Final Report

Modeled Impacts of Oil and Gas on air quality and human health

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Executive Summary

The primary goal of this modeling study is to estimate the modeled impacts on U.S. air quality and human health, of emissions associated with the Oil and Gas (O&G) sector. In order to estimate the impacts, two full-year photochemical modeling runs were developed, conducted and analyzed. These runs represent a 2025 Baseline case and the Zero-Oil&Gas scenario (both model runs represent the year 2025). The future year 2025 was selected for modeling because EPA recently released a 2025 modeling platform designed for national air quality policy analysis. The year 2025 also represents a realistic time frame in which a newly proposed air quality policy could be implemented. The tools used to carry out this study are the Sparse Matrix Operator Kernel Emissions (SMOKE) to develop the emissions inventories, the Comprehensive Air quality Model with extensions (CAMx) to conduct photochemical modeling, and the Benefits Mapping and Analysis Program (BenMAP) to estimate human health impacts.

Results will present the impacts of each scenario on modeled concentrations of O_3. Ambient concentrations of O_3 are controlled under the NAAQS, and exposure has been linked to negative human health impacts including increased mortality. Analysis of emissions inventories will focus on the impact of each scenario on emissions of VOCs and NOx from the O&G sector although changes to all species associated with O&G emissions will be modeled. Both VOCs and NOx are precursors to the formation of ozone, and are two species associated with O&G.

A 2025 "Baseline" case is developed to represent a business as usual scenario (no additional future controls). This Baseline case represents a best estimate of 2025 emissions inventory, including all national regulations promulgated by December 2014, plus state-level O&G controls passed in the states of Colorado and Wyoming (these state-level policies were not included in the base 2025 episode developed by the US EPA but were added to the "Baseline" described in this study).

A 2025 "Zero-Oil&Gas" scenario is developed to represent conditions in 2025 if there were no emissions from the O&G sector. To develop the "Zero-Oil&Gas" scenario, all emissions from the O&G sector (3.5 Million tons VOCs, and 1.2 million tons NOx) were removed from the Baseline case. By comparing modeled output from the Zero-Oil&Gas control scenario to the Baseline case, the impacts on air quality of emissions from the O&G sector can be estimated. The inventories for the modeling runs were developed for this study using two publically available full-year emissions inventories, developed by the U.S. Environmental Protection Agency (EPA) for the purpose of policy analysis.

Modeled impacts of the O&G sector on ozone formation were evaluated by calculating the maximum daily 8-hour averaged ozone concentrations (MDA8) for each day of each scenario and each 12km grid cell over the continental US. The MDA8 was then used to calculate five different ozone metrics to estimate how each scenario would impact the annual average, ozone season average (May through September), and the average MDA8 on days characterized by high ozone. In the Southern US, there are many areas where the model estimates that the O&G sector contributes greater than 1 ppb on average over the entire ozone season. The change in average MDA8 on days with high modeled ozone was also calculated for the Zero-Oil&Gas scenario throughout the model domain and at all regulatory ozone monitors throughout the country. Many states in the south and mountain-west realize modeled average ozone greater than 5 ppb attributable to emissions from the O&G sector on days characterized by high ozone. For the majority of metrics, maximum modeled ozone impacts (contribution to ozone from O&G sector emissions) were realized in Texas.

For the Zero-Oil&Gas scenario, the human health impacts associated with changes in ozone concentrations, relative to the Baseline scenario, are estimated. BenMAP receives MDA8 inputs values

for each model grid cell and each day during the ozone season (defined here as May 1st – September 30th) for both model runs, and calculates the difference in MDA8 between the Baseline case and the Zero-Oil&Gas scenario. The differences between the health impact in the baseline and ZeroOil&Gas cases – i.e., the health impacts attributable to O&G sector emissions, are as follows:

- Acute respiratory symptoms: 1,547,514
- Asthma exacerbations: 755,177
- School loss days: 551,592
- Asthma-related emergency department visits: 1,910
- Hospital admissions – respiratory: 618

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I. Introduction

This report documents the development and the results of two photochemical modeling runs designed for a modeling study conducted for the Clean Air Task Force (CATF). The primary goal of this modeling study is to calculate the modeled impacts on U.S. air quality and human health, of the total emissions from the oil and gas (O&G) sector estimated for the year 2025.

