Modeling Expected Air Quality Impacts of Oregon's Proposed Expanded Clean Fuels Program

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Glossary

BAU	business as usual
CI	carbon intensity
CFP	Clean Fuels Program
CNG	compressed natural gas
EC	elemental carbon
ENSO	El Nino Southern Oscillation
DEQ	Department of Environmental Quality
DPF	diesel particulate filter
FCV	fuel cell vehicle
FFV	flexible fuel vehicle
GHG	greenhouse gas
HD	heavy-duty
HPMS	Highway Performance Monitoring System
ICE	internal combustion engine
LEV	low-emission vehicle
MD	medium-duty
NEI	National Emissions Inventory
NOx	nitric oxide
OC	organic carbon
PM	particulate matter
RD	renewable diesel
SCC	Source Classification Code
THC	total hydrocarbons
UCD-CIT	University of California, Davis–California Institute of Technology

VMT	vehicle miles traveled
VOC	volatile organic compound
WRF	Weather Research and Forecast
ZEV	zero-emission vehicle

1. Introduction

Oregon has set ambitious greenhouse gas (GHG) reduction targets and adopted a number of policies to put the state onto a trajectory to achieve them. Reducing emissions from the transportation sector was identified as a critical need, since it accounted for 38% of Oregon's total GHG emissions in 2018, the last year for which full data is available.[1] To reduce transportation emissions, the state has adopted a number of policies, including California's Low-Emission Vehicle (LEV) and Zero-Emission Vehicle (ZEV) policies, as well [2]as the Clean Fuels Program (CFP). Adopted in 2009 and first implemented in 2016, the Clean Fuels Program sets a declining target for the average life cycle carbon intensity (CI), measured in grams of carbon dioxide-equivalent emissions per megajoule of fuel delivered to a vehicle (g CO_2e/MJ). Producers or importers of conventional vehicle fuels must track and report the total volume of fuel they provide and are assessed deficits based on the mass of GHG emissions emitted in excess of that year's target for their volume of fuel. Low-carbon fuel producers or importers can register with the regulator, the Department of Environmental Quality (DEQ), and are assigned credits based on the mass of GHG emissions below that year's target for their volume of fuel. Fuel producers must reduce the carbon intensity of their fuels to meet the target, or acquire sufficient credits to cancel out their deficits. This creates a market for CFP credits and the revenue obtained by low-carbon fuel producers from the sale of their credits helps offset the typically higher costs of producing low-carbon fuels. To date, Oregon's program has generated over 4.6 million credits, against 3.8 million deficits, and the share of non-petroleum fuels in the fuel pool has risen from approximately 7% to over 9%. [3]

In 2020, Governor Kate Brown issued Executive Order 20-04, which instructed state agencies to adopt a number of policies designed to significantly reduce the state's GHG emissions. Among them, was an extension of the CFP with targets of at least 20% in 2030 and 25% in 2035. The Oregon DEQ began work to extend the CFP and as part of the rulemaking process sought to better understand the impacts of an expanded CFP on air quality and public health. There is a strong body of evidence in scientific literature confirming net improvements in air quality associated with a transition from petroleum-fueled vehicles to non-petroleum alternatives. [4], [5] Assessment of public health impacts from policy-driven air quality improvements has historically been conducted at geographically aggregated scales, which can overlook impacts on certain disadvantaged communities. Accurate assessment of both the aggregate health impacts, as well as the distribution of such impacts, requires a more granular and spatially-explicit approach to air quality modeling and health impact assessment. [6]–[8]

To address this need, DEQ contracted with Dr. Colin Murphy at the UC Davis Policy Institute for Energy, Environment, and the Economy and Professor Michael Kleeman at the UC Davis Department of Civil and Environmental Engineering to study the anticipated impacts on air quality from the proposed displacement of petroleum by low-carbon alternative fuels. Based on compliance scenarios developed by ICF in consultation with DEQ, UC Davis generated state-wide estimates of vehicle activity and emissions using the EPA MOVES model. [9] The emissions from those scenarios were then combined with existing estimates of future non-vehicle emissions from the National Emissions Inventory and used as the basis for high-resolution (4-km cells in populated areas, 24-km cells elsewhere) spatial modeling of pollutant dispersion and chemistry.[10] Health impacts were then estimated using the EPA BenMAP software package.[11]

This project is intended to develop a spatial database of both vehicle emissions via the MOVES output, and air quality impacts, for three key scenarios: the business-as-usual scenario (BAU), the Clean Fuels Program scenario (Scenario A) and the maximum ambition scenario (Scenario C). Vehicle fleet and fuel use data for these two scenarios were taken from modeling done for Oregon DEQ by ICF, and the names of those scenarios were adopted for this report in order to maintain consistency.[1] The BAU scenario reflects the continuation of current policies, but little if any policy action driving a transition towards alternative fuels. This scenario was developed by UC Davis researchers for the purpose of comparing air quality impacts in this study. Scenario A represents adoption and successful achievement of the proposed 25% CI reduction target as described in Executive Order 20-04. Scenario C evaluates the emissions and air quality impacts of setting a CFP target in excess of that described in Executive Order 20-04 and instead achieving a 37% target, which is the maximum feasible target analyzed in current CFP compliance scenario modeling conducted by ICF.[12]

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[1] In earlier versions of this work. “Scenario A” was referred to as the “CFP Scenario” and abbreviated CFP and “Scenario C” was referred to as the “CFP Max” scenario and abbreviated CFP_Max. They were subsequently re-named to align with the names used by DEQ during scenario development. Earlier versions of this report, as well as some supplementary materials, retain the older naming convention.

2. Methodology

This study is largely based on methods that have been applied to previous studies seeking to better understand the sources and behavior of atmospheric pollutants in California.[13]–[15] The primary research activities conducted in this research fall into two phases. The first is developing an on-road emissions inventory using the EPA MOVES model that reflects expected air pollutant emissions reductions from the displacement of existing fuels with lower-carbon alternatives caused by the proposed expansion of the CFP. The second phase uses the MOVES outputs to model the behavior of air pollutants in the atmosphere after they are emitted.

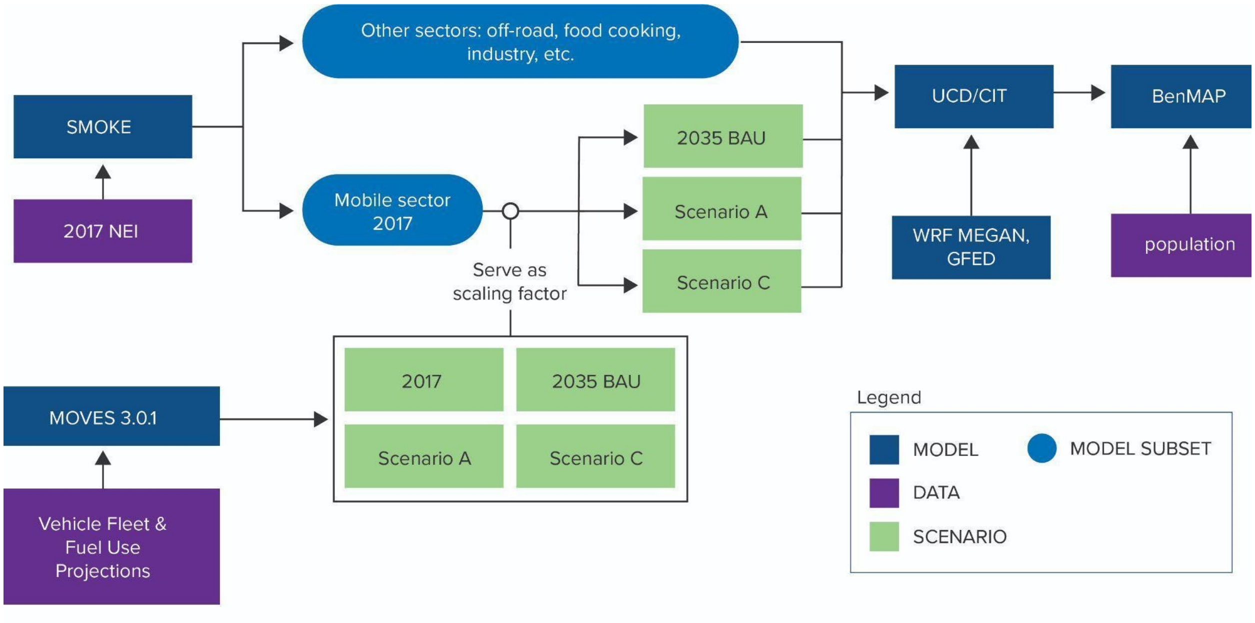


Figure 1. Model flow diagram for estimating impacts of clean fuels policy on air quality and public health

2.1 Developing the on-road emissions inventory using MOVES

Generating an emissions inventory with temporal and spatial details is very important to subsequent air quality modeling. This project will leverage the MOVES model to generate hourly county-level emissions for each of 36 counties in Oregon. Figure 2 shows the map of the 36 counties in the State of Oregon.

Figure 2. The 36 counties in the State of Oregon (Source: www.mapsofworld.com)

The basic emissions inventory is based on the U.S. EPA MOtor Vehicle Emission Simulator (MOVES) model, which is a state-of-the-science emission modeling system that can estimate emissions for on-road mobile sources at the county level for criteria air pollutants, GHGs, and air toxics.[9, p. 3] The model can also generate output for vehicle activity such as vehicle miles traveled (VMT), vehicle population, fleet mix by fuel type and vehicle class, vehicle age distribution up to 31 model years (age 0 through age 30), and so on. Specifically, this project uses MOVES3.0.1, which can generate vehicle activity and emission data for years 1990 and 1999-2060.

The base year of the project is 2017, which is also the base year of the MOVES3 model. The target future year is 2035, which is the Oregon CFP's target year. The focus of this project is to forecast criteria pollutant emissions for 2035 for the following different scenarios:

- The business-as-usual (BAU) scenario, which calibrates MOVES by using Oregon-specific forecast data and serves as the reference case;
- Scenario A, which corresponds to a 25% CFP target; and
- Scenario C, which corresponds to a 37% CFP target of Oregon.

Note that the default output of MOVES as a result of the model's built-in data is not used in this project to evaluate the impact of the proposed policy scenarios.

The estimated emissions inventory matching each scenario must capture the emissions of criteria pollutants (rather than GHGs) that can cause human health damage. The emissions inventory contains the county-level emissions for all 36 counties in Oregon, for the year 2035. The emissions correspond to a 24-hour day, for a typical weekday and a typical weekend day in each month from January through December.

2.1.1 Business-as-usual (BAU) scenario

Note that we do not use the default MOVES output with built-in data for this air quality study; instead, we calibrate the MOVES model by incorporating Oregon-specific activity forecast data such as VMT and vehicle population to better quantify Oregon's transportation emissions in the future. This calibrated MOVES output is referred to as the business-as-usual (BAU) scenario, which serves as the reference case for comparisons with the proposed policy scenarios.

The Oregon specific annual VMT for 2035 is used to replace the built-in MOVES VMT, which will affect the emissions output as emissions are usually calculated as the emission rate times the activity level (such as the VMT magnitude). The data provided by the Oregon Department of Transportation includes the annual VMT projections by county and vehicle class for 2035. For state highways the VMT data corresponds to the full 13 vehicle classes defined by Federal Highway Administration.[16] For non-state roadways, the VMT data is for the 6 Highway Performance Monitoring System (HPMS) classes. In practice, both highway and non-highway VMT projections are post-processed into HPMS categories which can work as input directly to MOVES.

However, the VMT based on HPMS reporting reflects the understanding of actual on-road traffic, regardless of the vehicle registration jurisdictions, and it is no longer consistent with the vehicle stock data generated from running the default MOVES model. Therefore, we developed a method to adjust the MOVES default population in order to project the anticipated 2035 vehicle population. Essentially, we keep the annual mileage accrual rates (in miles per year) the same and derive the BAU scenario's vehicle population by scaling the county-level default vehicle population using VMT scaling factors, i.e., the ratios of the Oregon-provided customized VMT to the default VMT. The adjusted vehicle population is another customized input to replace the built-in MOVES data for the purpose of generating reasonable emissions inventory.

Table 1 and Table 2 present comparisons of MOVES default and BAU statewide population and annual VMT (miles per year), across HPMS vehicle categories.

Table 1. Comparison of MOVES default and BAU statewide annual VMT (miles per year), across HPMS vehicle categories

HPMS category	2017 MOVES default annual VMT	2035 MOVES default annual VMT	2035 MOVES BAU annual VMT
Buses	211,700,067	279,049,379	480,542,162
Combination Trucks	2,277,812,916	2,736,839,946	3,325,363,823
Light Duty Vehicles	34,759,985,784	39,041,388,888	36,896,665,773
Motorcycles	248,204,225	279,043,612	283,714,166
Single Unit Trucks	1,441,475,638	2,183,261,523	2,479,729,882
Grand Total	38,939,178,629	44,519,583,348	43,466,015,806

Table 2. Comparison of MOVES default and BAU statewide vehicle population, across HPMS vehicle categories

HPMS category	2017 MOVES default population	2035 MOVES default population	2035 MOVES BAU population
Buses	11,270	13,672	23,469
Combination Trucks	36,337	36,508	43,953
Light Duty Vehicles	3,025,110	3,300,682	3,120,114
Motorcycles	107,356	125,073	127,166
Single Unit Trucks	115,982	159,452	181,104
Grand Total	3,296,056	3,635,385	3,495,806

2.1.2 Scenario A – The 25% Clean Fuels Program Target

Oregon DEQ provided the CFP compliance scenario in which low carbon alternative fuels and advanced technology vehicles are specified to meet a 25% CFP target, called Scenario A in this report. The compliance scenario was developed by ICF, on contract to Oregon DEQ. The scenarios were developed using modified VISION scenario tools in which vehicle population, VMT, and fuel consumption are connected by the annual VMT accrual rates and fuel economy. Scenario A reflected recent policy changes, including the adoption of the Advanced Clean Trucks Rule and updating its Low and Zero Emission Vehicle Program to be consistent with Oregon's SB 20144. Both will substantially increase the requirement for new vehicle sales to be zero-emission vehicles (ZEVs), including electric vehicles (EVs) nd plug-in hybrid electric vehicles (PHEVs).[17] Therefore, we need to alter the MOVES BAU output to create the Scenario A emissions inventory by incorporating the alternative vehicle penetration schedules and assumptions established in the Scenario A compliance scenario.

The emissions inventory is a result of the MOVES BAU emissions inventory adjusted for the impact of the alternative vehicle penetration. Starting from the BAU output that was developed earlier, we implement Scenario A's market split of vehicle-fuel technologies (such as EVs or PHEVs, among others) at the very detailed level including but not limited to the vehicle model-year level. As the base year is 2017, the incorporation processing starts with year 2018 data on new vehicle market shares, including all vehicle categories in the compliance scenario. Tables 3–6 summarize a set of the new vehicle market penetration trajectory by vehicle category to meet a 25% CFP target.

