904
Vendor EPD (various psi & SCM)	58,562	321	18,813	321	18,813	321	18,813	321	18,813
FY2016-19 Totals	254,196		76,186		80,503		66,202		56,708
4-Year Annual Average	63,549		19,046		20,126		16,551		14,177
Difference from Baseline					1,079		-2,496		-4,869
% of Baseline					6%		-13%		-26%

FA = Fly ash SCM

SL = Blast furnace slag SCM

Notes: The descriptions above classify concrete use by strength and percentage of SCMs. The GHG factors (other than from Vendor EPDs) used US average values base on these classifications. SCMs are presented in U.S. average values for a range of SCM content; 0-19% SCM substitution for Portland cement; 20 – 29% SCM; 30 – 39% SCM; and 40-49% SCM; and >50%. The Strength Classification "2500-3000psi_0-19% FA/SL" indicates mixes between 0 – 19% SMCs and does not indicate only mixes absent of SCMs (0%). This nomenclature is taken from the National Concrete Ready-Mix Association's National Average Environmental Product Disclosures. Likewise, "30-39% FA [or] SL" indicates mixes between 30 – 39% SCM replacement for Portland cement.

Cost Scaling

Cost differentials for SCMs versus Portland cement were reported in project interviews as being cost neutral or up to a 25% premium for slag and fly ash, depending on the alternative and market availability. ODOT reported not experiencing a cost increase for SCMs to date. Cost comparison data is not readily available for Portland/limestone cement versus Portland cement due to anti-trust concerns within the industry. Likewise, price information was not readily available for volcanic or glass pozzolans. However, reports reviewed for this section noted these options will become more economically viable as market demand and price for slag and fly ash SCMs increases.

Asphalt Plant Energy Efficiency

Stockpile Moisture Management

Managing moisture in material stockpiles (such as aggregate) is an effective way to lower fuel costs, reduce production time and increase product quality, while lowering climate impacts. A report by the National Asphalt Pavement Association (NAPA) states: For every 1% of moisture increase in aggregate stockpiles, energy use increases by 10% and production speed decreases by 10 – 20%.[87] Thus, at a nominal moisture content of 5%, aggregate moisture accounts for almost 50% of the energy required to dry and heat aggregates for asphalt mix production.[88] Depending on the type of energy or fuel being used at the production plant, this may lead to significant GHG emissions.

The impacts of moisture will vary across Oregon with plant operations, number and size of aggregate piles, regional climate, seasonal change and annual precipitation differences. There is no one-size-fits-all for this best practice, but since it is a simple and cost-effective management technique – like energy conservation in buildings – the opportunity should be exhausted before more expensive or operationally challenging climate actions are considered.

Best practices from NAPA include the following:

- Slope the surface beneath the stockpiles away from the face used to feed the plant.
- Pave the surface beneath the piles to accelerate drainage.
- Install permanent structures to prevent moisture, especially for fine aggregate and reclaimed asphalt pavement (which do not drain as well as coarse materials).
- Keep the loader bucket elevated into the pile and remove aggregates from the pile above ground level.
- Maintain as few piles as possible and avoid intermediate piles.[89]

Many parties in the supply chain have a role to play in stockpile management including material suppliers, delivery, loader and plant operators, and quality control personnel. Asphalt product customers, like

[87] National Asphalt Pavement Association. Management of Aggregate Stockpiles. Report online at https://www.asphaltpavement.org/uploads/documents/M2M/M2M%20Aggregate%20Stockpiles.pdf.
[88] Email exchange with staff at Asphaltpavement.org.
[89] Asphalt magazine. Maintaining proper aggregate stockpiles. Available online at http://asphaltmagazine.com/stockpiles/.

ODOT, also have a role to play by limiting the number of mixes being requested, which, in turn, reduces the number of stockpiles to be managed. [90]

Other Energy Efficiency Measures

EPA's EnergyStar Challenge for Industry provides a variety of resources for industries and asks participants to set a 10% reduction goal over five years. The program is currently piloting a project specific to asphalt plants.[91] Companies serving Oregon are already participating and have achieved reductions. CalPortland achieved the EnergyStar Challenge for Industry at four concrete plants in Oregon reducing energy use by between 10 – 53%. EPA EnergyStar currently has a focus program,[92] in partnership with NAPA, on energy efficiency in asphalt production plants; CalPortland, CRH Americas Materials, Lakeside Materials, and Riverbend Materials are participants.

Current Conditions

ODOT purchases between 1 – 1.9 million short tons of ACP annually for use in construction and maintenance projects. Between FY 2016-19, construction projects used an average of 900,000 short tons annually while Maintenance and Operations used an average of 400,000 short tons. Note: ODOT reports using between 20 – 30% RAP in all mixes.

GHG Inventory Results

Oregon asphalt producers currently lead the nation in publicly available EPDs for ACP (i.e., 17 available at the time of this report). Using an average of available EPDs from Oregon vendors result in an estimated factor of 47.5 kg CO_2e/short ton (with a range of 43.6 – 51.4). Multiplying this factor by the estimated quantities used by ODOT, the agency's estimated GHG emissions from the production of asphalt pavement is between 54,000 and 72,000 MT CO_2e annually.

Figure 8, produced by FHWA, provides a summary of all lifecycle stages for ACP: production, use and disposal.[93] Moisture management is a best practiced aimed at reducing fossil fuel use needed for the heating in the asphalt mixing portion of the produce system (identified in red box in Figure 8).