In order to estimate the impacts of emissions associated with the O&G sector, two full-year photochemical modeling runs were developed, conducted and analyzed. The future year 2025 was selected for modeling because EPA recently released a 2025 modeling platform designed for national air quality policy analysis. The year 2025 also represents a realistic time frame in which a newly proposed air quality policy could be implemented.

A 2025 "Baseline" case is developed to represent a business as usual scenario (no additional future controls). A 2025 "Zero-Oil&Gas" scenario is developed to represent conditions in 2025 if there were no emissions from the O&G sector. The inventories for each of these modeling runs were developed for this study using two publically available full-year emissions inventories, developed by the U.S. Environmental Protection Agency (EPA) for the purpose of policy analysis.

This report is organized as follows: In Section II, the development of the two emissions inventories will be described in detail. State level changes to VOC and NOx emissions will be reported with nation-wide maps showing spatial changes to emissions. In Section III, tools and procedures for conducting the photochemical grid modeling will be described. Section III will also present model results showing estimated impacts of the Zero-Oil&Gas scenario on daily maximum 8hr averaged ozone concentrations (MDA8) and annually averaged fine particulate matter. Finally, Section IV will introduce procedures for using human health impacts modeling tools to estimate the changes in human health outcomes (including changes to human mortality). The calculated human health impacts associated with the scenario will also be described in Section IV.

II. Emissions Inventory Development

The two inventories used in this study are based on the 2011 National Emissions Inventory (NEI), and a 2025 inventory, the latter projected from the 2011 NEI, and both developed by the EPA. Therefore, this section will first present a summary of the 2011 and the 2025 EPA inventories with a focus on the O&G sector. This section will then describe in more detail the emissions inventories developed for this study: the 2025 Baseline and the 2025 Zero-O&G scenario.

a. U.S. EPA's 2011 Platform version 6.2

The U.S. EPA's 2011 National Emissions Inventory (NEI) version 2 is the agency's best and most recent estimation of all natural and man-made emissions released during 2011 from all sources located in the 12-km national grid modeling domain shown in Figure 1 (EPA, 2015a). The 2011 NEIv2 was used to develop the 2011 emissions modeling platform version 6.2 (EPA, 2015b). The difference between an Inventory (the NEIv2) and the 2011v6.2 modeling platform is the development and application of additional input data needed to spatially and temporally allocation emissions, categorize reported emission species into the correct model species, and format the inventories for input into the air quality model. For example, NEIv2 emissions for non-point O&G are reported as an annual total by county. The data provided as part of the emissions modeling platform tells the emissions model how to allocate the annual totals of non-point O&G emissions to each hour of the model year and each grid cell within the model domain. The modeling platform also provides the ability to apply projection and control scenarios to the emissions inventory to represent growth of emissions and/or application of emissions controls.

The emissions model used for this platform is the Sparse Matrix Operator Kernal Emissions (SMOKE) model version 3.6 commonly used by the EPA for emissions processing (EPA, 2015b; Houyoux et al., 2002; IE UNC, 2015). All cases presented in this document are based on the 2011v6.2 modeling platform with changes made to the O&G emissions inventories that will be described in detail in the following sections.

Figure 1. Modeling domain, covering the continental US with 12km Grid Resolution

The EPA published a Technical Support Document in August 2015 which details the development of the 2011v6.2 modeling platform (EPA, 2015b). For ease of processing, the emissions inventories are split into 20 sectors listed in Table 1. Each emissions sector is reported and processed individually, and then all sectors are merged at the end of processing for input into the photochemical model. For the purpose of the air quality modeling study conducted for the CATF, only the emissions from the O&G sectors (both nonpoint and point source O&G) were changed from those developed by the EPA. No other sectors were changed. Therefore, information about the O&G sector inventories will be presented in this document. The reader is referred to the TSD document published by the EPA for details about all other sectors included in the modeling platform (EPA, 2015b).