Table 3. New car sales market share in the Scenario A compliance scenario

Year	Gasoline	Electric	FFV (ethanol)	Diesel	CNG
2018	94.4%	2.3%	1.8%	0.2%	0.0%
2019	90.5%	6.1%	2.3%	0.1%	0.0%
2020	81.5%	13.3%	2.3%	0.1%	0.0%
2021	78.0%	16.2%	2.3%	0.1%	0.0%
2022	74.8%	18.9%	2.3%	0.1%	0.0%
2023	71.7%	21.4%	2.3%	0.1%	0.0%
2024	68.9%	23.7%	2.3%	0.1%	0.0%
2025	66.2%	26.0%	2.3%	0.1%	0.0%
2026	59.4%	31.6%	2.3%	0.1%	0.0%
2027	53.0%	36.9%	2.3%	0.1%	0.0%
2028	47.0%	41.9%	2.3%	0.1%	0.0%
2029	41.3%	46.6%	2.3%	0.1%	0.0%
2030	35.6%	51.3%	2.3%	0.1%	0.0%
2031	29.9%	56.0%	2.3%	0.1%	0.0%
2032	24.7%	60.3%	2.3%	0.1%	0.0%
2033	22.5%	64.2%	0.0%	0.0%	0.0%
2034	18.2%	67.8%	0.0%	0.0%	0.0%
2035	14.2%	71.1%	0.0%	0.0%	0.0%

FFV, flexible fuel vehicle; CNG, compressed natural gas

Table 4. New light truck sales market share in Scenario A

Year	Gasoline	Electric	FFV (ethanol)	Diesel	CNG
2018	91.9%	0.3%	6.1%	1.4%	0.0%
2019	87.1%	0.3%	5.5%	6.8%	0.0%
2020	88.6%	0.9%	6.9%	2.8%	0.0%
2021	87.6%	1.4%	6.9%	2.8%	0.0%
2022	86.4%	2.0%	6.9%	2.8%	0.0%
2023	85.0%	2.7%	6.9%	2.8%	0.0%
2024	83.6%	3.5%	6.9%	2.8%	0.0%
2025	81.5%	5.4%	6.9%	2.8%	0.0%
2026	78.3%	7.4%	6.9%	2.8%	0.0%
2027	74.8%	9.5%	6.9%	2.8%	0.0%
2028	71.1%	11.9%	6.9%	2.8%	0.0%
2029	67.0%	14.4%	6.9%	2.8%	0.0%
2030	61.3%	20.5%	6.9%	2.8%	0.0%
2031	53.6%	26.0%	6.9%	2.8%	0.0%
2032	45.3%	31.8%	6.9%	2.8%	0.0%
2033	36.6%	38.0%	6.9%	2.8%	0.0%
2034	27.5%	44.5%	6.9%	2.8%	0.0%
2035	19.9%	64.0%	2.9%	0.0%	0.0%

Table 5. New class 3-6 truck sales market share in Scenario A

Year	Gasoline	Electric	FFV (ethanol)	Diesel	CNG
2018	24.9%	0.0%	12.2%	62.3%	0.6%
2019	0.9%	0.1%	0.0%	99.0%	0.0%
2020	27.5%	0.1%	6.6%	65.3%	0.4%
2021	27.5%	0.1%	6.9%	65.1%	0.4%
2022	27.8%	0.1%	6.7%	64.9%	0.4%
2023	28.1%	0.1%	6.8%	64.5%	0.4%
2024	28.6%	7.2%	6.9%	56.8%	0.4%
2025	27.9%	9.0%	7.1%	55.4%	0.4%
2026	27.2%	11.0%	7.2%	53.9%	0.4%
2027	25.3%	16.9%	7.4%	49.8%	0.4%
2028	22.7%	24.8%	7.5%	44.3%	0.4%
2029	20.2%	32.6%	7.7%	38.7%	0.4%
2030	17.5%	40.5%	8.0%	33.0%	0.4%
2031	16.0%	45.0%	8.3%	29.8%	0.4%
2032	14.5%	49.5%	8.5%	26.5%	0.4%
2033	13.0%	54.0%	8.7%	23.2%	0.4%
2034	11.4%	58.5%	9.0%	20.0%	0.4%
2035	9.9%	63.0%	9.3%	16.7%	0.4%

Table 6. New class 7 & 8 truck sales market share in Scenario A

Year	Gasoline	Electric	FFV (ethanol)	Diesel	CNG
2018	0.3%	0.0%	0.0%	99.7%	0.0%
2019	0.6%	0.1%	0.0%	97.8%	1.5%
2020	0.8%	0.0%	0.0%	98.3%	0.8%
2021	0.5%	0.0%	0.0%	97.8%	1.6%
2022	0.5%	0.0%	0.0%	97.9%	1.5%
2023	0.5%	0.0%	0.0%	98.0%	1.4%
2024	0.5%	3.7%	0.0%	94.2%	1.3%
2025	0.5%	5.2%	0.0%	92.7%	1.3%
2026	0.5%	7.4%	0.0%	90.4%	1.3%
2027	0.5%	11.1%	0.0%	86.5%	1.3%
2028	0.5%	14.8%	0.0%	82.5%	1.3%
2029	0.5%	18.5%	0.0%	78.5%	1.3%
2030	0.5%	22.2%	0.0%	74.5%	1.4%
2031	0.5%	25.9%	0.0%	70.6%	1.5%
2032	0.5%	29.6%	0.0%	66.7%	1.5%
2033	0.5%	29.6%	0.0%	66.5%	1.7%
2034	0.5%	29.6%	0.0%	66.2%	1.8%
2035	0.5%	29.6%	0.0%	66.0%	1.9%

In the car and light-truck cases, the gasoline category captures three vehicle technologies: gasoline internal combustion engine (ICE) vehicles, gasoline regular hybrids, and the gasoline equivalent of plug-in hybrids based on the VISION default eVMT share of 0.62.

In the medium-duty/heavy-duty cases, the diesel (or gasoline) category combines two vehicle technologies: diesel (or gasoline) ICE vehicles and the diesel (or gasoline) equivalent of plug-in hybrids based on the VISION default eVMT share of 0.10.

However, considering there are no tailpipe emissions associated with the electric vehicle (EV) equivalent of plug-in hybrids, the electric portion of PHEVs is not added to the electric category in Tables 3–6. Thus, the electric category in Tables 3–6 simply reflects the market split of the full EVs (i.e., battery electric vehicles and fuel cell vehicles). That also explains why in some years the market shares do not always sum to one in Tables 3–6.

Through this modeling process, the gasoline and diesel vehicle stock will be shrinking and, accordingly, the gasoline and diesel consumption will be declining as well. In contrast, there will be more alternative fuel vehicles such as EVs and compressed natural gas (CNG) vehicles and, as a result, the alternative fuel usage will increase, which is the goal of a low carbon fuels program. Note that the total VMT and vehicle population between the BAU and Scenario A are the same, although their distributions to each fuel type is different.

2.1.3 Scenario C - The 37% Clean Fuels Program Target

The Scenario C emissions inventory, similar to that of Scenario A, is a result of the MOVES BAU emissions inventory adjusted for the impact of the alternative vehicle penetration specified in Scenario C.

Scenario C reflects the target to reduce lifecycle GHGs in Oregon's current low carbon fuel scenario modeling by 37%. However, a lifecycle carbon intensity standard like Oregon's CFP program is not a tailpipe criteria emission standard, so the high expectation for CI reductions is not directly related to the quantity of criteria emissions during the vehicle operation stage. The criteria emissions directly coming from vehicle operation on the road is highly dependent on the scenario specifications.

Market penetration in Tables 3-5 also applies to Scenario C. Table 7 presents new class 7 & 8 truck sales market share in Scenario C, which is the only different table compared to Scenario A. The difference between vehicle fleets in Scenario A and Scenario C is only on the heavy-duty side (class 7 & 8 truck sales):

- Scenario C has more CNG vehicles;
- Scenario C has more electric vehicles, because fuel cell vehicles (FCVs) are introduced in Scenario C while maintaining the same amount of battery electric vehicles as in the other scenario; and
- Scenario C has more renewable diesel replacing conventional diesel (while biodiesel is the same between the two scenarios), but the MOVES modeling framework does not distinguish criteria pollutant or GHG emission differences between renewable diesel and fossil diesel. The composition of renewable diesel is slightly different than its petroleum equivalent, most notably due to very low sulfur, which can result in lower particulate matter (PM) emissions in some vehicles, notably those that lack a diesel particulate filter (DPF). In newer vehicles, such as those likely to dominate the Oregon fleet in coming decades, exhaust after-treatment devices on the vehicle control the vast majority of PM, minimizing the difference in expected PM emission rates between vehicles fueled by renewable diesel and those fueled by conventional diesel.[18]

Table 7. New class 7 & 8 truck sales market share in Scenario C

Year	Gasoline	Electric	FFV (ethanol)	Diesel	CNG
2018	0.3%	0.0%	0.0%	99.7%	0.0%
2019	0.6%	0.1%	0.0%	97.8%	1.5%
2020	0.8%	0.0%	0.0%	98.3%	0.8%
2021	0.5%	0.0%	0.0%	96.3%	3.1%
2022	0.5%	0.0%	0.0%	96.5%	2.9%
2023	0.5%	0.0%	0.0%	96.6%	2.8%
2024	0.5%	3.7%	0.0%	92.8%	2.7%
2025	0.5%	5.2%	0.0%	91.4%	2.6%
2026	0.5%	7.4%	0.0%	89.1%	2.6%
2027	0.5%	11.1%	0.0%	85.3%	2.6%
2028	0.5%	14.8%	0.0%	81.2%	2.6%
2029	0.5%	18.5%	0.0%	77.2%	2.7%
2030	0.5%	22.2%	0.0%	73.1%	2.8%
2031	0.5%	25.9%	0.0%	69.2%	2.9%
2032	0.5%	29.6%	0.0%	65.2%	3.1%
2033	0.5%	34.6%	0.0%	59.8%	3.3%
2034	0.5%	34.6%	0.0%	59.4%	3.6%
2035	0.5%	39.6%	0.0%	54.0%	3.8%

Fuel cell vehicles (FCVs) are added in the heavy-duty fleet starting 2033 and their limited population is not expected to have a significant impact on the overall emissions in 2035. The additional CNG trucks will have a minor air quality impact as well, due to their small vehicle stock.

2.1.4 Comparison of emissions across scenarios

Table 8 shows a comparison of statewide emissions for a typical 24-hour weekday in July 2035. Both Scenario A and Scenario C will help dramatically reduce criteria emissions directly from vehicle use. That is, the Oregon’s Clean Fuels Program is expected to have significant air quality co-benefits, in addition to its primary benefit of climate change mitigation.

Table 8. Comparison of statewide emissions for a 24-hour weekday in July 2035

Pollutant name	BAU emissions (grams/day)	Scenario A emissions (grams/day)	Scenario C emissions (grams/day)	Scenario A emission reduction (%)	Scenario C emission reduction (%)
Ammonia (NH3)	3,303,739	2,326,310	2,318,161	-29.6%	-29.8%
Atmospheric CO2	57,957,142,933	41,162,590,603	40,818,155,590	-29.0%	-29.6%
Carbon Monoxide (CO)	272,229,003	222,898,708	223,269,570	-18.1%	-18.0%
Non-Methane Hydrocarbons	18,253,909	15,701,586	15,694,399	-14.0%	-14.0%
Oxides of Nitrogen (NOx)	42,781,037	33,885,978	33,243,441	-20.8%	-22.3%
Primary Exhaust PM10 - Total	774,818	629,109	623,268	-18.8%	-19.6%
Primary Exhaust PM2.5 - Total	697,974	566,946	561,565	-18.8%	-19.5%
Primary PM10 - Brakewear Particulate	4,171,827	4,171,827	4,171,827	0.0%	0.0%
Primary PM10 - Tirewear Particulate	1,433,639	1,433,639	1,433,639	0.0%	0.0%
Primary PM2.5 - Brakewear Particulate	521,478	521,478	521,478	0.0%	0.0%
Primary PM2.5 - Tirewear Particulate	215,045	215,045	215,045	0.0%	0.0%
Sulfur Dioxide (SO2)	312,290	221,735	220,661	-29.0%	-29.3%
Total Gaseous Hydrocarbons	24,133,594	19,421,975	19,841,109	-19.5%	-17.8%
Volatile Organic Compounds	19,147,500	16,621,764	16,612,560	-13.2%	-13.2%

Fleet turnover or vehicle retirement is a gradual process; the lifetime of an average car is over 15 years in the U.S.[19] Even assuming high EV sales fractions leading up to 2035, gasoline and diesel vehicles still make up most of the on-road vehicle fleet. In addition, older internal combustion engine (ICE) vehicles emit more pollution per vehicle due to age-related deterioration. Therefore, the 2035 policy scenario emissions are not expected to be near zero, since the fleet will still be largely composed of conventional vehicles.

Because the study uses the same amounts of VMT and vehicle stock across the BAU, Scenario A, and Scenario C, the tire wear and brake wear PM emissions will be the same as well, as shown in Table 8. This is consistent with the assumption that an electric vehicle will incur the same level of tire wear and brake wear PM emissions as its gasoline or diesel counterpart. In practice, electric vehicles typically experience significantly less brake wear due to their use of regenerative braking. Quantifying the difference for vehicles of the type expected in the Oregon fleet in 2035 is beyond the scope of this analysis, so the assumption of no change should be taken as an underestimate of potential impacts.

Compared to Scenario A, Scenario C can result in slightly further reduction in emissions for most of the criteria pollutants. However, Scenario C may emit slightly more carbon monoxide (CO) and total hydrocarbons (THC) emissions as more heavy-duty CNG trucks are added in this scenario. In the 2035 timeframe, the overall emission impact of CNG and fuel cells is expected to be quite small, as in 2035 those vehicles can only account for a small portion of the heavy-duty fleet, in the context that there is a much larger light-duty fleet. In the longer term, fuel cells may play an important role in mitigating the emissions of criteria pollutants (and GHGs) due to their cumulative vehicle stock growth in Oregon.

2.2 Pollutant Transportation, Chemistry and Exposure Modeling

2.2.1 Emissions Inventories

Emissions inventories for the state of Oregon were based on the National Emissions Inventory (NEI) for the year 2017 created by the United States Environmental Protection Agency.[20] Statewide emissions with 4-km spatial resolution for year 2017 were processed through the Sparse Matrix Operator Kerner Emissions modeling system (SMOKE-4.7), including nonpoint, nonroad, residential wood burning and commercial, rail, oil and gas, point fire, electricity generation, airport, industrial, marine vessels, agricultural and mobile emissions.[21] The current project used the SAPRC chemical mechanism speciation data in SMOKE.[22]

Biogenic emissions were generated using the Model of Emissions of Gases and Aerosols from Nature (MEGANv2.1) based on the meteorological fields generated using the Weather Research and Forecast (WRF) model.[23] The gridded geo-referenced emission factors and land cover variables required for MEGAN calculations were created using the MEGANv2.1 pre-processor tool and the ESRI_GRID leaf area index and plant functional type files available at the Community Data Portal.