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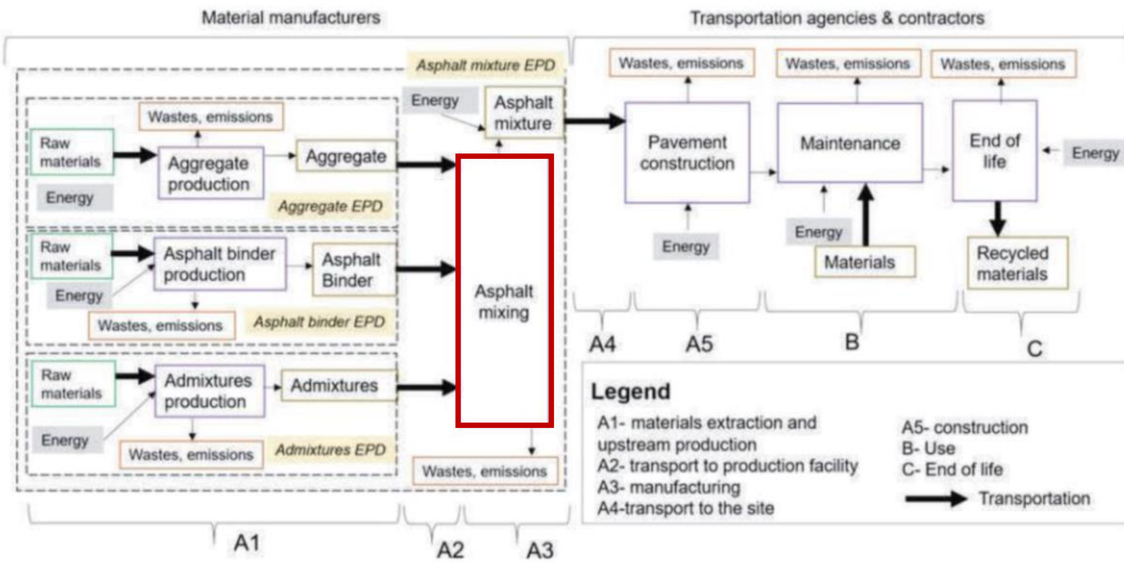
[90] Ibid

[91] For details visit https://www.energystar.gov/industrial_plants/industrialfocus/asphalt_pavement_production

[92] For additional details on EnergStar pilot program for Asphalt visit https://www.asphaltpavement.org/uploads/documents/Sustainability/EnergyStar_PilotProgram.pdf

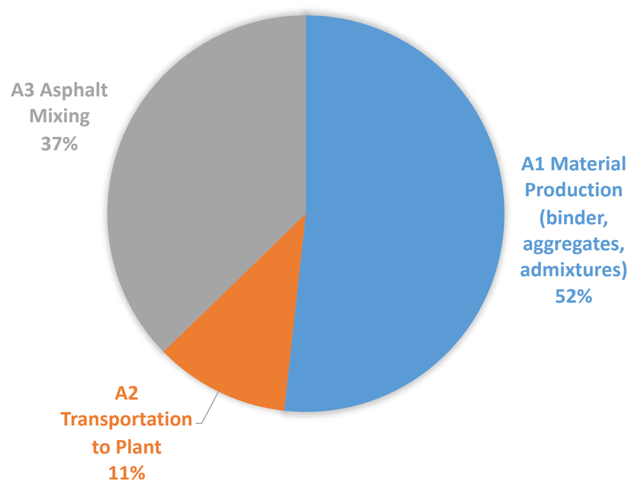
[93] https://issuu.com/calcontractor/docs/cam_enviro_2021_-_issuu?fr=sODVlYTQwMTYwMjg

Figure 8: Summary of ACP production lifecycle stages



Furthermore, EPDs, which provide emissions for the upstream stages of production, are averaged in Figure 9 to depict a comparison between the impacts of A1 through A3. It is important to acknowledge the sample size for this comparison is small, 17 EPDs, and that EPD practice is an evolving field that will only improve over time. Ideally, this comparison would have a larger, regionally specific sample size. That said, this comparison uses the most regionally accurate data set currently available in Oregon.

Figure 9: Comparison of GHG impacts for ACP production between lifecycle stages (A1 - A3)



Other Alternatives

Process controls and monitoring beyond moisture, include oxygen levels, temperature settings, and air flow control. Modern monitoring sensors and control system reduce energy use, in addition to improving productivity, quality and efficiency of the production line.[94]

[94] EPA Energy Efficiency Improvement and Cost Saving Opportunities for Cement Making at https://www.energystar.gov/sites/default/files/tools/ENERGY%20STAR%20Guide%20for%20the%20Cement%20Industry%2027_08_2013_Rev%20js%20reformat%2011192014.pdf?a8b0-3dfe

Market Study

Availability and Access

Moisture management is best considered on a regional basis, particularly for states like Oregon with distinct climate regions. Stockpile moisture is not as much of a concern in drier parts of the state as it is in the Willamette Valley or on the Pacific Coast. Seasonal variation is also a factor in Oregon. Aggregate moisture reduction strategies outlined above might be difficult to implement for portable plants due to the temporary nature of their operations in any given location. Figure 10 shows precipitation by geographic region. Purple and green on the map show the areas with the greatest precipitation while the areas in yellow and orange represent the least.