Table 1. EPA's list of emissions inventory sectors with sector description

Category Description	Name
EGU non-peaking units	ptegu
Point source oil and gas	pt_oilgas
Remaining non-EGU point sources	ptnonipm
Agriculture	ag

Agricultural fires	agfire
Area fugitive dust	afdust
Biogenic	beis
Locomotives and category C1 & C2 commercial marine vessels	c1c2rail
Commercial marine	c3marine
Remaining nonpoint	nonpt
Nonpoint source oil and gas	np_oilgas
Residential wood combustion	rwc
Nonroad	nonroad
Onroad	onroad
Point source prescribed fires	ptprescfire
Point source wild fires	ptwildfire
Canadian dust	othafdust
Canadian and Mexican point sources	othpt
Canadian and Mexican nonpoint and nonroad sources	othar
Canadian and Mexican onroad sources	othon

The continued development and improvement of the emissions inventory associated with the O&G sector was a large focus during development of the 2011 NEI (EPA, 2015a). O&G inventory improvements include but are not limited to: updated emissions factors for some O&G sources, incorporation of new information provided by the Western Regional Air Partnership, improved resolution of area source emissions (emissions assigned to counties instead of by basins), and the addition of new SCC codes that provide the ability to apply more detailed information (ie: distinction between natural gas and coal bed methane wells). Additionally, the EPA created a tool called the Nonpoint oil and gas emissions estimation tool in order to provide a consistent method to generate O&G inventories when they were not provided by the states (EPA, 2015a; ERG, 2014).

The oil and gas tool ("the tool") is an access database with detailed county-level activity data (production, spud counts, feet drilled, completions and well counts all by well type), operational characteristics (equipment information), and emissions factors (Eastern Research Group, 2014). The tool is only used to generate emissions for states that do not provide state data. The following states submitted state specific non-point O&G data: California, Wyoming, Colorado, Kansas, Oklahoma, Texas, Louisiana, Missouri, Ohio, West Virginia, Pennsylvania and New York. All other states (with O&G production activity) used EPA non-point O&G emissions data generated using the tool.

The NEI reports emissions totals for criteria air pollutants (CAPs) and hazardous air pollutants (HAPs). CAPs are pollutant species associated with the National Ambient Air Quality Standards (NAAQS – EPA, 2015c), and HAPs are species associated with the Air Toxics Program (EPA, 2015d). Lead (Pb), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2), particulate matter with a diameter 10 micrometers or less (PM_{10}), and particulate matter with a diameter 2.5 micrometers or less ($PM_{2.5}$) are all CAPs with ambient concentration limits defined by the NAAQS. Volatile organic compounds (VOCs) and ammonia (NH_3) are not CAPs, but they are precursors to the formation of ozone (O_3) and $PM_{2.5}$, the latter two species are CAPs and are controlled under NAAQS. This study will evaluate and report the impacts of changes in emissions from the O&G sector on modeled concentrations of O_3 and $PM_{2.5}$.

b. U.S. EPA's 2025 Projected Future Emissions Inventory

Using the 2011 NEI v6.2 as a starting point, the U.S. EPA developed a 2025 future case by projecting population and production growth as well as the impact of federal emissions regulations promulgated as of December 2014. Each emissions sector is projected independently based on applicable criteria. Here the data and methods used to project the O&G sector will be summarized. The reader is referred to the TSD for information regarding the projection methods for other emissions sectors (EPA, 2015b).

Point and area O&G inventories for 2025 are projected by applying first a growth factor and then a control factor. Individual factors are developed for each O&G production area or "play" and for both natural gas and crude oil. O&G production growth is projected from 2011 to 2025 using play specific growth factors calculated using projection estimates from the US Energy Information Administration's 2014 Annual Energy Outlook (AEO, ref: EIA, 2014), as well as comments received from states on earlier NEI projections. For counties with O&G production that did not fall into one of the "plays" with data reported by the AEO, a "rest-of-Supply Region" growth factor was developed.