Wildfire emissions were represented using the Global Fire Emissions Database (GFED).[24] GFED uses satellite images of burned areas combined with vegetation maps to estimate smoke released each day during wildfires. Spatial resolution of GFED emissions inventories are 0.25 degrees, which is equivalent to ~27.75 km over Oregon. Wildfire emissions were assigned particle size and composition profiles based on measurements during biomass burning experiments.[25]

2.2.2 Future Mobile Emissions Inventories

Mobile emissions were scaled for each county in Oregon at the Source Classification Code (SCC) level from the base year 2017 to the future year 2035, based on MOVES results.[26] Three energy scenarios were considered in this study—a business as usual (BAU) scenario, a 25% CFP scenario (Scenario A), and a 37% CFP scenario (Scenario C). Future mobile emissions in each county were generated using Eq. (1):

$$(NEI\ Mobile\ Emissions)_{SCC}^{2035} = (NEI\ Mobile\ Emissions)_{SCC}^{2017} \times \frac{(MOVES\ )_{SCC}^{2035}}{(MOVES\ )_{SCC}^{2017}} \qquad \text{Eq (1)}$$

Emissions from sectors other than mobile sources were maintained at their year 2017 levels.

In Oregon, nitrogen oxides (NOx) and PM emissions strongly affect ambient concentrations of airborne particulate matter with diameters less than 2.5 µm ($PM_{2.5}$). Comparing the 2035 BAU and Scenario A, emissions from on-road gasoline vehicles are reduced by 25% for PM and 22% for NOx; emissions from on-road diesel vehicles are reduced by 2% for PM and 6% for NOx. Further reductions from Scenario A to the Scenario C are modest, with only a 2% PM reduction and a 2.13% NOx reductions for on-road diesel vehicles.

2.2.3 Air Quality Simulation

Meteorology Model

Hourly meteorology inputs to drive the regional chemical transport model at 24-km and 4-km resolution during the years 2016 and 2030-2039 were simulated using the Weather Research and Forecasting (WRF) v4.3 model (www.wrf-model.org). The WRF model was configured with 31 vertical layers from the ground level to the top of the domain, defined by an atmospheric pressure of 100 hPa. Initial and boundary conditions for meteorological simulations for the year 2016 were obtained from the North American Regional Reanalysis (NARR) database created by the National Center for Environmental Prediction (NCEP). Initial and boundary conditions for the year 2035 were obtained from the Community Climate System Model (CCSM) using the Representative Concentration Pathway (RCP) 4.5 Scenario.

Chemical Transport Model

The UC Davis-California Institute of Technology (UCD-CIT) airshed model is a reactive 3-D chemical transport model (CTM) that predicts the evolution of gas and particle phase pollutants in the atmosphere in the presence of emissions, transport, deposition, chemical reaction, and phase change. The basic capabilities of the UCD-CIT model are similar to the Community Multiscale Air Quality (CMAQ) model maintained by the US EPA, but the UCD-CIT model has several source apportionment features and higher particle size resolution, which make it attractive for the current project.

Particle source tracers are empirically set to be 1% of the total mass of primary particles emitted from each source category, so they do not significantly change the particle radius and the dry deposition rates. For a given source, the simulated concentration of artificial tracer directly correlates with the amount of PM mass emitted from that source in that size bin. The corresponding number concentration attributed to that source can be calculated using Eq. (2)

$$num_i = \frac{tracer_i \times 100}{\frac{\pi}{6} Dp^3 \rho}, \qquad \text{Eq (2)}$$

where $tracer_i$ represents the artificial tracer mass in size bin i, Dp is the core particle diameter, and ρ is the core particle density. Core particle properties are calculated by removing any condensed species to better represent the properties of the particles when they were emitted.

Nine primary source categories were explicitly tracked within the comprehensive PM simulations, including: 1) onroad gasoline mobile; 2) offroad gasoline equipment; 3) onroad diesel mobile; 4) offroad diesel equipment; 5) wood burning; 6) food cooking; 7) aircraft; 8) natural gas and biogenic; 9) tire & brake wear; and (10) miscellaneous, i.e., emissions not included in the categories listed above. Mobile mitigation strategies will change the emissions of primary PM grouped within types 1, 3, and 9 in the current configuration. Mobile mitigation strategies will also change the emissions of NOx and volatile organic compounds (VOCs) that will affect the formation of secondary particulate matter components such as nitrate.

Long-term Simulation Strategy

The El Niño Southern Oscillation (ENSO) strongly affects meteorology and air quality in Western US. ENSO cycles typically last seven years, making it necessary to simulate multi-year time periods when analyzing future air quality. The computational burden of this task can be reduced by selecting a subset of episodes across the approximately decadal time period to build an accurate estimate of the long-term average concentrations in the presence of inter-annual climate variability. The uncertainty attributable to climate variability decreases as the number of sample points (simulation episodes) increases. For the present study, an entire decade of air quality could be simulated for every future energy portfolio, but in practice the long-term $PM_{2.5}$ and ozone (O_3) concentrations can be determined with the required accuracy by simulating a smaller number of representative episodes randomly selected across the target decade. California studies have used 32 episodes of 7-day duration to represent long-term population-weighted $PM_{2.5}$ concentration to $\pm 0.5\ \mu g/m^3$.[27] The same number of episodes are adopted in the present Oregon analysis to represent long-term air pollution concentrations in the presence of ENSO effects.

BenMAP Health Impact Analysis

The public health impact of air pollution within each energy scenario was calculated using the BenMAP-CE v1.4.8 model developed by US EPA.[28] The population dataset was prepared using PopGrid v4.3 (Census 2010) according to the instructions provided in the BenMAP manual. The mortality health impact function used in this study is from Krewski et al. (2009). This health impact function is used for calculation of all-cause mortality in people older than 30 years old.

BenMAP calculates health impacts between a control scenario and a base case scenario. The historical year 2016 analysis uses the UCD-CIT year 2016 simulation result as the base case and a uniform $PM_{2.5}$ mass concentration of 3 $\mu g/m^3$ for the control case. The effects of motor vehicles are evaluated using $PM_{2.5}$ tracer concentrations as the base case scenario and 0 $\mu g/m^3$ for the control case. The analysis in future years uses the BAU scenario as the base case and Scenario A or Scenario C as the control case.

3. Results

Table 9 summarizes the Oregon statewide emissions of oxides of nitrogen (NOx), airborne particulate matter (PM), oxides of sulfur (SOx), and ammonia (NH_3) under the 2017, 2035 BAU, Scenario A, and Scenario C. Note that totals in Table 9 reflect emissions from mobile, point, and area sources.

Table 9. Air Pollution emissions summaries for Oregon under the 2017, BAU, Scenario A, and Scenario C.

	NOx (kmol/day)	**PM (kg/day)**	**$PM_{2.5}$ (kg/day)**	**SOx (kmol/day)**	**NH_3 (kmol/day)**
2017	55,141	462,542	247,468	5,793	5,948
2035 BAU	53,499	459,907	244,982	5,792	5,924
Scenario A	52,594	458,182	243,279	5,790	5,890
Scenario C	52,570	458,167	243,266	5,790	5,889

3.1 Chemical Transport Model Output and Quality Control

Quality control simulations for the year 2016 were carried out across Oregon using the source-oriented UCD-CIT regional air quality model before the same modeling system was applied to the year 2035 BAU, Scenario A, and Scenario C simulations. Figure 3 to Figure 6 show the year 2016 annual average concentration of $PM_{2.5}$ mass, elemental carbon (EC), organic carbon (OC), and nitrate. Figure 7 shows the on-road gasoline mobile emission tracer concentration (tracer 1) and Figure 8 shows the on-road diesel mobile emission tracer concentration (tracer 3).

Figure 3 to Figure 8 show that $PM_{2.5}$ mass and component concentrations over land in the year 2016 are highest in major cities, such as Portland and Eugene, and in areas along the I-5 corridor. The $PM_{2.5}$ EC concentrations displayed in Figure 4 are primarily from on-road heavy-duty diesel vehicles. The pattern of EC is also consistent with gasoline and diesel mobile emissions source tracers, which are shown in Figure 7 and Figure 8. The $PM_{2.5}$ OC concentrations illustrated in Figure 5 are mainly from food cooking and residential combustion. The spatial patterns of $PM_{2.5}$ nitrate illustrated in Figure 6 have spatial gradients that are less sharp than primary pollutants such as EC.

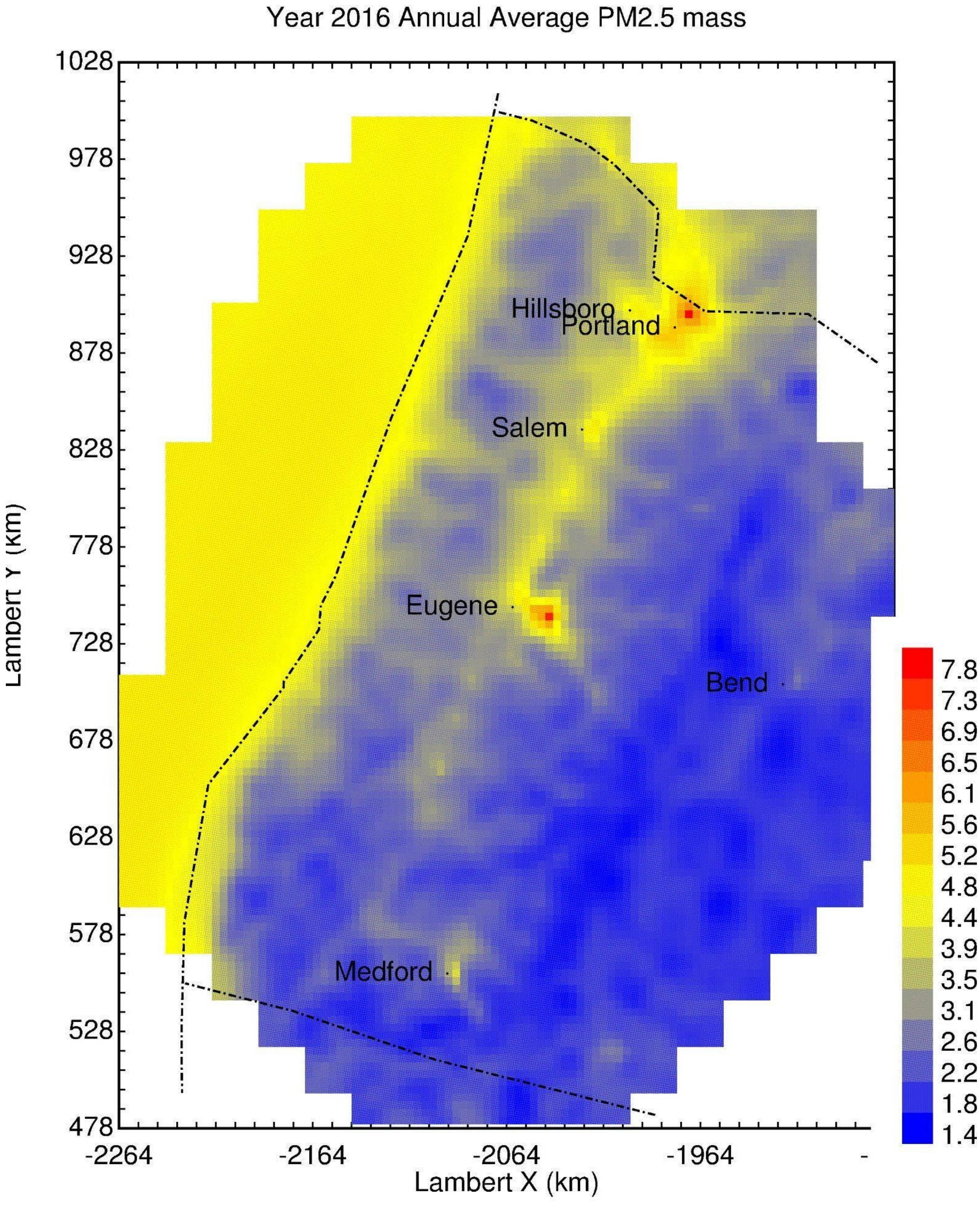


Figure 3. Year 2016 Annual Average $PM_{2.5}$ mass concentration. Units are µg/m^3.

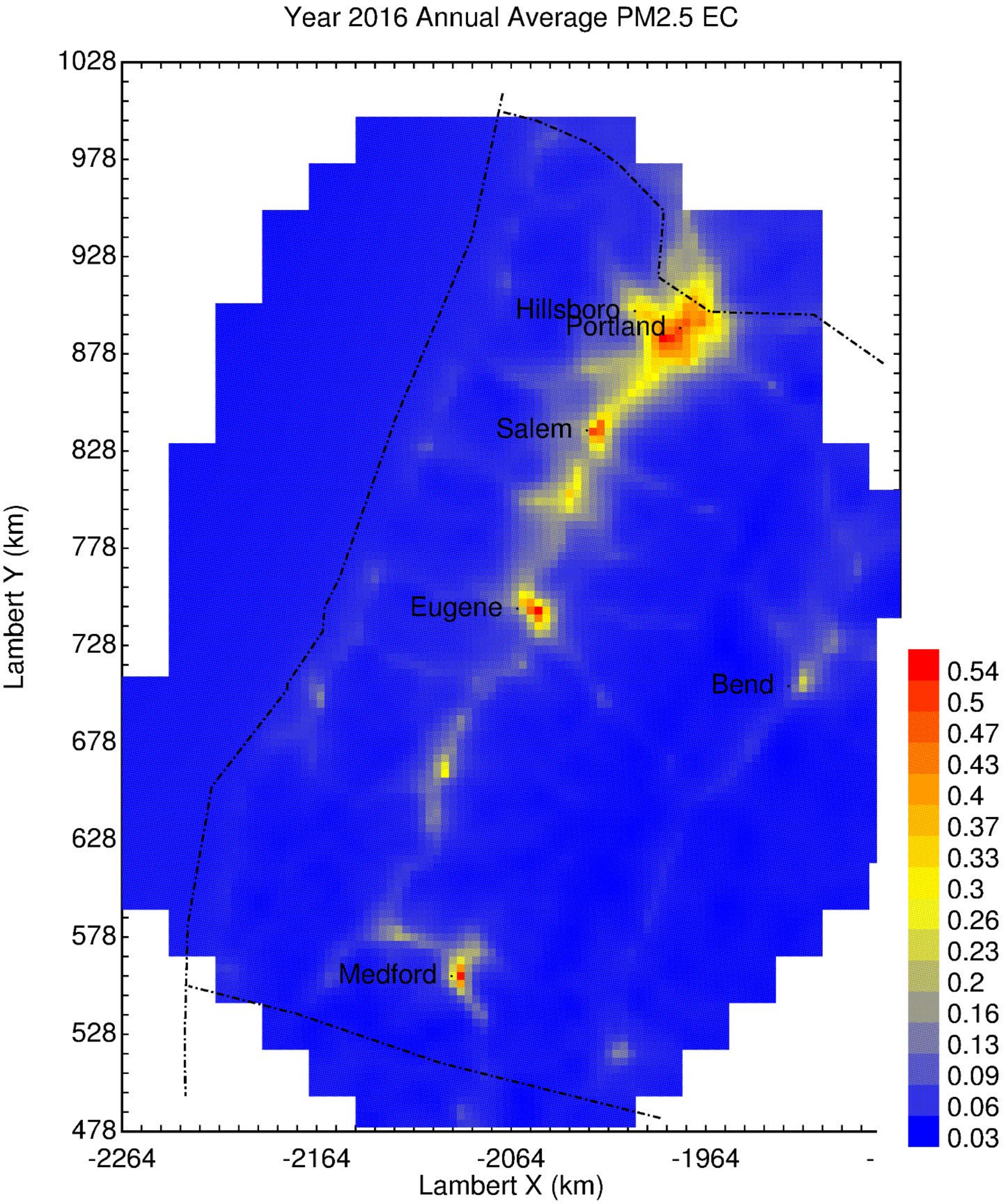


Figure 4. Year 2016 annual average $PM_{2.5}$ element carbon (EC) concentration. Units are µg/m^3.