Figure 10: Precipitation in Oregon by region

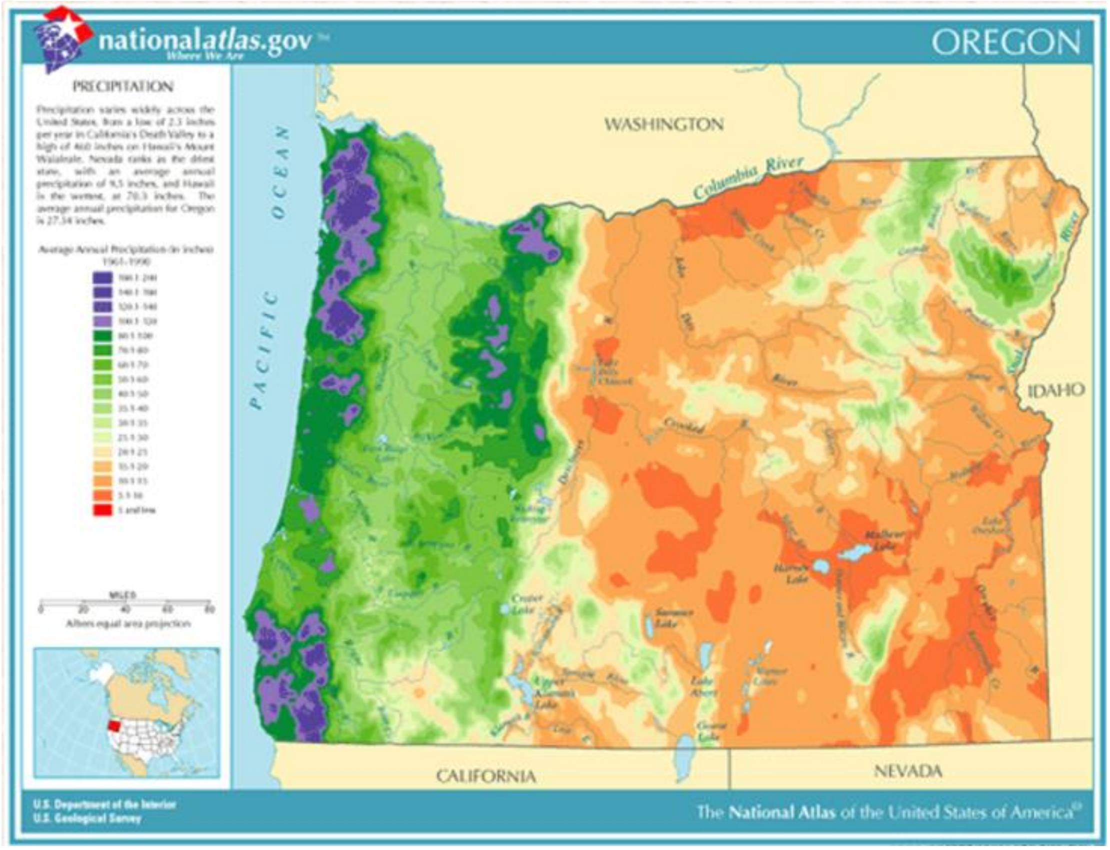
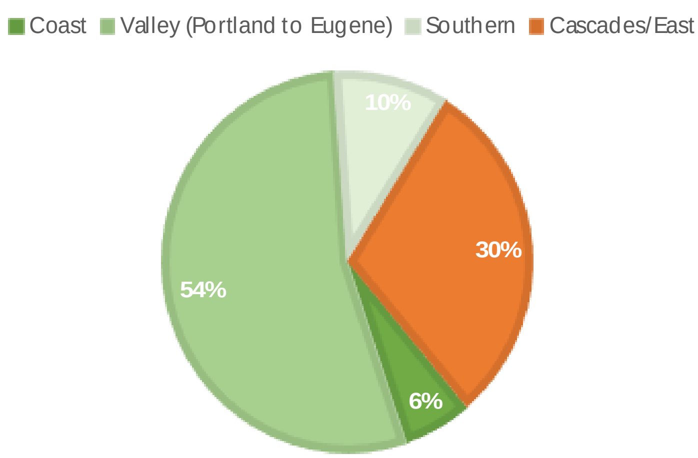


Figure 11 depicts estimated use of ACP in four regions of the state: Coast, Valley, Southern and east of the Cascades. As can be seen, roughly 70% of Oregon ACP use is in areas with average or above average annual precipitation. ACP plants in areas with greatest precipitation are the areas where moisture control will result in the greatest opportunities for fuel use and GHG emission reductions.

Figure 11: ACP use by Oregon region



Costs

Costs associated with this action include installation of permanent structures and paving underneath stockpiles. Permanent structures must be engineered to meet local buildings codes for wind and seismic loads, with estimated total project costs at or above $100,000.[95] The size of stockpiles will vary from site to site, ranging from 1,000 to 20,000+ short tons with any given plant having between three and ten piles, even more in some cases. Costs will vary significantly depending on site-specific conditions. Once implemented, the practices should have minimal operating expenses and will save roughly 10% of fuel or electricity costs for every 1% of moisture reduction and an increase in production. Lastly, there might be opportunities to work with ETO, or directly with utilities to identify potential financial incentives (beyond fuel savings) incentives for asphalt plants to reduce fuel and electricity use through efficiency upgrades. Plant operators should contact ETO for support in identifying opportunities and available incentives. Any plant within ETO's service territory that uses natural gas is likely eligible to receive incentives.[96]

Lifecycle Considerations

- Energy efficiency upgrades, like moisture management techniques, typically have lifespans much longer than a single year, so these improvements will provide benefits well into the future.
- Avoided fuel use provides reduced emissions at the tailpipe as well as upstream emission for fuel production.

GHG Benefit and Cost Scaling

The following estimates are provided to illustrate a sense-of-scale for emission reductions. Note: baseline energy use conditions at all asphalt plants that serve ODOT are unknown. As previously shown, roughly 37% of ACP emissions are generated at the plant during production. ODOT's total annual average emissions from ACP production is about 65,000 MT CO_2e. If plant emissions equal 37% of total, 24,000 MT CO_2e can be attributed to the production of ACP for ODOT.

If all ACP plants that contract with ODOT participated in the EnergyStar Challenge for Industry (10% reduction over five years), the reduction potential at the end of year five is estimated at 2,400 MT CO2e/year. Research conducted for this project found some of ODOT's vendors have already participated in the EnergyStar program, so a reasonable range of potential reductions for this practices is estimated at 1,000 – 3,000 MT CO2e per year (again, measured at year five after successfully completing the challenge).

Co-Benefits

- Energy cost savings
- Air quality improvements beyond GHG emissions from reduced fuel use and tailpipe emissions

95 Email exchange with staff at Asphlatpavement.org.
96 For an Energy Trust of Oregon service territory map visit https://www.energytrust.org/wp-content/uploads/2016/11/GEN_ServiceTerritoryMap.pdf

Asphalt Plant Renewable Fuels and Energy

ACP, as with all highway construction material production, requires a considerable amount of energy to produce. The asphalt binder needs to be heated to reduce viscosity and adequately bind to aggregate. And the particles making up the aggregate also need to be heated to dry out moisture. This best practice recommendation focuses on the fuel used at production plants in Oregon to make ACP and discusses opportunities for alternative fuels that could lower GHG emissions.

The alternative practices discussed below support mobile asphalt plants to make the switch from RFO to renewable diesel or renewable propane, and support fixed plants in making the switch from natural gas to renewable natural gas and/or renewable hydrogen. Depending on plant operations and current fuel and energy use, the following fuels may represent GHG emission reductions.