Control factors applied to the O&G sector include controls on growth only, representing rules that apply to new and modified sources only. Rules covering VOCs from the O&G sector include the New Source Performance Standards (NSPS). NSPS cover O&G storage tanks, gas well completions, pneumatic controllers and compressor seals. Within the O&G sector, Reciprocating Internal Combustion Engines (RICE), gas turbines and process heaters are also controlled under NSPS although these controls will have a larger impact on NOx emissions than VOC emissions. The modeled NSPS controls apply to growth only (new equipment) and the projection assumes a zero retirement rate for existing equipment. The 2012 NESHAP does include glycol dehydrators but according to the TSD, the NEI was not modified to take these rules into account.

c. Emission Inventories Prepared for this Modeling Study

This section reports the development of two full-year emissions inventories used in this modeling study to estimate the air quality and human health impacts of emissions associated with the O&G sector in the US. This section will report the impact of the scenario on emissions of VOCs and NOx from the O&G sector. Both VOCs and NOx are precursors to the formation of ozone, and are two species associated with O&G. The Zero-Oil&Gas emissions scenario described in this section will also impact emissions of other species. All changes to the emissions inventories (including all changes to species not specifically presented in this document) will be represented in the photochemical modeling runs and therefore the results presented in this document will include impacts of changes to all emissions species.

2025 "Baseline" Emissions Inventory

The 2025 Baseline inventory is designed to represent a "Business As Usual", or the best estimation of what actual emissions will be in 2025. The 2025 EPA inventory as described in Section II.b serves as the starting point for the 2025 Baseline inventory. While the 2025 EPA inventory does include the impact of NSPS on O&G emissions growth for specific sources (as discussed in the previous section), the 2025 EPA inventory does not include the 2014 Colorado O&G rules and the 2015 Wyoming O&G rules, both covering existing sources (CDPHE, 2014a; WYDEQ, 2015). Since these rules have been finalized, and are expected to lead to reductions in the corresponding state's VOC emissions in 2025, an effort was made to incorporate these rules in the 2025 Baseline emissions inventory. The only difference between the

2025 EPA inventory and the 2025 Baseline inventory is the reduction of emissions in the states of Colorado and Wyoming resulting from the O&G rules in those two states. All other emission sectors, and all O&G emissions outside Colorado and Wyoming remain unchanged from the 2025 EPA case.

Colorado

The Colorado Department of Public Health and the Environment (CDPHE) published a report presenting the estimated costs and VOC emissions reduction benefits of the 2014 Colorado O&G rules (CDPHE, 2014b). This CDPHE Cost Benefit analysis was used to estimate the emissions reductions from O&G source types covered by the rule. The cost/benefit analysis was conducted using data from 2010-2012 Colorado Air Pollutant Emissions Notice (APEN) database to determine the count of individual units in Colorado to which the rules were applicable. Therefore, it is reasonable to apply these results to an emissions inventory generated to represent 2011 activity data. Additionally, the CDPHE submitted state O&G data to the EPA for the 2011 NEI, therefore it is reasonable to assume some level of consistency between the 2011 NEI and the report published by the CDPHE for the Colorado O&G rules. Using two different sources of data in this manner will likely introduce error. Here is it assumed that that those errors are small when compared to the uncertainty associated with the O&G inventory (Zavala-Araiza et al., 2015).

Reductions were calculated and applied to the following emissions sources in the state of Colorado: pneumatic controllers associated with O&G production, tanks, fugitives, and glycol dehydrators. Reductions were applied independently to individual Colorado Counties using the county (FIPS) code, and to individual O&G processes within each county using the Standard Classification Codes (SCCs). Reductions were multiplicative and were applied to all emissions species from the corresponding source (for example: to reduce emissions from a unique source/county by 25%, all O&G emissions from that source/county would be multiplied by 0.75).