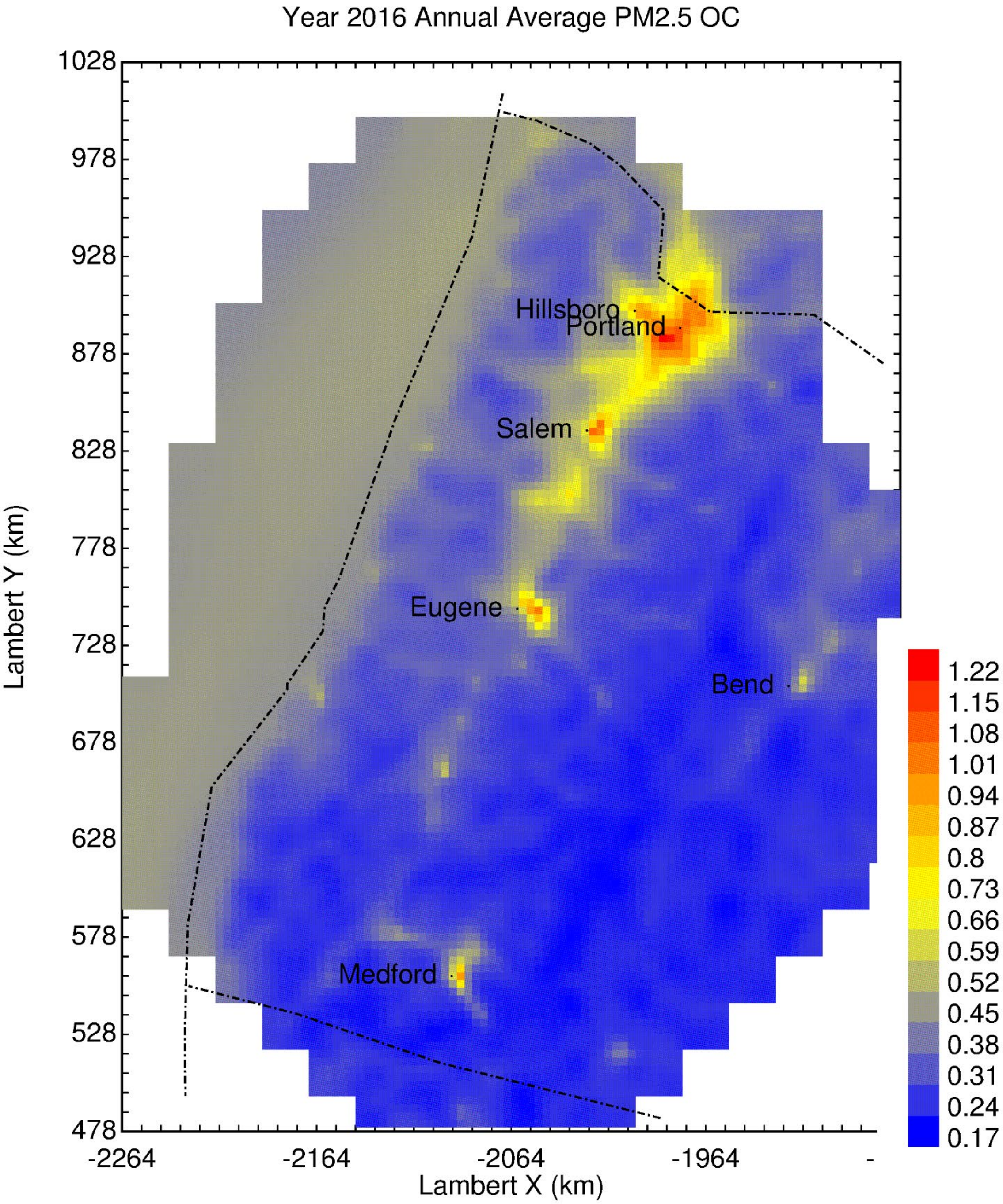


Figure 5. Year 2016 annual average $PM_{2.5}$ organic carbon (OC). Units are µg/m^3.

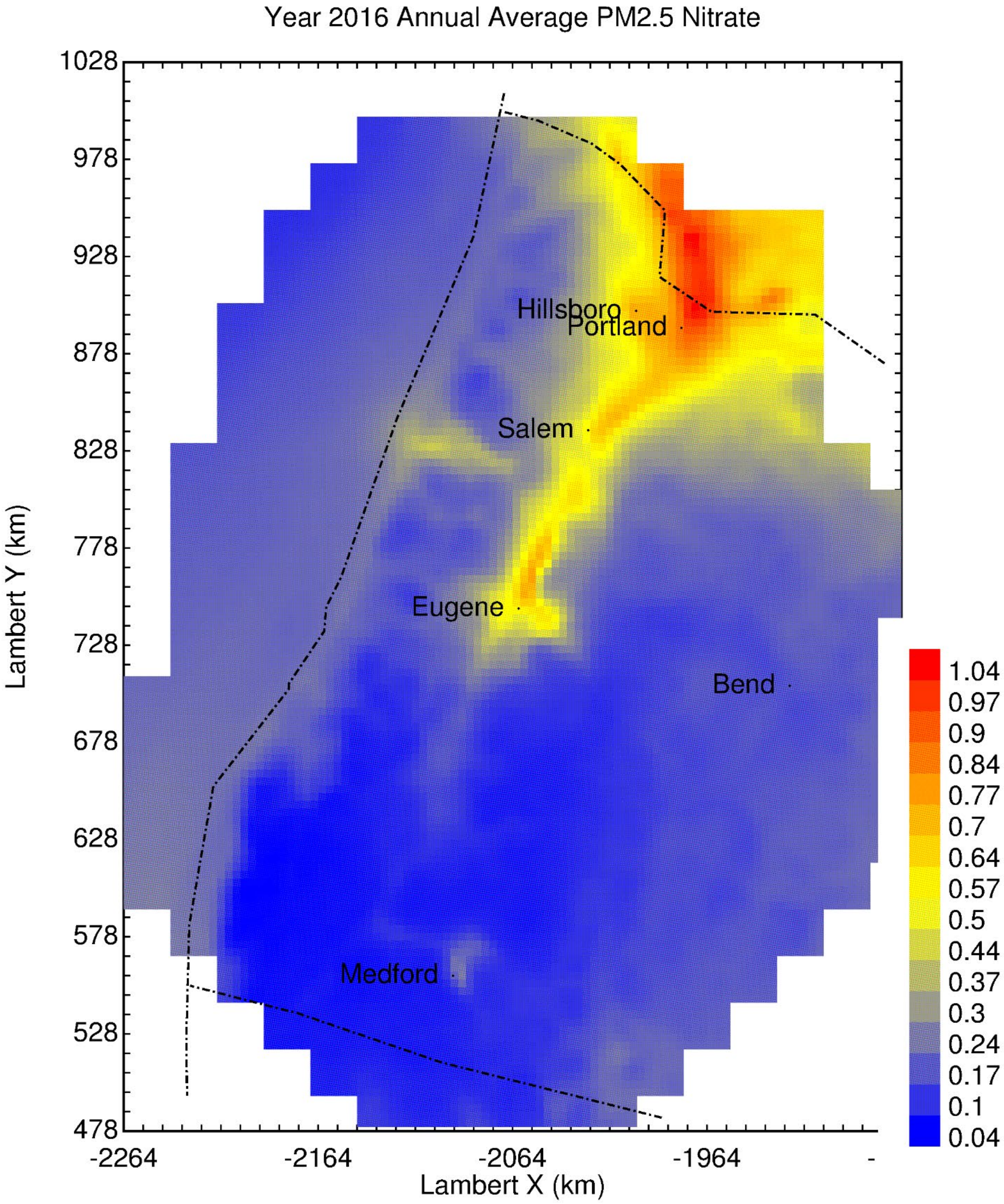


Figure 6. Year 2016 annual average $PM_{2.5}$ nitrate concentration. Units are µg/m^3.

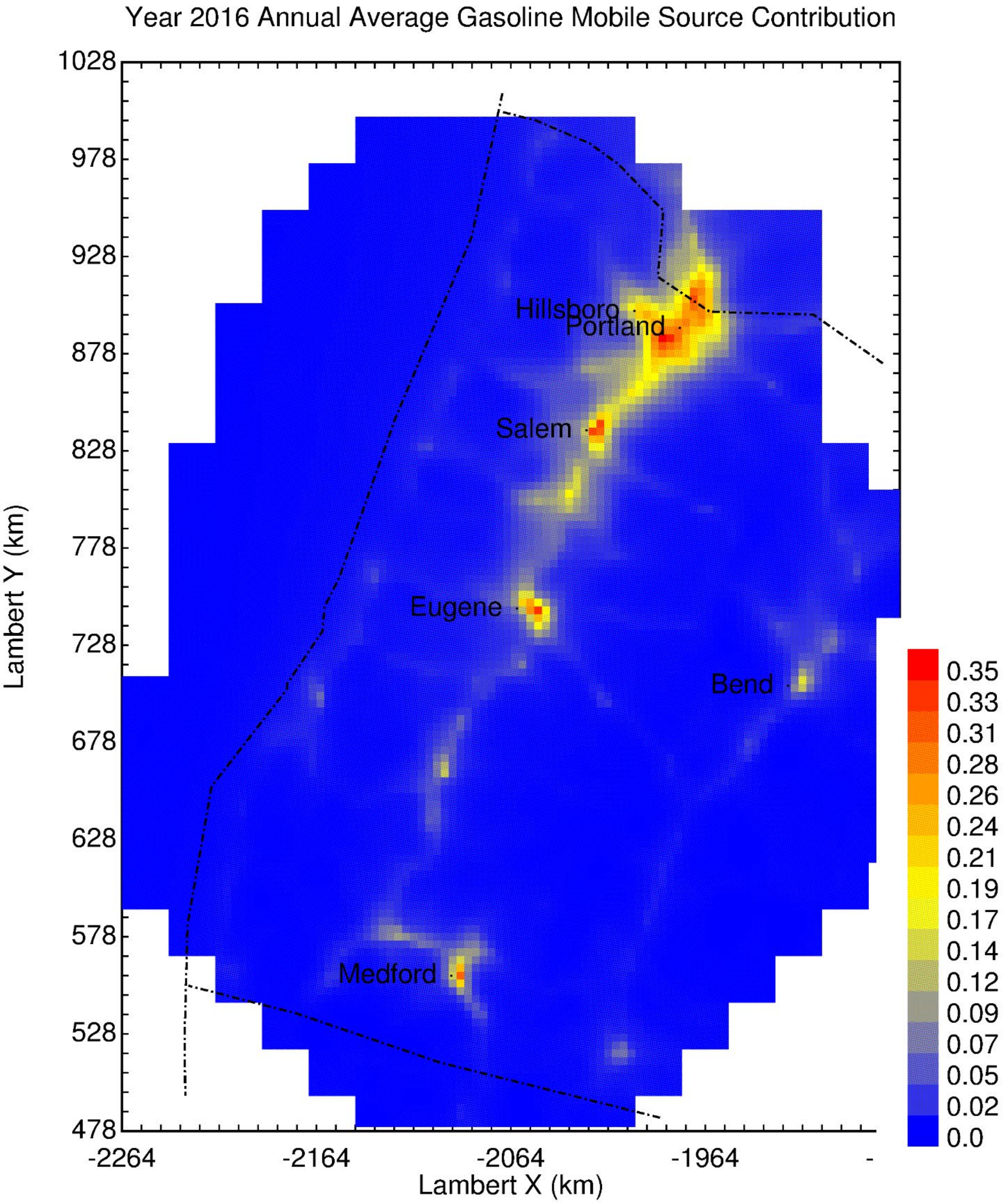


Figure 7. Year 2016 annual average primary $PM_{2.5}$ mass from on-road gasoline engines. Units are µg/m^3.

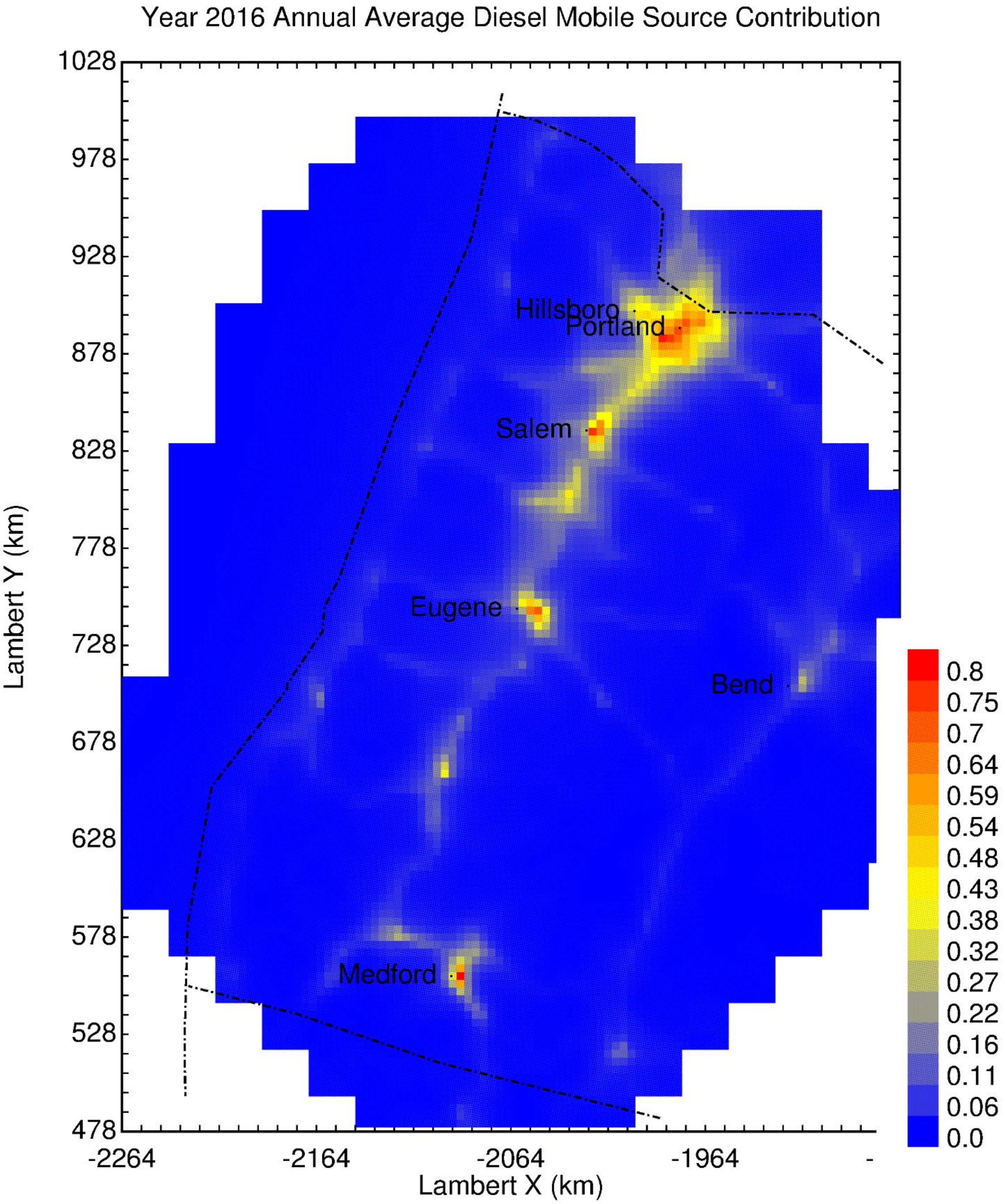


Figure 8. Year 2016 annual average primary $PM_{2.5}$ mass from on-road diesel engines. Units are μg/m^3.