Renewable Diesel (or Biodiesel) for Portable Plants to Replace RFO

Substitution of lower-lifecycle climate impact fuels (specifically renewable diesel and biodiesel products) for fossil diesel or RFO, represents a significant opportunity to reduce the climate impact of diesel equipment without negatively impacting operations or the quality of services provided. While renewable diesel is considered a drop-in fuel, initial testing in diesel equipment used in asphalt production is likely needed to fully evaluate operational viability. It is presumed that switching to renewable or biodiesel is likely to only require the cleaning of equipment, replacement of burner tips and modification of flow controls to get the heat rate to perform according to the need. And, it's important to note, any fuel switch would likely require these updates (not just a switch to diesel). Even with these minor upgrades, using biodiesel or renewable diesel is a commercially viable way to reduce GHG emissions from ACP production at portable plants.

Renewable Propane for Portable Plants and Fixed Plants

Renewable propane offers a drop-in fuel solution for fossil-fuel propane and is a byproduct of renewable diesel production. Like renewable diesel, renewable propane can be produced with a variety of feedstock materials (used cooking oil and/or animal fats). Renewable propane can substitute 100% of fossil propane where and when there is adequate supply.

Renewable Natural Gas for Fixed Plants

As previously explained, RNG is produced during the decomposition of organic waste materials in landfills, wastewater treatment plants, and dairy operations. Acquiring a supply of RNG requires that a facility is located near a source of RNG. Alternatively, Oregon natural gas utilities, specifically NWN, is planning to offer a 4% RNG retail product beginning in 2022. Subject matter experts anticipate RNG will ultimately replace 15-20% of total natural gas sold in Oregon, if every source is captured and injected to the existing natural gas pipeline.

Renewable Hydrogen for Fixed Plants

Hydrogen is an excellent heat-producing fuel that produces only water as the byproduct of combustion. Hydrogen is the original fuel for gas lamp districts and was later replaced with methane (i.e., natural gas). Hydrogen can be made in low-carbon ways by using electrolysis of water to separate hydrogen atoms from oxygen atoms. This process can be powered by renewable electricity - "green hydrogen" - and could be developed to scale to meet all the thermal needs of industry. However, progress for the infrastructure for hydrogen production is in the early stages of development. While the technology exists and performs as needed, a massive scaling of technology is required to deliver the fuel needed for the current load of natural gas.

In the future, hydrogen could be produced at an end-user facility where electricity and water connections allow a local plant to produce its own fuel onsite for immediate use. Or, more likely in the near term, production of hydrogen would occur at a standalone facility and then be injected into a natural gas pipeline. When injected into a pipeline, hydrogen is generally thought to be usable up to 15% in traditional natural gas systems. At some point, the entire gas delivery system will need to be upgraded for hydrogen to completely replace natural gas. Further, operating plants will need to replace their burners and commission their systems to deliver the right amount of heat.

Real World Examples

- Malarkey Roofing Company uses bio-digester gas from Portland Bureau of Environmental Services Columbia Boulevard wastewater treatment plant.[97] The private business can utilize up to 25% of the biogas fuel produced at the wastewater facility, which powers a historical average of 67% of the roofing manufacturing facility.

Current Conditions

As described previously, ODOT purchases between 1 million and 1.9 million short tons of ACP annually. Between FY 2016-19, construction projects used an average of 900,000 short tons annually, while maintenance used an average of 400,000 short tons. ODOT reports using between 20 – 30% RAP in all mixes.

Within Oregon, total ACP tonnage produced is estimated at an average of 3.4 million tons annually (2018-2020). The majority (85 – 90%) is produced at stationary plants fueled by natural gas, while the remainder (10 – 15%) is produced at portable plants fueled by RFO. Production by portable plants is highly variable between years, as is use of ACP by regions in Oregon.

GHG Inventory Results

Estimated GHG emissions from the production of asphalt pavement used in ODOT projects ranged between 54,000 and 72,000 MT CO_2e annually during FY 2016-19. The four-year average was 65,000 MT CO2e. This estimate is more accurate than other states due to Oregon vendors currently leading the nation in available EPDs for ACPs. Computing averages of available EPDs results in an average emission factor of 47.5 kg CO_2e/short ton (with a range of 43.6 – 51.4). Asphalt *mixing* plant emissions are predominately from fuel combustion for heating, which represent 37% of the total production GHGs, or between 20,000 – 26,000 MT CO2e for ODOT projects.

[97] For details visit https://www.portlandoregon.gov/bes/article/500421

Other Alternatives

- Participation in EnergyStar for Industry Challenge to reduce total fuel needs.
- Onsite moisture management or other actions to increase energy efficiency.
- Renewable hydrogen produced with 100% renewable electricity. Use of this fuel may well become best practice in the mid- to long-term (5-15 years) for industrial combustion needs, but does not offer an immediate, commercially available solution like the other renewable fuels and renewable electricity, without developing onsite hydrogen production to serve onsite consumption.

Market Study

Availability and Access

Renewable Diesel

The near-term barrier to increasing renewable diesel use is limited production capacity domestically, and, therefore, limited supply volumes. It is understood that additional supply of renewable diesel will be available in the market over time, but it will likely take another two to five years to see additional supply come to fruition. A second related challenge is that renewable diesel is not consistently available throughout Oregon and, specifically, is not available at card lock fuel stations. To improve distribution, a minimum purchase volume (100,000 gallons annually) is typically required to support card lock operators investing in the addition capital infrastructure. Supplying this fuel via card locks would allow for greater access to smaller jurisdictions and other small-scale private business uses.

Renewable Propane

Blue Star Gas has informed ODOT they have renewable propane available for use. Their supply comes from Renewable Energy Group (REG) in Louisiana and is transported via rail to Blue Star Gas terminals in Oregon and California. Blue Star Gas reports no minimum purchase amount required to provide renewable propane as a transportation fuel. Blue Star's renewable propane is currently available at locations in western Oregon and the supplier is open to discussing eastern Oregon locations as needed. As of this writing, it is unclear if renewable propane supply is available to serve stationary needs, or only the transportation market.