Table 2 summarizes the total Colorado VOC emissions, by source type, for the 2025 EPA inventory and 2025 Baseline inventory developed for this study. The difference and percentage reduction between the inventories, as shown in Table 2, represents the application of the 2014 Colorado O&G rules based on the CHPHE cost/benefit analysis. The following paragraphs describe in more detail how these reductions were calculated and how they were applied to develop the 2025 Baseline inventory.

Table 2. Colorado oil and gas VOC emissions by category for the 2025 EPA and the 2025 Baseline inventories (tons/year), plus the absolute and percentage difference between the two inventories.

(tons/year)	2025 EPA	2025 Baseline	Difference	% Reduction
Dehydrator	3,864	2,318	1,546	40%
Fugitive	57,751	24,255	33,496	58%
Pneumatic Devices	35,300	32,757	2,543	7%
Tanks	160,940	99,783	61,157	38%
No Additional Controls	93,082	93,082	0	0%
Total	350,938	252,197	98,742	28%

Tanks: In its 2025 projection, US EPA applied a 70.3% reduction to new tanks to model the impact of the NSPS. The Colorado O&G rules apply to VOC emissions from both new and existing tanks, but because new tanks were already covered, we calculated the reductions to the 2025 projection due the impact of the Colorado rules on existing tanks only.

First we calculated the abatement percentage that the CDPHE assumes for controls on tanks.

- The cost/benefit analysis conducted by the CDPHE estimates that the Colorado O&G rules will reduce VOC emissions from tanks by 60,873 tons per year (tpy)[1], which is approximately a 52% reduction compared to 2011 emissions in the NEI (CDPHE, 2014b).

Then we applied this percent control only to tanks that were existing in Colorado at the time of the 2011 inventory.

- We multiplied the VOC emissions in the 2011 Inventory (117,065 tpy) by this 52% reduction to get the reduction for existing tanks, 61,157 tpy.

Finally, we subtracted these VOC tons from the 2025 projection and calculated the net percent reduction.

- Subtract this reduction (61,157 tpy) from 2025 Inventory emissions (160,940 tpy) to get 2025 Baseline emissions of 99,783 tpy. The 61,157 tpy reduction represents a 38% reduction from 2025 Inventory emissions.

Therefore, a 38% reduction was applied to all 2025 emissions from tanks across the state to represent Colorado controls on existing tanks. The resulting 61,157 tpy VOC reduction from O&G tanks in Colorado closely matches the reduction of 60,873 tpy of VOC emissions estimated by the CDPHE. While the goal was to match the CDPHE reduction exactly, the additional reduction of 284 tpy, 0.18% of total tank emissions in Colorado, is not expected to change the result.

Dehydrators: The Colorado rules call for a 95% reduction of VOC emissions from all new and existing glycol dehydrators that emit greater than 6 tpy. Additionally, all dehydrators that emit greater than 2 tpy and are located within 1,320 feet of a building/infrastructure must also achieve 95% reductions in VOC emissions (CDPHE, 2014b). At the time the cost/benefit analysis was conducted, the CDPHE did not have the data needed to determine what percentage of dehydrators emitting between 2 and 6 tpy of VOCs were close enough to a building to trigger the controls. Therefore, they estimated the total VOC reduction from all dehydrators first assuming 100%, then 0% of 2-6 tpy dehydrators would trigger the controls. The resulting range of VOC reductions is approximately 1,472 to 1,736 tpy according to the CDPHE[2]. According to the 2011 NEI, the total VOC emissions from glycol dehydrators in Colorado is 4,018 tpy. If the CDPHE reduction range (1,472 to 1,736 tpy) is applied to the 2011 NEI (4,018 tpy), the resulting reduction range is 37% to 43% with an average reduction of 40%. According to the 2025 TSD published by the EPA, NESHAP controls on new glycol dehydrators were not included, therefore for this baseline representation, the 40% reduction is applied to all glycol dehydrators in the 2025 inventory, both new and existing. The total glycol dehydrator inventory is 3,864 tpy of VOCs, therefore the final reduction from this source category is 1,546 tpy (40% of 3,864 tpy).