Figure 9 to Figure 11 show $PM_{2.5}$ mass model predictions and measurements in urban areas, including Portland (Figure 9 and Figure 10), and Eugene (Figure 11 and Figure 12). Figure S1 in the Appendix shows the map of available measurement sites in Oregon. The dots in each figure represent measurements while the lines represent model predictions. $PM_{2.5}$ mass concentrations in urban areas are generally under-predicted during winter months, possibly due to an under-estimation of wood smoke emissions in these urban areas. $PM_{2.5}$ mass predictions during summer months are generally in good agreement with measurements.

Table 10 shows model performance statistics for the year 2016 across the measurement sites summarized in Figure 9–Figure 12. Despite the under-prediction in winter months, the annual-average model performance meets the minimum performance criteria typically used in chemical transport modeling studies .[29] The wood smoke emissions rate will be studied in future iterations of the model process, but this issue should not influence the predicted change in mobile source emissions associated with changes to fuel composition.

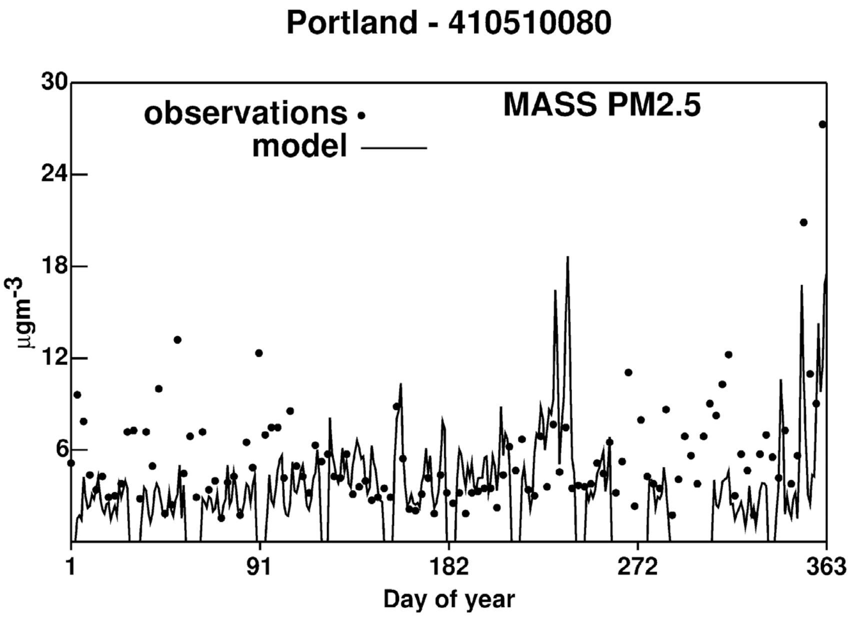


Figure 9. Year 2016 model simulation comparison to measurement at site – 410510080 (Portland).

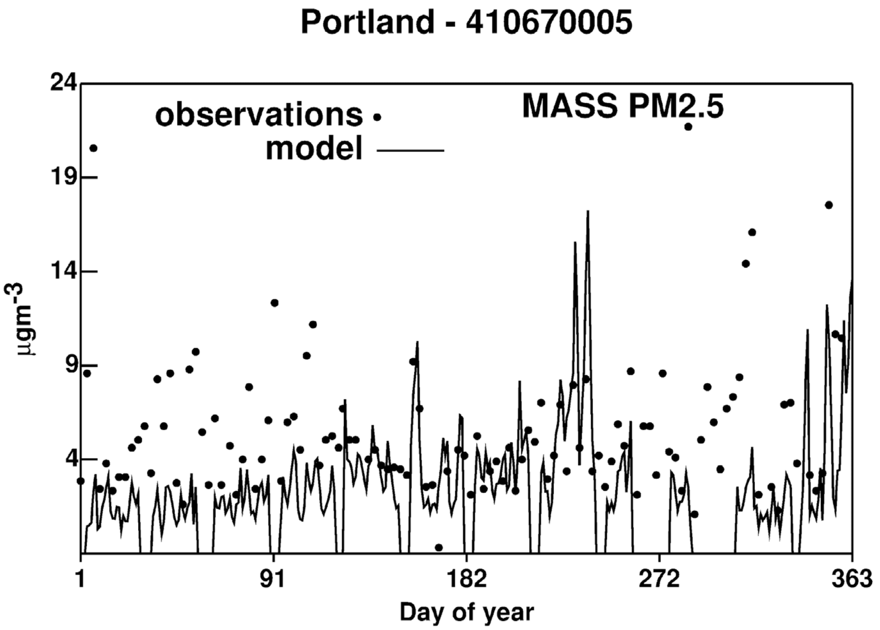


Figure 10. Year 2016 model simulation comparison to measurement at site – 410670005 (Portland).

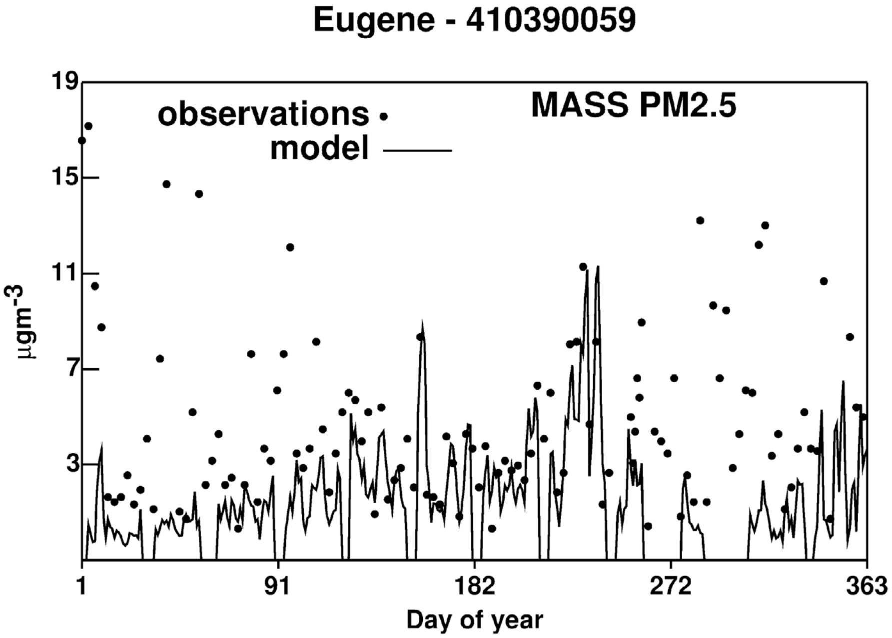


Figure 11. Year 2016 model simulation comparison to measurement at site – 410390059 (Eugene).

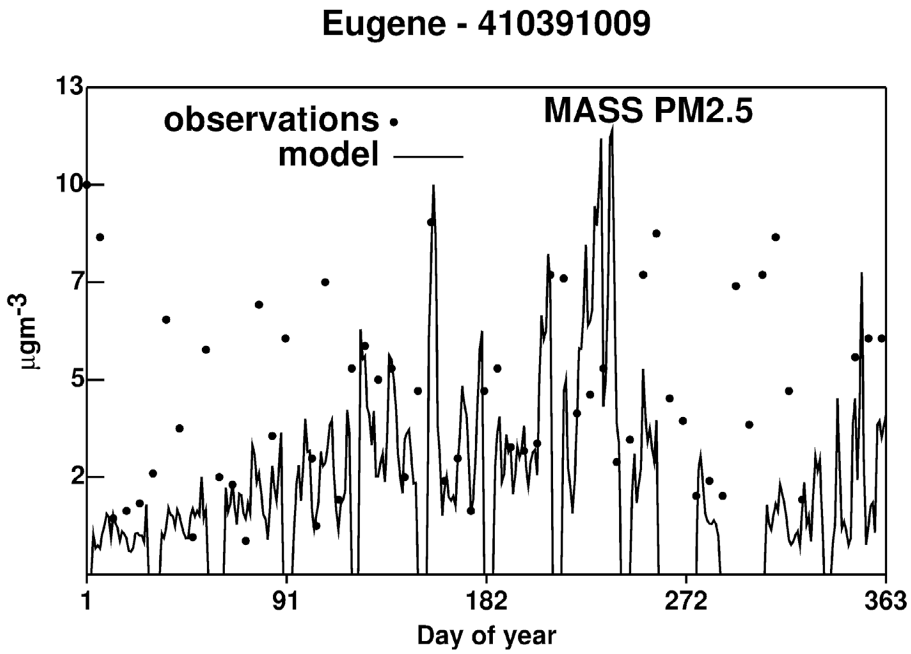


Figure 12. Year 2016 model simulation comparison to measurement at site – 410391009 (Eugene).

Table 10. Mean Fractional Error (MFE) and Mean Fractional Bias (MFB)

Goal*	<0.5	<±0.3
Criteria*	<0.75	<±0.6
Site	MFE	MFB
Portland -410510080	0.45	-0.22
Portland - 410670005	0.54	-0.44
Eugene - 410390059	0.61	-0.55
Eugene - 410391009	0.54	-0.4

* Based on criteria suggested by Boylan and Russell (2006) [29]

Figure 13 and Figure 14 show the time series of primary $PM_{2.5}$ mass concentrations associated with on-road gasoline vehicles (tracer 1) and on-road diesel vehicles (tracer 3) during the year 2016. Concentrations for the primary $PM_{2.5}$ mass associated with these on-road sources generally increase during the colder winter months due to reduced height of the planetary boundary layer. These seasonal patterns will persist in future years.

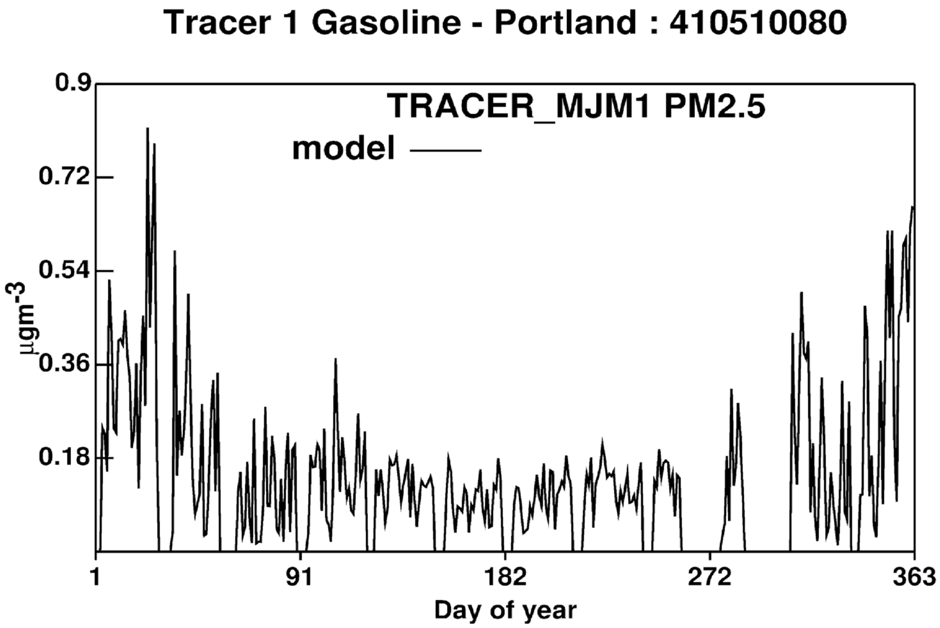


Figure 13. PM2.5 concentrations associated with gasoline mobile tailpipe emissions during 2016 in Portland (410510080).

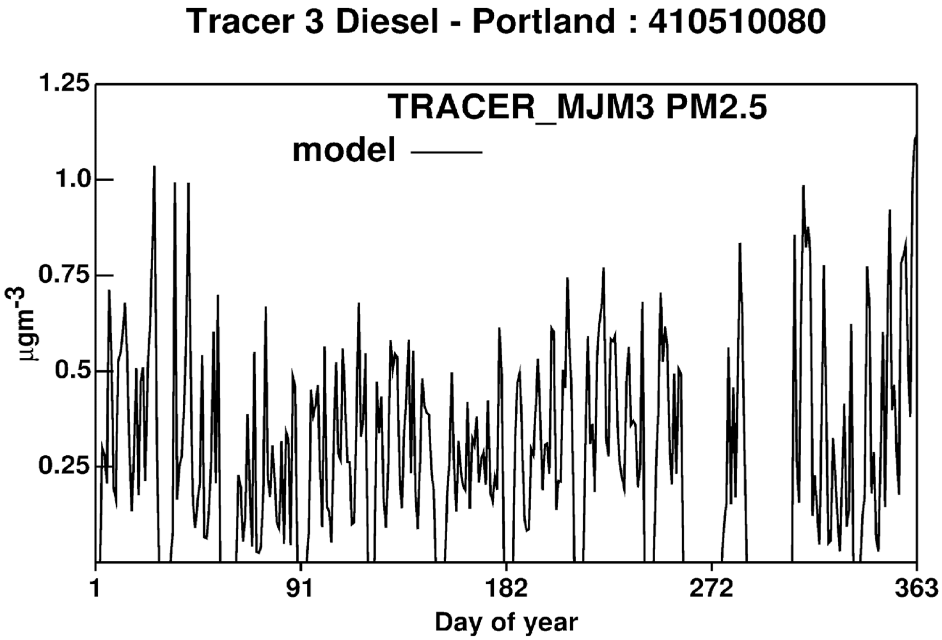


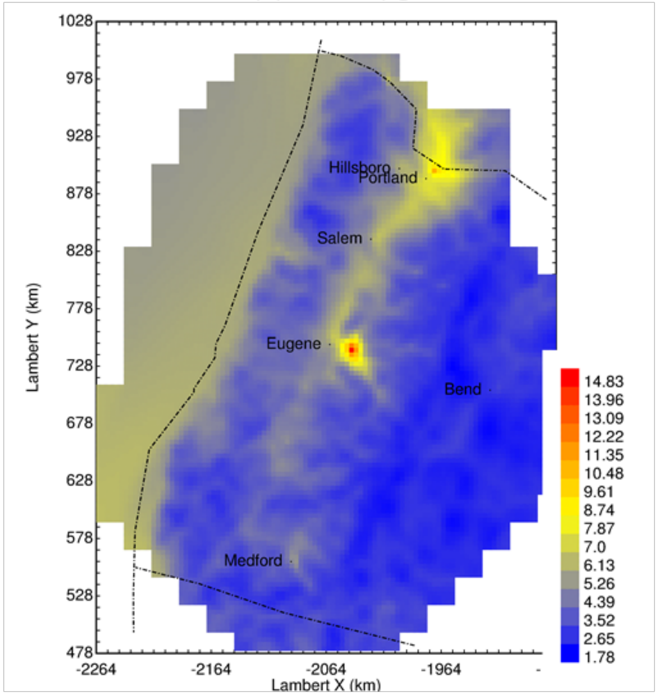
Figure 14. PM2.5 concentrations associated with diesel mobile tailpipe emissions in 2016 at site in Portland (410510080).