Renewable Natural Gas

Available supply of RNG has typically gone toward the mobile fuel market to capture the significant financial incentives available as part of the Clean Fuels Program and California's Low-Carbon Fuel Standard. However, as part of interviews conducted for this project, NWN shared that as early as 2022 they anticipate offering a 4% RNG product option for stationary applications. Dairies, landfills, or wastewater treatment facilities represent existing RNG production options that provide other contract options for RNG in the marketplace, provided facilities are co-located with these sources.

Renewable Hydrogen

A few producers are organizing to make hydrogen available for public sale. Douglas County Public Utility District in Washington State is the farthest along toward that goal. Eugene Water and Electric Board

(EWEB) has also expressed interest in making renewable hydrogen from their hydroelectric dams. At this time, no renewable hydrogen is available from local sources in the Pacific Northwest, but supply is anticipated to be available within five to fifteen years.

Renewable Electricity

Oregon investor-owned utilities, PGE and Pacific Power, offer a variety of renewable electricity programs for their customers. Some of these programs offer anytime enrollment and no contracts, while others – like community solar programs – have limited, open enrollment periods and require minimum contract periods. Third-party brokers also offer RECs from renewable electricity typically generated from more distant, often out-of-state projects.

Costs

During industry interviews conducted for this project, costs referenced included the following:

Renewable Diesel

- The fuel itself is cost neutral for locations near Portland and the Willamette Valley (utilizing Clean Fuel Program credits); additional distribution charges apply east of the Cascades. At present, distribution charges range from $0.20 per gallon (truck and trailer delivery) to $0.39 per gallon (tank wagon delivery). These charges are anticipated to decline as the renewable diesel distribution system expands in 2022 or as the fuel becomes the default diesel used in Oregon.
- Additional fuel tanks ($10 - $15k per tank).
- Replacement burner tip ($1k per replacement).

Renewable Propane

- Pricing is reported to be close to the cost of traditional propane (utilizing Clean Fuel Program credits). Prices reported at the time of this report are $1.90 per gallon equivalent.[98] Renewable propane pricing is reported as volume-dependent; to provide an accurate price quote, a better understanding of annual fuel use is required. At this time, it is unclear how per gallon prices may change for use in portable asphalt plants and whether that fuel use falls under the Clean Fuels Program. Without the CFP credit, market prices for propane (as of January 2021) are $2.85 per gallon.

Renewable Natural Gas

- RNG is not yet readily available in the stationary fuels market-place and therefore pricing information is not publicly available. Fossil natural gas prices (as of January 2021) are $2.19 per gallon of diesel equivalent.[99]

[98] Price provided by an Oregon fuel supplier with available supply of renewable diesel.
[99] Clean Cities Alternative Fuel Report (Jan 2021). Online at https://afdc.energy.gov/files/u/publication/alternative_fuel_price_report_january_2021.pdf

Renewable Electricity

- Renewable electricity price premiums vary with utility and program option and range between a $0.001 and $0.008 cents per kilo-watt hour (kWh) over average grid electricity.

Making the Transition

- The largest GHG reduction opportunity related to mobile ACP plant fuel switching, as determined by this project's advisory group, is use of biodiesel or renewable diesel as a substitute for RFO. RFO represents the most carbon-intense fuel currently in use by Oregon asphalt producers.
- Higher biodiesel blends are an option, but there are concerns about cold weather use.
- Stationary asphalt plants in Oregon operate using natural gas. Infrastructure investments have already been made and will be difficult to leave stranded. Plants using natural gas should focus on energy efficiency and reevaluate renewable fuel supply options as RNG and renewable hydrogen become available in the Oregon marketplace. These plants should also consider buying verified carbon offsets to reduce the emissions from the fuel until that supply becomes available.

Lifecycle Considerations

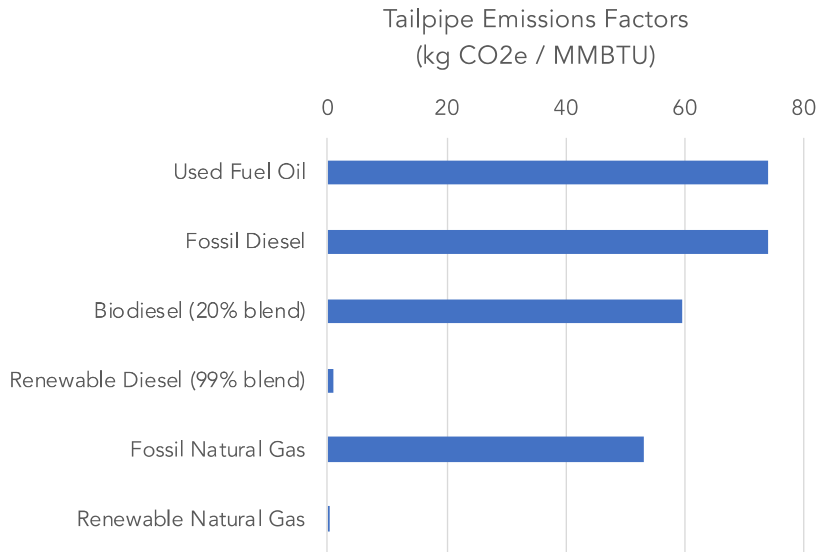
GHG pollution from tailpipes is often the focus when considering climate impacts from fuel combustion. However, there are also GHG emissions from the production of fuels (i.e., embodied carbon). Biofuels offer significant GHG reductions at the tailpipe, but commonly have greater impacts than fossil fuels during production. This is because the most common feedstock for biofuels are agricultural crops, such as soybeans in renewable diesel. Ideally, biofuels are produced to the largest extent possible with "waste" materials such as used cooking oil or tallow. Use of waste material feedstock for renewable diesel offers some of the lowest impact fuels available on the market. Unfortunately, waste materials are not available in the quantities required to produce the volumes of diesel fuels currently consumed, which is why crop feedstocks are used for production.