Pneumatic Controllers: In its 2025 projection, US EPA applied a 77% reduction to new pneumatic controllers to represent the impact of the NSPS. In Colorado, counties that are not in attainment of the 8-hour ozone standard already have rules covering pneumatic controllers, and the resulting emissions reductions have already been incorporated into the inventory. The Colorado O&G rules call for the

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[1] CDPHE, "Cost-Benefit Analysis." Tables 3, 6, 9, 11, 15. Add up reduction totals for the various tank controls: 5,162+457+117.7+1,750.4+53,386=60,873.

[2] Id at Pg. 34.

replacement of all new and existing high bleed pneumatic controllers with low bleed, throughout the state. To avoid overlap, we applied reductions only to controllers that exist in the 2011 inventory and are located outside of the ozone non-attainment area.

First we calculated the abatement percentage that the CDPHE assumes for controls on pneumatic controllers.

According to the Greenhouse Gas Reporting Program (GHGRP), 16% of existing emissions are from high bleed pneumatic controllers (EPA, 2014a). The high bleed VOC emissions factor is 37.5 standard cubic feet per hour (scf/h).[3] The low bleed VOC emissions factor, based on measurements made at well sites, is 5.1 (Allen et al., 2013). Therefore, the replacement of high bleed to low bleed will lead to an 86% reduction in VOC emissions. If we assume a 95% replacement, the resulting reduction is 82%, applied to 16% of emissions is 13%.

Then we applied this percent control only to pneumatic controllers that were existing in Colorado at the time of the 2011 inventory and located outside of the non-attainment area.

When that reduction is applied only to pneumatic controllers located outside the non-attainment area in 2011, 2,543 tpy is reduced in those areas.

Finally, we subtracted these VOC tons (2,543) from the 2025 projection and calculated the net percent reduction. That same total tpy reduction applied to all pneumatic controller emissions outside the non-attainment areas in 2025 is approximately 7% of the 2025 total.

Fugitive Emissions: Fugitive emissions are estimated to decrease an average of 58% for well pads and compressor stations, based on the tiered approach outlined in the CDPHE document.[4] The decrease in total fugitive emissions is 33,496 tpy when the estimated 58% reduction is applied to the corresponding fugitive sources (by SCC).

While the Colorado O&G rules were designed to reduce VOC emissions only, errors in emissions reporting lead to small changes in additional species from O&G sources. Table 3 reports the total NOx emissions inventory for the unchanged 2025 EPA case and the 2025 Baseline case. The total decrease in NOx emissions as a result of the application of the Colorado O&G rules is less than 1% of the total O&G NOx emissions.

Table 3. Colorado oil and gas NOx emissions by category for the 2025 EPA and the 2025 Baseline inventories (tons/year), plus the absolute and percentage difference between the two inventories.

(tons/year)	2025 EPA	2025 Baseline	Difference	% Difference
Dehydrator	129	88	41	32%
Fugitive	1	0	0	58%
Pneumatic Controller	0	0	0	0%
Tanks	573	355	218	38%
No Additional Controls	97113	97113	0	0%
Total	**97816**	**97557**	**259**	**0%**

[3] 40 C.F.R. Table W-1A to Subpart W. Available at: http://www.ecfr.gov/cgi-bin/retrieveECFR?gp=1&SID=0c3d3ddf4b6741d9088476b986a5e429&ty=HTML&h=L&n=40y21.0.1.1.3&r=PART#ap40.21.98_1238.1