3.2 Future Air Quality simulations

3.2.1 PM concentrations and source contribution comparisons between BAU, Scenario A, and Scenario C

Results for future year simulations under the BAU, Scenario A, and Scenario C scenarios can be compared for total $PM_{2.5}$ mass and primary $PM_{2.5}$ mass concentrations associated with on-road gasoline vehicles and on-road diesel vehicles. $PM_{2.5}$ chemical components such as elemental carbon (EC) and organic carbon (OC) that are associated with combustion sources in the BAU and Scenarios A or C can also be compared. All changes in these $PM_{2.5}$ sources/components are related to changes in the mobile emissions associated with adoption of low carbon fuels.

(a) BAU – μg/m³



(b) Scenario (BAU - A) – μg/m³ (c) Scenario (A - C) – ng/m³

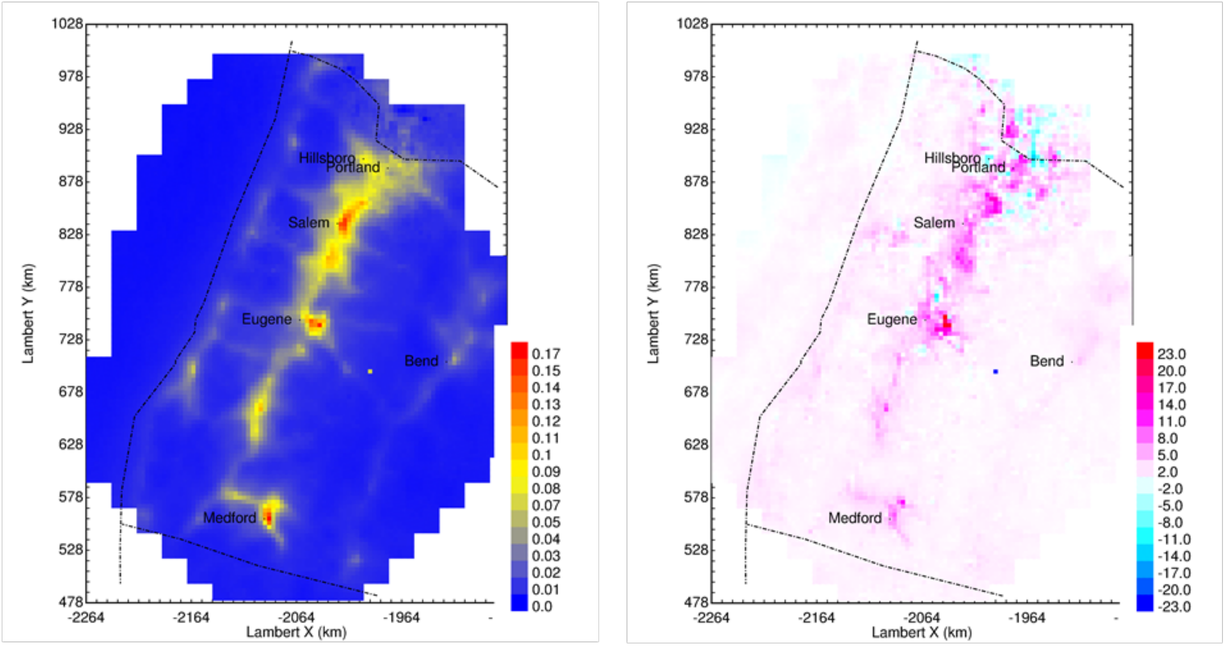
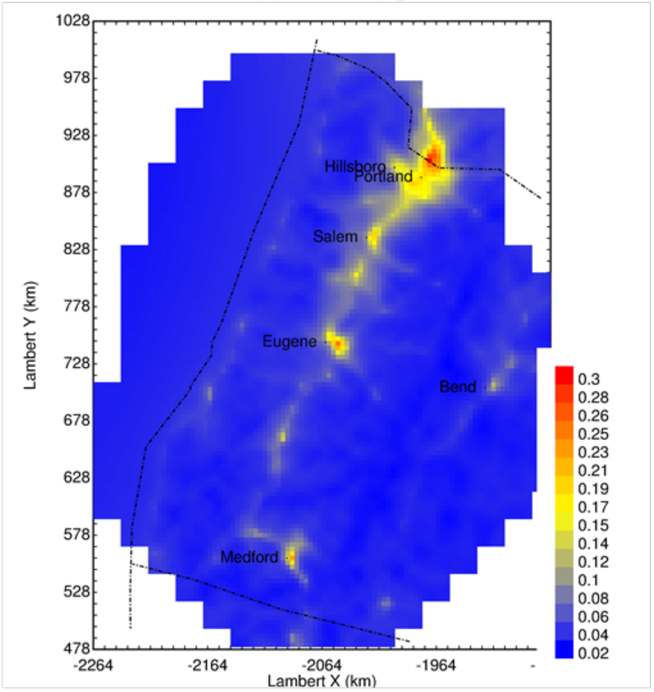


Figure 15. (a) PM$_{2.5}$ mass concentration for BAU scenario (μg/m^3), (b) the difference between BAU and Scenario A (μg/m^3), and (c) the difference between Scenario A and Scenario C (ng/m^3).

(a) BAU – µg/m³



(b) Scenario (BAU -A) – ng/m³

(c) Scenario (A - C) – ng/m³

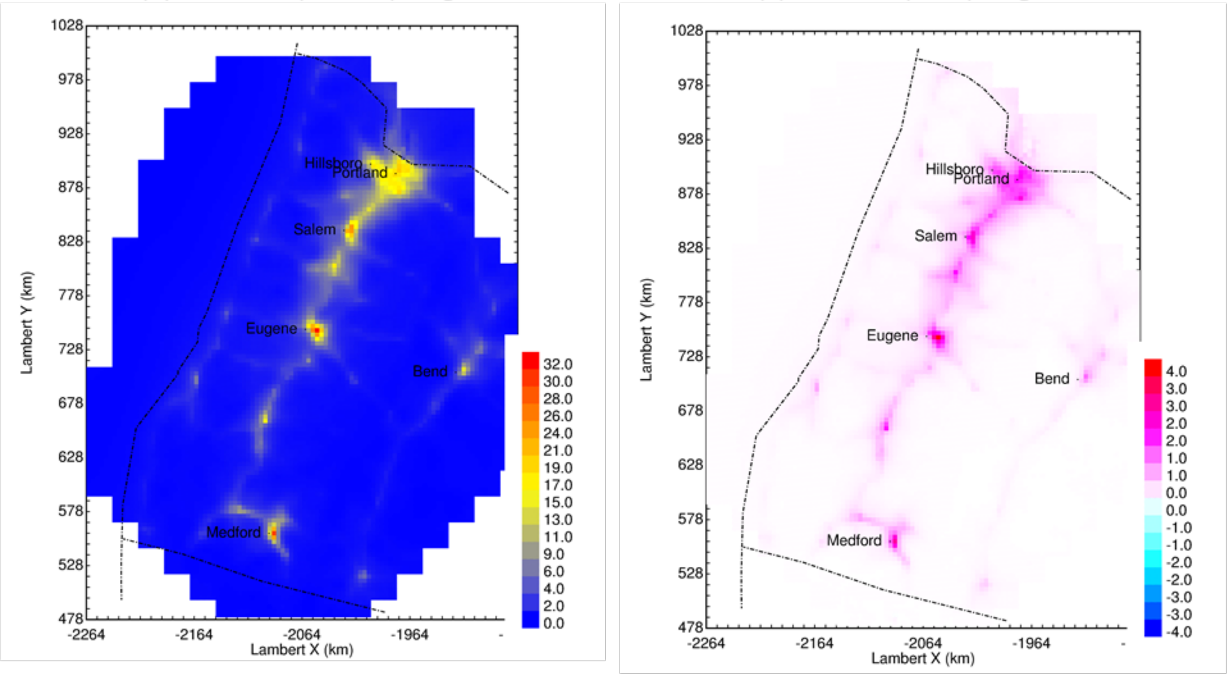
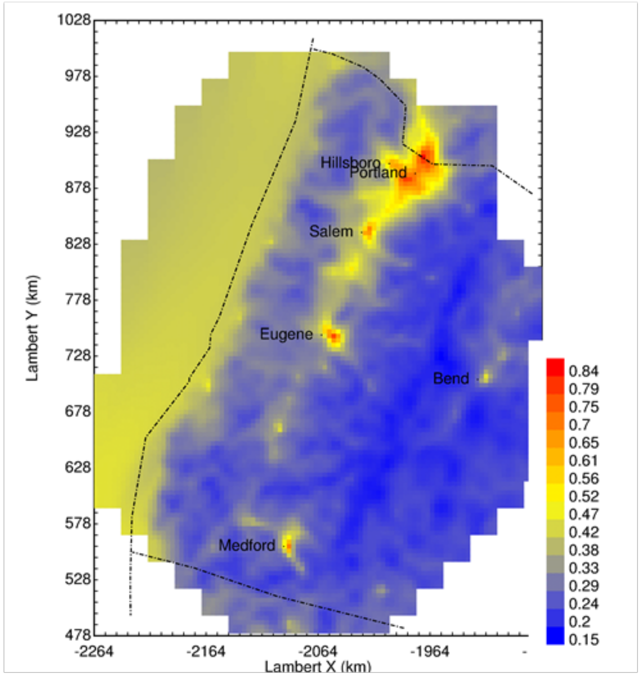


Figure 16. (a) $PM_{2.5}$ EC concentration for BAU scenario (µg/m^3), (b) the difference between BAU and Scenario A (ng/m^3), and (c) difference between Scenario A and Scenario C (ng/m^3).

(a) BAU – µg/m³



(b) Scenario (BAU - A) – µg/m³

(c) Scenario (A - C) – ng/m³

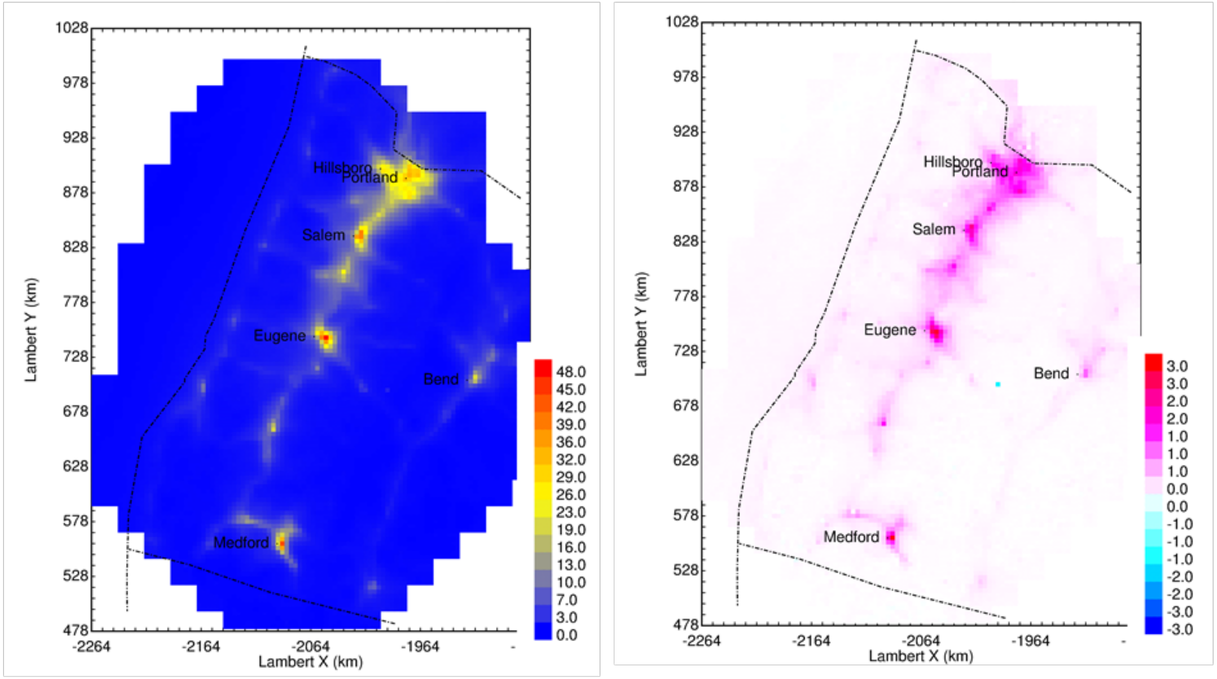
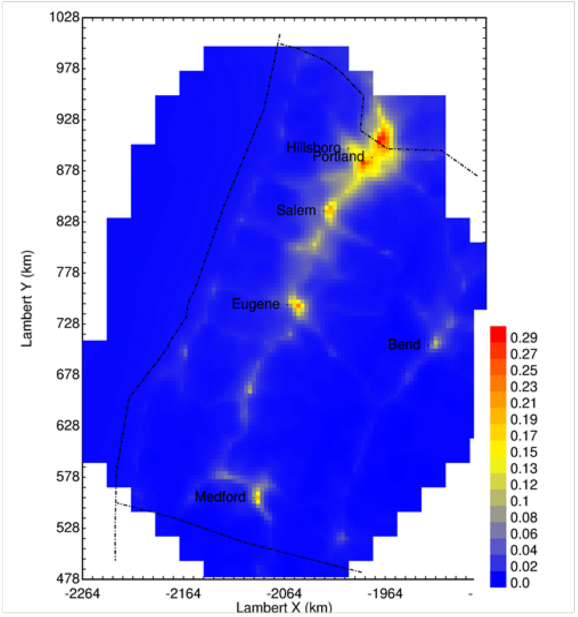


Figure 17. (a) $PM_{2.5}$ OC concentration for BAU scenario (µg/m³), (b) the difference between BAU and Scenario A (ng/m³), and (c) difference between Scenario A and Scenario C (ng/m³).