GHG Benefits and Cost Scaling

Figure 10 compares tailpipe GHG emissions (kg CO2e / MMBTU) for natural gas, RFO, biodiesel (20% blend) and renewable diesel (99% blend).[100] RFO is the most GHG-intense fuel of the group per unit of heat. If Oregon ACP producers were to replace 100% of fossil fuel use with 100% renewable fuels, reductions are estimated between 20,000 – 26,000 MT CO_2e per year. The range represents unknowns related to the precise types of fuels being used (natural gas vs. RFO) and the annual fluctuation inherent with ODOT's procurement of ACP (i.e., increased program funding means more ACP is used). If portable ACP producers were to switch from RFO to biodiesel (B20 blend), emissions would be reduced by 1,000 MT CO_2e annually. If these producers were to switch to a 100% biodiesel or renewable diesel product, emissions reductions are estimated to be about 5,000 MT CO_2e per year.

[100] Values on the graphic are from EPA Greenhouse Gas Emissions Factors for Greenhouse Gas Inventories (April 2021). Biogenic CO2 from renewable fuels excluded from reporting.

Figure 10: Comparison of tailpipe emissions factors



Cost Scaling

The following table (**Error! Reference source not found.**13) summarizes fuel costs, estimated GHG reductions, and provides cost impacts per unit of GHG reductions, using a marginal cost difference[101] between RFO and various biofuel blends. Note the costs per gallon are assumed to be at market prices and do not receive the Clean Fuels Program financial incentives for use of biofuels. Recycled fuel oil prices are not readily available; therefore, RFO is used as a proxy to represent low value petroleum products for illustration purposes. Cost impacts below focus on a substitution of bio or renewable diesel for RFO. Prices for renewable natural gas for stationary uses is currently unavailable and therefore that substitution is not included.

Note: Prices do not include CFP credits, and without such a financial incentive, renewable fuel substitution for plant operators will be expensive.

[101] The marginal cost difference is equal to alternative fuel ($ / gallon) – baseline RFO ($ / gallon) = additional cost required to procure alternative fuel and realize GHG reductions. In other words, it is the additional cost required to purchase alternative fuels beyond what is currently paid for RFO.

Table 13 shows market prices for biofuel (without CFP credits) are significantly higher than low-value petroleum-based fuels in the marketplace and therefore would represent high-cost mitigation for asphalt plant operators compared to their current operations and fuel use. [102]

Table 13: Comparison of fuel costs and GHG reductions

Fuel Type	U.S. Average Cost per Gallon or Equivalent (prices as of Jan 2021)	Cost per Million BTU ($ / MMBTU)	Cost Increase vs RFO per Million BTU	GHG Reduced vs RFO (kg CO2e / MMBTU)	Cost per MT CO2e Reduced ($ / MT)
Residual Fuel Oil (#5/6)	$1.40	$9.65	N/A (Baseline)	N/A (Baseline)	N/A (Baseline)
Biodiesel (20% blend)	$2.47	$17.25	$7.60	-14.7	$520
Biodiesel (100% blend)	$3.49	$26.56	$16.91	-73.4	$230
Renewable Diesel (R100)	$3.20	$24.61	$14.96	-73.4	$200

Residual Fuel Oil Price: https://www.eia.gov/dnav/pet/pet_pri_refoth_a_EPPR_PWG_dpgal_a.htm
Biofuels Prices: Clean Cities Alternative Fuel Price Report (Jan 2021).

Pavement Lifecycle Asset Management

Pavement design and management is a complicated and context-specific profession. The following text is largely taken from content provided by ODOT subject matter experts and interviews with researchers and practitioners of pavement management.[103] ODOT's pavement engineers provide this description of their program's development:[104]

> *[ODOT] historically has done well managing Oregon's roads through an active Pavements program. A centralized Pavement Services Unit utilizing close integration of Pavement Management, Design, and Construction and Materials has paid dividends from an asset management perspective – with Oregon ranking 10th in the most recent highway condition rating by the US Bureau of Transportation Statistics at a pavement funding level relatively low compared to other states. (https://www.bts.gov/road-condition)*
>
> *ODOT has been aggressive in incentivizing asphalt pavements that are both high in recycled content and long-lasting. Through sound management practices over decades, the current condition of Oregon's highway network makes pavement reconstruction rare. This allows less intensive rehabilitation projects to be prevalent. Requiring lower energy usage during construction may be feasible in certain situations,*

[102] https://afdc.energy.gov/files/u/publication/alternative_fuel_price_report_january_2021.pdf
[103] Good Company relays these suggestions humbly and with the understanding these ideas are not an attempt to shore up weaknesses, rather it is offered to support the program advancing to another level of environmental efficiency.
[104] ODOT Pavements Approach (2021) from Chris Duman, PE, State Pavement Quality & Materials Engineer ODOT, et al

provided it is not accompanied by a reduction in pavement quality which would lead to increased cost and GHG emissions over time. Currently, ODOT is conducting internal testing and validation of the research ODOT has funded promoting balanced mix design. As new processes are tested and implemented over the next 2-5 years, it is expected to both increase pavement life and increase recycled contents. Both items will provide tangible and measurable results towards reducing overall GHG emissions.

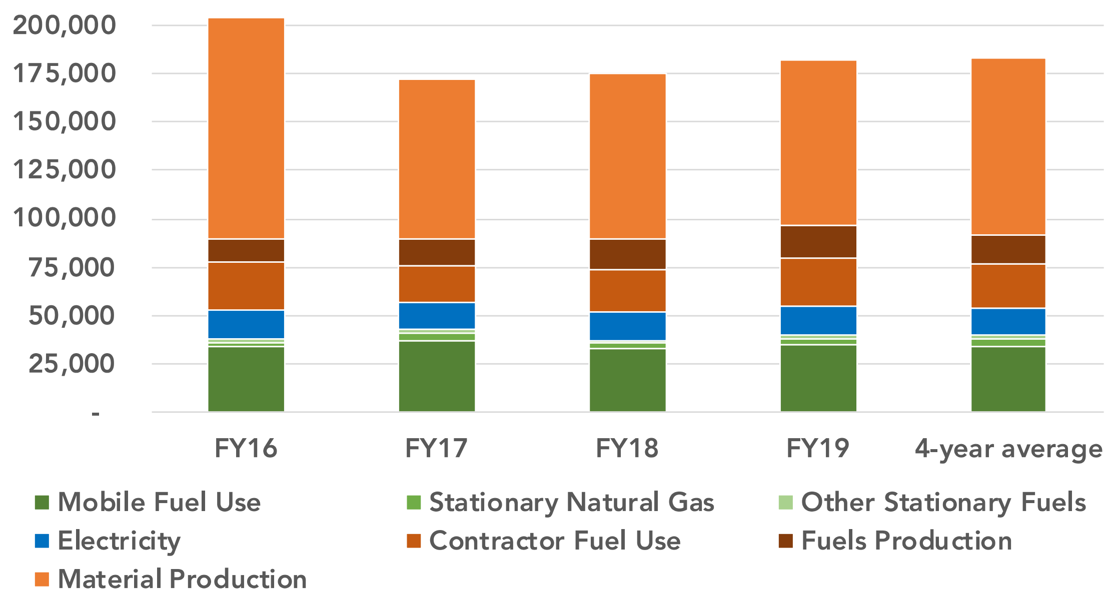
Scaling Pavement Emissions and GHG Inventory Highlights