[4] CDPHE, "Cost-Benefit Analysis." Tables 32 and 34

Wyoming

The 2015 State of Wyoming O&G rules are available on-line (WYDEQ, 2015). Like the Colorado rules, the Wyoming rules were designed to reduce emissions of VOCs only from O&G. The application of the Wyoming O&G rules is based on both this online documentation as well as the analysis developed by the State of Colorado. The Wyoming O&G rules are applied only in the ozone non-attainment area of the Upper Green River Basin (UGRB) as shown in Figure 2. The non-attainment area covers the entire Sublette County, and parts of the Counties of Sweetwater and Lincoln. Based on well locations in these three counties overlaid with geographical information about the Upper Green River Basin non-attainment area, approximately 4% of gas production in Sweetwater County is located in the non-attainment area, and in Lincoln County approximately 31% of the gas production is located in the non-attainment area.[5] Emissions reductions will be applied only to these three counties, and in the case of partial counties, control percentages will be reduced to represent the percentage of O&G wells in each county covered by the rules. For example, if O&G controls are expected to reduce emissions of VOCs by 25% from a particular SCC in Sweetwater County, a reduction of 1% (25% x 4%) will be applied to total emissions associated with that SCC in Sweetwater because only 4% of wells are located in the non-attainment area. This assumes that emissions are equally distributed between well sites in those partial counties. Data is not available to test this assumption.

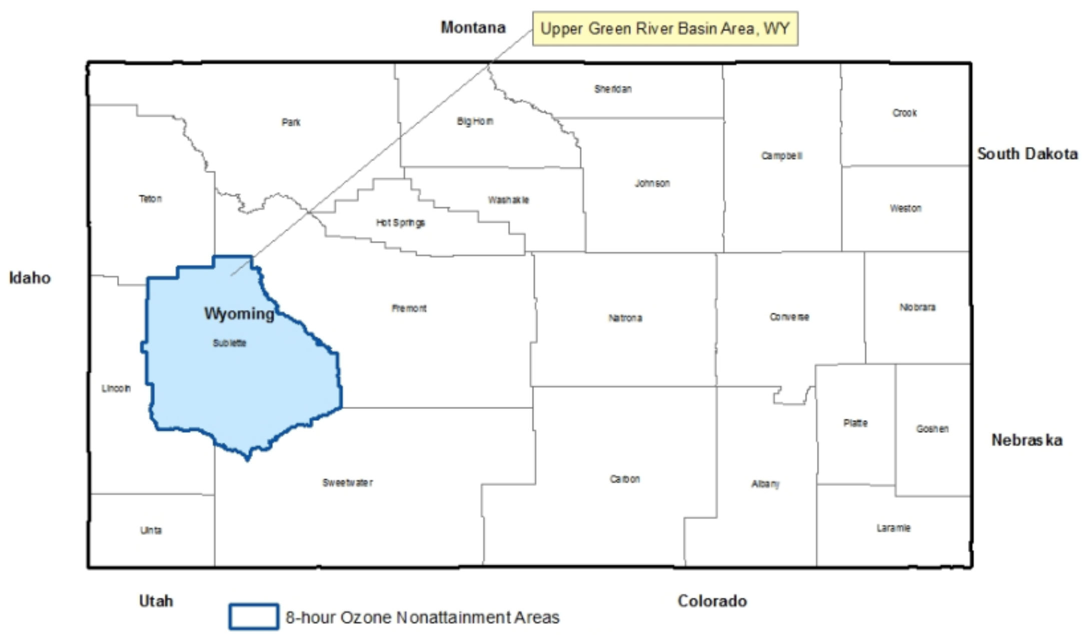

Figure 2. Map of 2008 ozone non-attainment area in the Upper Green River Basin (UGRB) in Wyoming.

Table 4 summarizes the Wyoming O&G VOC emissions inventory for the unchanged 2025 EPA case and the 2025 Baseline case. The following paragraphs describe in more detail the how reductions were applied to the state of Wyoming to develop the 2025 Baseline inventory.

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[5] Well locations: Production and geographical (lat/long) data for wells in Wyoming can be downloaded for each county here: http://wogcc.state.wy.us/productioncountyyear.cfm?Oops=#oops#&RequestTimeOut=6500 (2015 data was downloaded in July 2015, included data for January through May 2015).
Non-attainment area: A shapefile of the Upper Green River Basin non-Attainment area can be downloaded here as part of the "8-Hour Ozone (2008 Standard)" file: http://www3.epa.gov/airquality/greenbook/gis_download.html

Table 4. Wyoming oil and gas VOC emissions by category for the 2025 EPA and the 2025 Baseline inventories (tons/year), plus the absolute and percentage difference between the two inventories.