Figure 15, Figure 16, and Figure 17 show BAU long-term $PM_{2.5}$ total mass, EC, OC concentrations in the year 2035 (panel a) along with changes caused by the adoption of low carbon transportation fuels Scenario A and Scenario C (panel b and c). Total mass, EC, and OC reductions occur mainly along the I-5 corridor, especially for major cities such as Eugene and Salem. $PM_{2.5}$ EC concentrations are predicted to decrease ~20%, and $PM_{2.5}$ OC is predicted to decrease ~14% due to the adoption of low carbon fuels.

(a) BAU – μg/m³



(b) Scenario (BAU – A) – ng/m³

(c) Scenario (A – C) – ng/m³

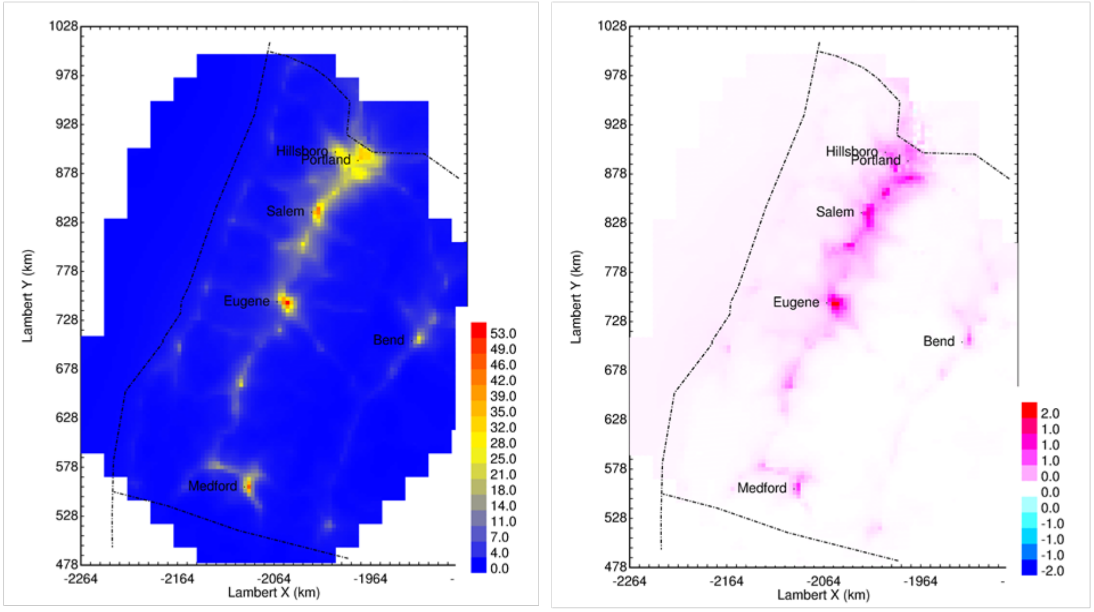
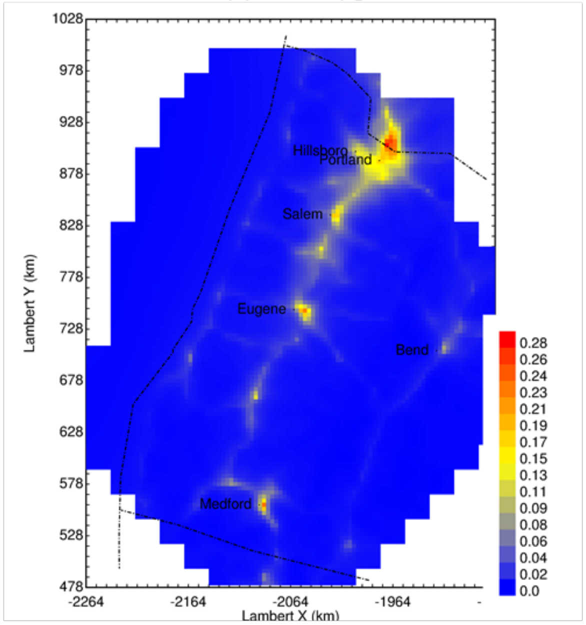


Figure 18. (a) Tracer 1 (gasoline mobile) concentration for BAU scenario (μg/m³), (b) the difference between BAU and Scenario A (ng/m³), and (c) the difference between Scenario A and Scenario C (ng/m³).

Figure 18 shows predicted changes to the primary $PM_{2.5}$ mass associated with on-road gasoline vehicles (tracer 1) between the BAU and Scenarios A and C. The greatest reductions of ~25% are predicted to occur in Salem and Eugene, while predicted concentrations in Portland decrease by a more modest ~10%. The difference between Scenarios A and C is not as significant as the difference between the BAU and Scenario A.

(a) BAU – µg/m³



(b) Scenario (BAU - A) – ng/m³

(c) Scenario (A - C) – ng/m³

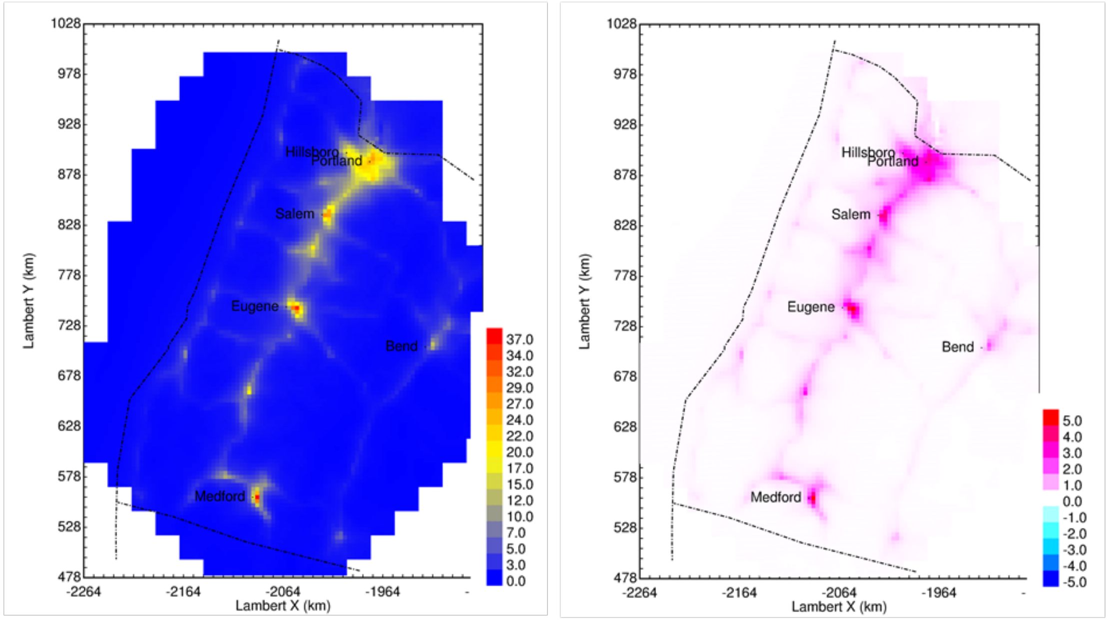
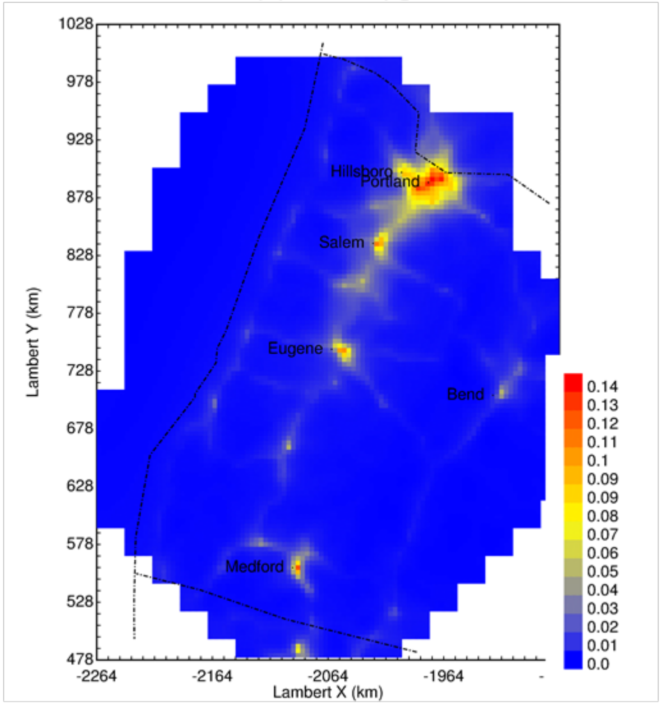


Figure 19. (a) Tracer 3 (diesel mobile) concentration for BAU scenario (µg/m^3), (b) the difference between BAU and Scenario A (ng/m^3), and (c) the difference between Scenarios A and C (ng/m^3).

Figure 19 shows predicted changes to the primary $PM_{2.5}$ mass associated with on-road diesel vehicles (tracer 3) between the BAU and Scenarios A and C. Diesel mobile emissions reductions of ~15% are apparent in major cities including Salem, Eugene, and Portland. Comparing Figure 18c and Figure 19c, we can see that Scenario C has larger reductions than Scenario A for diesel (tracer 3). There are ~1.8% reductions between Scenario C and Scenario A for tracer 3, however, only ~0.5% reduction between Scenario C and A for tracer 1, which likely reflect the fact that the Scenarios A and C differ primarily in the presence of more diesel substitutes in Scenario C.

(a) BAU – μg/m³



(b) Scenario (BAU - A) – μg/m³ (c) Scenario (A - C) – ng/m³

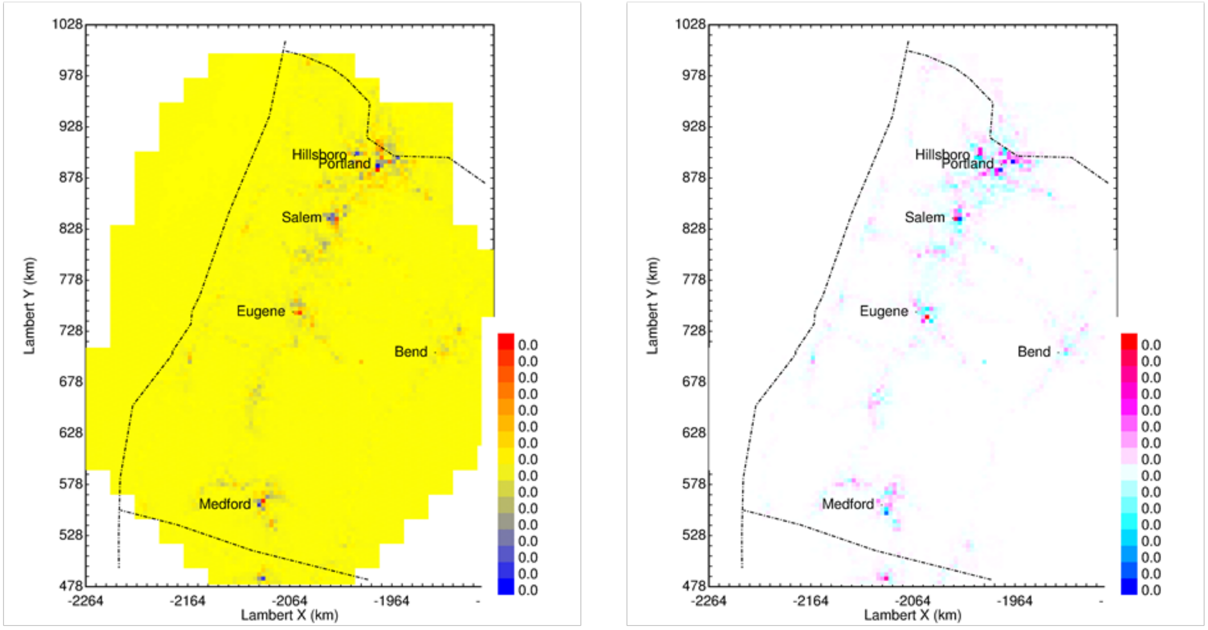


Figure 20. (a) Tracer 9 (tire & brake wear included) concentration for BAU scenario (μg/m^3), (b) the difference between BAU and Scenario A (ng/m^3), and (c) the difference between Scenario A and Scenario C scenarios (ng/m^3). Values displayed as 0.0 are lower than 0.5 units for the indicated plot.

Figure 20 shows predicted changes to the primary $PM_{2.5}$ mass associated tire and brake wear (tracer 9). All scenarios show same level of tire and brake wear related pollution, with maximum values of approximately 0.14 µg/m^3.

3.3 Health Impact comparison between BAU and compliance scenarios

The analysis described above estimates total PM in the atmosphere and allows separate tracking of primary PM (particulate matter emitted directly from the vehicle) and secondary PM (particulate matter formed by reactions of other pollutants in the atmosphere). Table 11 shows the BenMAP health impact analysis for all-cause mortality based on the changes to total $PM_{2.5}$ mass and primary $PM_{2.5}$ mass associated with on-road vehicles summarized in Figure 15, Figure 18, Figure 19, and Figure 20. BenMAP modeling was performed for the part of the state covered by the 4-km grid cell UCD-CIT modeling, shown in Figure 15–Figure 18. Both vehicle activity and population were judged to be too low in the remainder of the state for changes in air quality from policy-driven shifts in fuel portfolio to produce a meaningful and reliable result. Additionally, the Krewski (2009) health impact function selected for use in the BenMAP analysis focuses on segments of the population that are 30 years old or older. Future work is planned to extend the work reported here to a wider scope of demographic classes, as well as model morbidity independent of mortality.

Background concentrations for $PM_{2.5}$ total mass were assumed to be 3 µg/m^3 and background concentrations for $PM_{2.5}$ primary particles emitted from motor vehicle tailpipes were assumed to be 0 µg/m^3 for these calculations. The 2035 BAU scenario was set to be the base case and the background concentration was taken as the comparison case in the BenMAP analysis for future conditions. The program predicts 242.26 excess deaths per year for every 1,000,000 people in the 2035 BAU scenario because of exposure to increased concentrations of $PM_{2.5}$ total mass from all sources, including non-transportation sources relative to the assumed background concentrations.

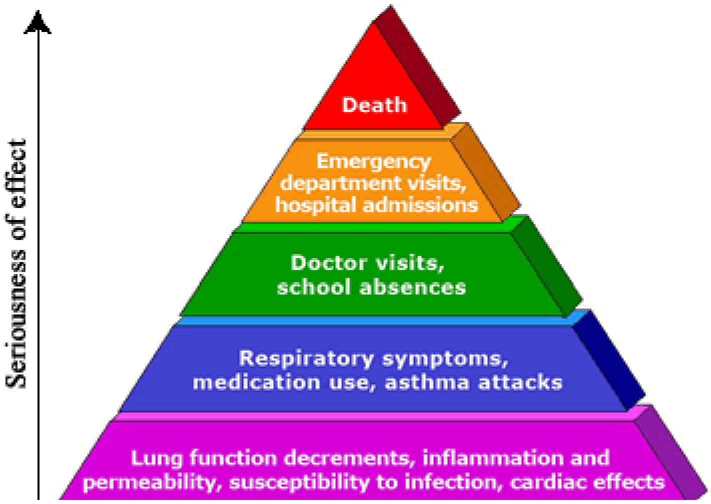


Figure 21. Relationship between number of people affected by air pollution related public health problems and severity of effect

Primary PM emitted from on-road gasoline vehicles accounts for an estimated 8.44 excess deaths per 1,000,000 people, and primary PM emitted diesel vehicles accounts for an estimated 7.89 excess deaths per 1,000,000 people in the 2035 BAU scenario.