Figure 13, below, is meant to provide a *sense-of-scale comparison* of prioritizing pavement preservation (smooth highways), versus reducing the footprint from embodied (manufacturing) emissions. Figure 13 compares driver emissions from fuel combustion while traveling on Oregon's highway system (grey) to the estimated climate benefit from Oregon's pavement lifecycle optimization and management program (orange) to ODOT's average annual operational GHG emissions (blue). Both pavement preservation (smoothness) and durability are priorities for GHG benefits. The more durable the surface is, the lower per year embodied emissions are per lane-mile. Life cycle management of pavement through timely preservation treatments benefits smoothness and durability and reduces the emissions over time.

Figure 11: Scale of emissions comparison

Figure 12 takes a closer look at ODOT's Operational Emissions (blue box in **Error! Reference source not found.**). Note: after smoothness and durability, the embodied emissions in producing pavement materials and the fuel use associated with installing it are a substantial part of the operational emissions.

Figure 12: ODOT's emissions (MT CO_2e) by fiscal year with 4-year average



Best Practice

Designing pavement roads for smoothness, density and durability generally moves any pavement type toward a lower-carbon future. Subject matter experts interviewed for this project encouraged ODOT to maintain these base principles. Academic professors and industry representatives spoke highly of ODOT's data quality, condition assessments, and encouraged a review of all pavement life cycle - by regions - to determine which has the lowest life cycle impacts. The way to measure life cycle impacts requires knowing which pavement design had the lowest cost and GHGs per service year, per lane mile. It is understood ODOT's records are detailed and individual segments have been optimized, but a question remains: *Of all the optimized individual segments, which have proven themselves to be the best in the geographic, traffic, aggregate supply and weather conditions per year of use?*

Asphalt Concrete Pavement Life Cycle

ODOT provides the following summary of existing approaches, policy and research regarding asphalt concrete pavement lifecycle:

> *ODOT has experimented with even higher Recycled Asphalt Pavement (RAP) contents, and will continue to in the future. In addition to increased recycled product, innovations in materials and construction offer opportunity for reduced greenhouse gas emissions (GHG). However, there is significant risk in rushing to adopt new technologies – a single project failure can offset the GHG emissions and life cycle cost savings of multiple successes. For these reasons, ODOT is in the process of simple, but significant changes in our asphalt concrete pavement specifications. Requiring and incentivizing better construction practices will increase pavement service life. Looking at investment costs on a life cycle or annual cost basis as opposed to simply looking at construction costs is beneficial from a monetary and also GHG perspective. This has been a multi-year effort, and one that appears to be a success.*

The use of RAP has not been without challenges – modifications to ODOT's design process and materials used have been necessary to mitigate some of the negative effects of using high amounts of recycled product. One example is the use of polymer-modified asphalt (PMA). PMA has been used on high–volume roadways almost exclusively since 2008. This is an example of ODOT using a more expensive and energy intensive product. However, these increased costs are a justified investment when analyzed over the life of the pavement. Slight increased cost and energy use is expected, but has been shown to increase pavement life by 2-10 years.

Increasing the amount of RAP is of particular interest, with much research funded by ODOT and also nationally on how to best accomplish this without sacrificing quality and longevity. Using high RAP contents without requiring other changes produces a brittle asphalt mixture, prone to cracking with a reduction in service life. Asphalt pavements fail by two mechanisms - cracking and rutting. Requiring mixtures that are both crack and rut resistant requires a balanced approach, which is the main principle of Balanced Mix Design (BMD). The research funded by ODOT has been focused on creating test parameters to quantify asphalt mixtures as both crack and rut resistant. The ability to test a mixture in a laboratory prior to placement enables innovation by producers. This innovative process allows the introduction of new technologies, and also an increased usage of recycled products - primarily RAP. ODOT is progressing towards pilot projects using BMD in an upcoming research project.

Contractors use RAP for paving ODOT highways because of economic benefits of reusing that material. This is due to the structure of our specifications, and has resulted in RAP contents almost always being at the maximum allowed. This is caused by ODOT paying the same amount for mixtures containing asphalt as those without. As we embrace new technologies and processes, it is reasonable to believe that increased RAP contents may be used – if they can be used without detriment to the final product. New products, additives and construction processes may be used – and reduction in overall costs to paving contractors will almost always result in lower GHG emissions.

...

Also of significance is the general overall thickness of the pavements managed by ODOT. The thick existing pavements are the product of conservative designs and relatively low asphalt pavement costs in the 1900s (author's note - before 2000). This has and will continue to allow extensive use of chip seals and thinner pavement treatments while avoiding full-depth reconstruction where possible. In addition to high construction costs, reconstructing roadways is an extremely energy intensive process.

Asphalt Concrete Best Practices

- First, continue to reward smoothness and density in construction specifications to reduce the emissions coming from vehicles due to pavement roughness. Emissions reductions achieved by paving rough roads are estimated to be 3-4% over poorly maintained pavement. This 3-4% represents a rough reduction in fuel use of 88,000,000 gallons of gasoline and diesel reduced by the users of the system (based on 2.2 billion gallons consumed in Oregon each year).[105] At a cost of $2.50 per gallon this represents a savings to the people of Oregon of $220,000,000 and may justify the additional investment in maintaining more lane miles per year or to provide additional oversight during installation.
- Second, optimize for durability. Use the pavement management system to track how specification changes impact service life across Oregon's varied climates.