Adoption of low-carbon transportation fuels decreases air pollution mortality in proportion to concentrations, resulting in a health savings. Adoption of low carbon fuels (Scenario A and Scenario C) reduces mortality associated with primary PM emitted from gasoline vehicles by ~16% and mortality associated with primary PM emitted from diesel vehicles by ~12.5%. No changes are predicted in mortality associated tire and brake wear emissions since these are approximately constant across the future scenarios. Total air pollution mortality is estimated to decrease by 4 to 5 excess deaths per 1,000,000 people due to the adoption of low-carbon transportation fuels, with a larger corresponding decrease in morbidity.

Attribution of mortality from secondary particulates is estimated by comparing total mortality under Scenarios A and C against mortality in the BAU scenario, and excluding the impacts of primary PM. In both 2035 scenarios, primary and secondary PM each account for approximately 50% of the total reduction in excess mortality compared to the 2035 BAU.

Table 11. BenMAP Health Impact Analysis - all-caused mortality between BAU and Scenario A/C. Tracer results show the impacts of primary PM from the indicated source. Secondary PM resulting from pollutants emitted by vehicles constitutes the remainder. Economic values were quantified using VSL = 7.6M USD.

Year	Scenario	Mortality	Mortality per 1,000,000	Economic Value
$PM_{2.5}$ MASS				
2035	BAU	608.04	242.46	(cost) $ 4,234,770,176
2035	Scen A saving	12.12	4.83	$ 84,411,920
2035	Scen C saving	12.56	5.01	$ 87,779,543
Tracer 1 - Gasoline				
2035	BAU	21.16	8.44	(cost) $ 147,378,448
2035	Scen A saving	3.42	1.36	$ 23,807,160
2035	Scen C saving	3.50	1.39	$ 24,346,360
Tracer 3 - Diesel				
2035	BAU	19.79	7.89	(cost) $ 137,825,424
2035	Scen A saving	2.49	0.99	$ 17,331,380
2035	Scen C saving	2.81	1.12	$ 19,573,342
Tracer 9 - Including tire & brake wear				
2035	BAU	11.28	4.50	(cost) $ 78,577,400
2035	Scen A saving	0.00	0.00	0
2035	Scen C saving	0.00	0.00	0

4. Discussion

The modeling presented in this report indicates that the proposed expansion of Oregon's Clean Fuels Program (CFP) is likely to produce a significant air quality benefit, with associated reductions in mortality. While quantification of Oregon-specific morbidity impacts is outside the scope of this project, some national-based morbidity effect is included in the health benefits calculation within BenMAP, which relies on a Value of Statistical Life estimate that includes a combined morbidity and mortality impact.[30] This aligns with the prevalent consensus within transportation and air quality research literature: displacing petroleum-based transportation fuels for non-petroleum alternatives typically yields improved air quality. The modeling conducted in this study indicates that the changes in Oregon's transportation fleet and fuel mix consistent with the proposed expansion of Oregon's CFP is likely to significantly reduce emissions of criteria air pollutants through 2035. These reductions should reduce the incidence of air quality related health impacts, thereby reducing anticipated premature mortality by around 12 deaths per year in 2035, as compared to a counterfactual BAU scenario in which the transportation fleet and fuels stayed largely unchanged. Comparatively little difference in mortality outcomes was noted between the Scenarios A and C, largely reflecting the expected prevalence of vehicles equipped with particulate filters and sustainable catalytic reduction (SCR) systems in the Oregon fleet by the end years of this study, and to a lesser extent some of the analytical and modeling choices made during CFP compliance scenario development.

4.1 Modeling and Analytic Uncertainty

As with any modeling study, there are several sources of uncertainty that likely impact the outcomes presented in this report. The air quality impacts of any transportation system are dependent on a number of factors, including characteristics of the vehicle and energy systems in the transportation system, as well as natural or climatic factors that influence the behavior of pollutants after they are emitted. This uncertainty is magnified by the fact that estimates of secondary pollutant formation, a critical component of this analysis, is affected by emissions from sectors outside the scope of this study as well as by projections of future weather conditions. Changes in global average temperature often yield non-linear impacts on weather in any given region, and secondary pollutant formation often follows non-linear relationships between input factors. Similarly, the Oregon vehicle fleet that produces the pollutants modeled in this study is, in real life, determined by the vehicle purchase and operation decisions made by Oregon residents and travelers, and all long-term modeling of such decisions is inherently uncertain.

Despite these factors, the results and key lessons of this study offer significant guidance to policy makers and other interested stakeholders. While there are numerous uncertainties and non-linear relationships embedded within the analysis performed here, the outcome aligns with similar work done elsewhere as well as informal heuristics used to generate informal estimates of air pollution impact. The most prevalent and relevant changes to Oregon's vehicle fleet under the compliance scenarios are a replacement of internal combustion engine vehicles by zero-emission vehicles. The sales share of EVs rises significantly, but does not reach 100% by 2035. This results in a fleet still predominantly consisting of internal combustion engine vehicles in 2035. The substitution of a significant fraction, but not the majority, of vehicles with zero-emission equivalents would be expected to yield a reduction in air pollution mortality of a comparable magnitude, which it does in this study.

Future work can build on the methods and results presented in this study to improve understanding and ultimately reduce the uncertainty associated with these projections.

4.2 Interpreting the Scenario C Outcomes

The relatively small difference between health impacts between Scenarios A and C seems, at first glance, to be an unexpected outcome. Given that low carbon fuels have historically also produced significant air quality co-benefits, the 3.6% increase in avoided mortality seems aberrantly low, coming from a nearly 50% increase in program stringency. Deeper examination of the technologies and modeling assumptions involved, however, offers an explanation.

The CFP compliance scenarios studied here were developed, in large part, by considering the impact of two policy-driven changes in Oregon's vehicle fleet that would occur in 2035. The first change is a shift in ZEV adoption rates, driven by the adoption of Oregon SB 1044 and California's Advanced Clean Trucks rules. This will result in a significant transition from gasoline ICE vehicles in the light-duty sector in favor of EVs, and a smaller but still significant transition towards EVs in the medium- and heavy-duty sectors. These transitions will provide robust CFP credit generation potential, and also reduce deficit generation by eroding the market for high carbon petroleum fuels. The effect of these policies, combined with modest growth in volumes of other alternative fuels, will provide sufficient credit for the CFP to attain the 25% program target specified in Executive Order 20-04. Critically, meeting the 25% target will not require significant growth in biodiesel and renewable diesel consumption, so such growth is largely absent in Scenario A.

Because attainment of the CFP target appeared to be feasible based on already existing or planned policy changes, DEQ and the scenario research team, in consultation with a variety of stakeholders, considered what additional measures were likely to be feasible given the expected economic, technological and regulatory landscape expected in Oregon through 2035. Expanding the consumption of renewable diesel (RD) was a key option for generating additional CFP credits. At present, RD accounts for about 25% of the total diesel fuel pool in California, due in large part to the strong incentive provided by its Low Carbon Fuel Standard. There are several billion gallons of RD production capacity projects at some stage of development in North America, most of which could conceivably ship to the Oregon market. In fact, the rapid growth of Oregon's renewable fuels market was one reason behind the quick expansion of RD production capacity in North America. As such, displacing 25% of the residual diesel volume in 2035 with RD was judged to be a reasonable outcome from a significant increase in the CFP target.

The Scenario C scenario was therefore developed with that additional 25% displacement of petroleum diesel as its core, with smaller deployments of other alternative fuels including RNG and hydrogen in addition. A strong body of research exists that demonstrates the potential of RD to reduce life cycle GHG emissions when displacing petroleum, and similar forward looking modeling studies also project significant growth in this sector.[31] While significant air quality benefits from RD have been noted by multiple studies in the past, recent work has indicated that RD offers minimal air quality benefit when consumed in modern diesel engines, particularly those equipped with diesel particulate filters (DPFs) and sustainable catalytic reduction (SCR) systems, such as those required by Federal regulation since 2010.

The relatively limited air quality benefit from the additional RD modeled in Scenario C should therefore be interpreted as a reflection of the expected penetration of trucks using the most effective emission control technology in Oregon, coupled with an artifact introduced by the way the two compliance scenarios were developed. It is exceedingly unlikely that in the real world, the difference between a 25% CFP target and a 37% one would be limited solely to the presence or absence of the volume of RD considered in this study; rather, the different targets would yield different levels of incentive across the full portfolio of fuels and we would expect to see changes in the composition of Oregon's vehicle fleets and fuel portfolio across a much wider scope of fuel types.

It is also important to note the impact of time horizon in interpreting this result. Existing regulations require post-2010 model year heavy-duty diesel vehicles to be equipped with DPF and SCR systems. Given the long lifespan of diesel vehicles, a significant fraction of vehicles on the road today and for the next several years would come from pre-2007 or 2010 model years. By 2035, however, only a very small fraction of total vehicles would remain. This study performed explicit emissions characterization and air pollution modeling for the expected fleet only in 2035, which means that the study did not capture the value of RD in reducing PM and NOx emissions over the intervening years.

Taken together these factors suggest that the relatively minimal gap between Scenarios A and C reported in this study may be a slight underestimate of likely real-world impact. RD would be expected to yield greater emissions benefits in the near term, when a greater fraction of the fleet is not required to operate DPF and SCR systems. Also, in practice, increasing CFP target stringency from 25% to 37% would be reflected by a change in the full portfolio of fuels coming into the Oregon market, rather than an increase almost solely in one type of fuel. At the same time, the results presented in this report strongly suggest that the vast majority of air quality benefit in 2035 and beyond will come from the transition to ZEVs rather than the replacement of petroleum fuels by somewhat cleaner non-petroleum alternatives. It is also important to note that this study only considers emissions from vehicles operating within Oregon and assumes minimal, if any, fuel production activity within Oregon. Given the well-described relationship between petroleum production and processing and air pollutant emissions, it is entirely possible that the fuel portfolio changes discussed in this report would yield effects that would not be captured by the analysis conducted herein.

Finally, it is important to reiterate the distinction between criteria air pollutants and GHGs. While this study finds relatively little benefit to air quality from higher CFP targets, this finding does not call the GHG benefits of such fuels into question, nor does it account for climate-driven impacts on health or economic activity.

5. Conclusion

UC Davis researchers modeled the expected impacts for two proposed compliance scenarios for Oregon's Clean Fuels Program. Based on this modeling, both proposed compliance scenarios are likely to yield significant reductions in health impacts, primarily through the reduction of vehicular PM. Approximately 12 deaths per year would be avoided in 2035 by the changes reflected in Scenario A, and approximately 12.5 deaths per year would be avoided by the changes reflected in Scenario C, both compared to a modeled business-as-usual scenario. These results align with expectations of impact based on the portfolio of technologies and fuels that would likely be used to comply with an expanded CFP.

6. Funding Acknowledgement

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7. Appendix

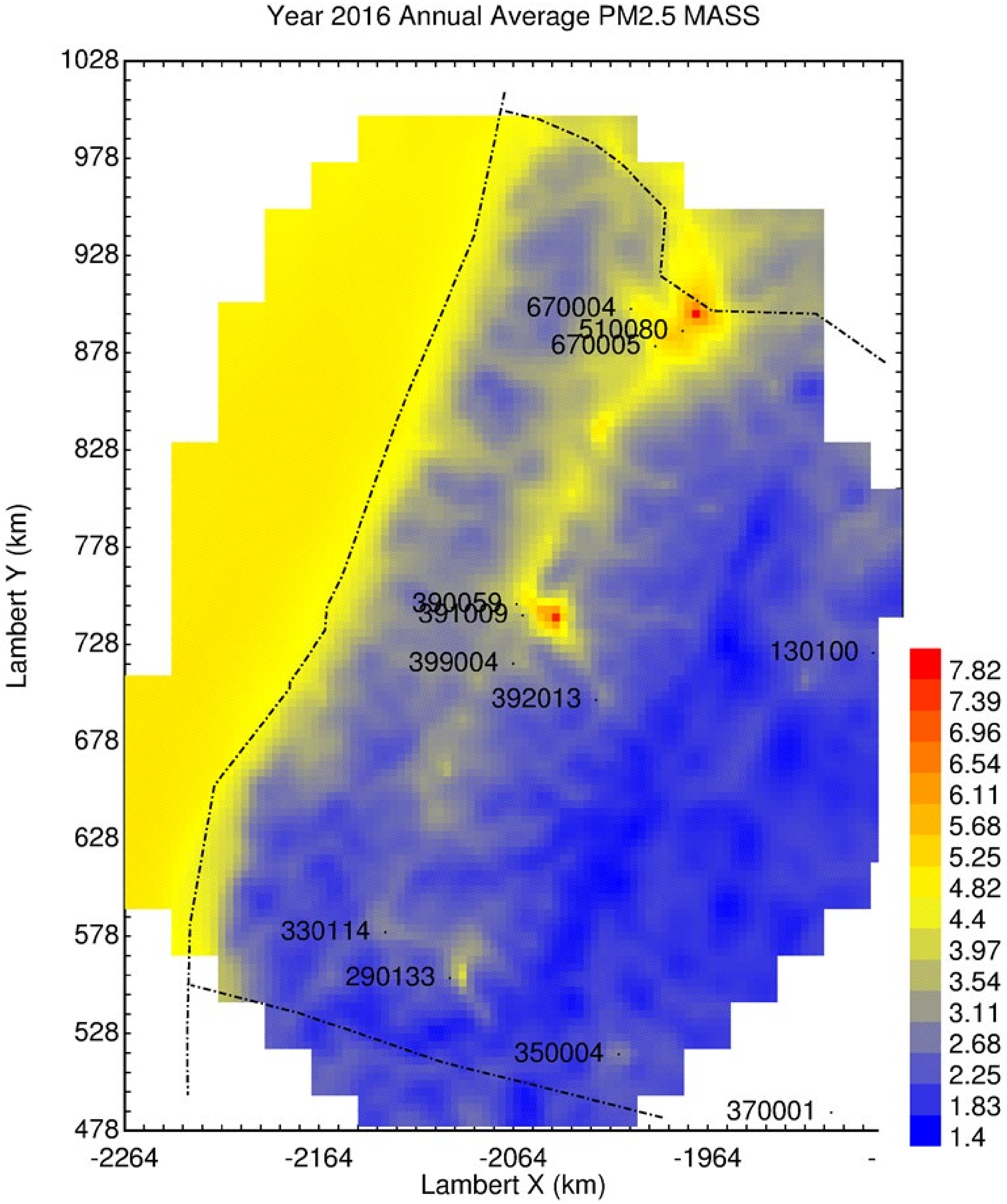

Figure S1. Location of PM2.5 measurement sites.

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