[105] Per Oregon 2022 Fuel Supply Forecast. 1.565.3 million gallons of gasoline and 687 million gallons for a total of 2,252 Visit online for details https://www.oregon.gov/das/OEA/Documents/Clean%20Fuels%20Forecast%202022.pdf

- Greater quality control during installation to ensure proper tack layering to prevent delamination of layers.
- Studded tires damage pavement - FHWA rough estimates were $20 to $30 million in repairs per year and Oregon estimates range from $10 to $40 million per year.
- RAP reduces the overall need for aggregate but can have a shorter lifespan compared to a mix with 100% virgin asphalt. The balance point of maximum recycled content that still has a normal life span is not yet known. Rejuvenator technologies (chemical additives) allow for higher recycled asphalt contents that can be used during production without compromising the long-term performance of the pavement.
- Recycled asphalt shingles often fouls other binders and have been ruled out by most DOTs.
- New research is considering the use of hard to recycle plastics as a binder. Proceed with caution on researching this as the most commonly cited plastics for ACP use also are the most commonly recycled and have very high market value. Research should focus on the plastics that have zero or negative value and avoid those with high paying existing markets such as low density polyethylene. Also, some initial research indicated that the plastics may make asphalt brittle and subject to cracking.
- Warm mix reduces emissions by a negligible amount, but may have some durability benefits.
- Separate chip seal accounting from ACP accounting.

Literature to Consider:

1. **Demonstration to Advance New Pavement Technologies Pooled Fund**
   A $10,000 contribution from a DOT will be used to provide up to $250,000 from FHWA, including up to 100 hours of technical assistance and resources for developing case study reports and videos for each selected demonstration project.[106]
2. **Mechanistic-Empirical Simulations and Life Cycle Cost Analysis to Determine the Cost and Performance Effectiveness of Asphalt Mixtures Containing Recycled Materials**
   Life cycle cost analysis of the cost benefits of using binder grade bumping and high binder content in Oregon asphalt mixtures using laboratory derived mechanistic-empirical models.[107]
3. **Predicting Excess Vehicle Fuel Use Due to Pavement Structural Response using Field Test Results and Finite Element Modelling**
   In this study, a comprehensive numerical modelling factorial is developed to determine the response of pavement structures under a wide range of contributing factors with modelling of asphalt pavement energy dissipation due to the viscoelastic structural response.[108]

Portland Cement Concrete Pavement Life Cycle

ODOT provides the following summary of existing approaches, policy and research regarding concrete pavement lifecycle:

> *Decisions made long ago have positioned the State's highway systems for long life with less intensive pavement treatments. Oregon was an early adopter of continuously reinforced concrete pavement (CRCP), primarily on interstate highways. While expensive to construct, longer than expected performance has been the norm. In addition, CRCP has allowed thin asphalt overlays as a preservation*

[106] https://www.pooledfund.org/Details/Solicitation/1542
[107] https://www.researchgate.net/publication/325371016_Mechanistic-Empirical_Simulations_and_Life_Cycle_Cost_Analysis_to_Determine_the_Cost_and_Performance_Effectiveness_of_Asphalt_Mixtures_Containing_Recycled_Materials
[108] https://www.researchgate.net/publication/335439567_Predicting_excess_vehicle_fuel_use_due_to_pavement_structural_response_using_field_test_results_and_finite_element_modelling

treatment, economically extending pavements for additional decades. This is not a viable option for jointed concrete pavement, a much more common asset among other state highway agencies (SHA) due to lower initial construction costs – but requiring more costly preservation.

In the last 20 years, ODOT has funded multiple studies through our Research Section specific to pavement materials. The findings of these research projects have helped to shape our specifications, and will continue to guide us as we move forward. The more recent of these projects have also attempted to compare GHG benefits or detractors of potential changes to pavement materials.

Portland Cement Concrete Best Practices

- Further develop ODOT's performance based Standard Specifications recognizing regional differences when approving concrete mix designs.[109]
- Do not specify a specific alternate cement as it may require aggregate from farther away and undo the GHG benefits from additional transport.
- Use EPDs to understand the GHG potential and impact of materials used in ODOT's concrete mix designs as well as guide future specification changes.
- Join the National Concrete Consortium and leverage the lessons learned of other DOTs.
- Join Innovondi Group with 58 global cement and concrete producers, including Oregon State University and Princeton University to see latest advances. Leverage OSU's best-in-class concrete research group.

Literature to Consider:

1. **Concrete Solutions to Climate Change: How Local Policy Can Promote Sustainable Construction Activities**
   Outline of the climate impacts of concrete and the development and use of low-carbon concrete, and discussion local policies related to its use.[110]
2. **Concrete Performance Engineered Mixtures**
   Overview of PEM project and different testing measures.[111]

[109] See AASHTO PP 84 as well as FHWA's relevant guidance: https://www.fhwa.dot.gov/pavement/pubs/013686.pdf.
[110] https://rockinst.org/issue-area/concrete-solutions-to-climate-change/
[111] https://cptechcenter.org/performance-engineered-mixtures-pem/

Conclusions and Next Steps

ODOT's first GHG inventory was an important step to reduce the agency's carbon footprint. GHG emissions from the materials and fuels used to construct and maintain the state's highway system were described by source, scope and intensity. Mitigation opportunities, potential, and tradeoffs were vetted by subject matter experts and advisory group members. While this initial GHG inventory was not comprehensive due to limited data availability, significant improvements were made simply through awareness. The agency now has a roadmap to reduce operational GHG emissions.

Throughout this project, many emission reduction practices were highlighted that ODOT is doing well: use of renewable diesel and allowance of alternative cements among others. The agency will continue to share these achievements where and when appropriate. This project also identified opportunities for improvement, to name a few: increase the use of renewable fuels in both stationary buildings and mobile equipment, update internal data systems to monitor climate impacts from material use, and support ODOT contractors to reduce emissions at the plant and during installation. ODOT will utilize this report to implement forthcoming work plans on specific actions to reduce emissions. Furthermore, this project helped create a path for future inventories that will be necessary to confirm progress toward the agency's climate goals.