(tons/year)	2025 EPA	2025 Baseline	Difference	% Difference
Dehydrator	4,061	3,403	658	16%
Fugitive	22,247	20,047	2,200	10%
Pneumatic Controller	42,064	37,330	4,735	11%
Tanks	83,952	82,972	980	1%
No Additional Controls	20,189	20,189	0	0%
Total	172,513	163,941	8,572	5%

Tanks: Tank reductions in Wyoming apply to new and existing tanks located in the UGRB. Like Colorado, tank controls are applied only to existing tanks because NSPS covers all growth. We apply the same calculation method to calculate the emissions reductions from tanks in Wyoming that we used on the tank inventory in Colorado (see Colorado method above). The 52% reduction estimated for Colorado, if applied to the 2011 Wyoming tank inventory (63,726 tpy), would be equal to a 33,138 tpy reduction from existing tanks in Wyoming in 2011. In order to apply this to the 2025 inventory, the goal reduction of 33,138 tpy is compared to the 2025 Wyoming tank inventory of 83,952 tpy. The resulting reduction percentage of 40% (33,138/83,952) is applied to tanks in the non-attainment area only. This leads to a total reduction of 980 tpy, approximately 1% of the total tank VOC emissions in the state of Wyoming.

Dehydrators: The Wyoming rules cover both new and existing glycol dehydrators located in the UGRB, requiring a 98% reduction from all facilities emitting over 4 tpy of VOCs. Similar to Colorado, data on the number of dehydrators in Wyoming that meet the threshold is not available. Instead, the same reduction applied to dehydrators in Colorado is applied to Wyoming, except it is adjusted to represent a 98% reduction in Wyoming (versus the 95% reduction required in Colorado). The adjusted reduction of 42%, when applied to dehydrators in the non-attainment area, leads to a 658 tpy reduction in VOC emissions. This method assumes that the non-attainment area of Wyoming has the same size distribution of glycol dehydrators as the state of Colorado. Data to test this assumption is not available.

Pneumatic Controllers: The Wyoming rule requires that all new and existing high bleed pneumatic controllers (both continuous and intermittent) located in the UGRB be replaced with low or zero bleed. Because there was no emissions growth between the 2011 and 2025 inventories for pneumatic controllers in Wyoming, we assumed that all emissions in 2025 were from sources that existed in 2011 (no new controllers). Since we are assuming no new controllers, we applied the abatement percentage to all emissions in the non-attainment area. In Wyoming, we assume an aggressive zero bleed conversion because wells in the UGRB already have vapor recovery units on-site which can be used to set up closed-loop systems that capture bleeding gas. The high bleed continuous emissions factor is 37.5 scf/h[6], the low bleed emissions factor is 5.1, and the intermitted bleed emissions factor is 17.4 (Allen et al., 2013). Therefore, a conversion from high to low will be an 86% reduction, from intermitted to low will be a 54% reduction, and converting to zero bleed will be a 100% reduction. Here, 78% of high and

[6] 40 C.F.R. Table W-1A to Subpart W. Available at: http://www.ecfr.gov/cgi-bin/retrieveECFR?gp=1&SID=0c3d3ddf4b6741d9088476b986a5e429&ty=HTML&h=L&n=40y21.0.1.1.3&r=PART#ap40.21.98_1238.1.

intermittent bleed is replaced with low bleed, and 20% of high and intermitted bleed is replaced with zero bleed based on the aggressive conversion assumption. According to GHGRP data, 16% of pneumatic controller emissions are from high bleed controllers, and 80% are from intermittent controllers (EPA, 2014a). A resulting 74% reduction is applied to all 2025 pneumatic controllers at wells located in the non-attainment area.[7]

Pneumatic Pumps: In addition, the Wyoming rules require a 98% reduction in emissions from all pneumatic pumps in the non-attainment area. The resulting reduction for both pneumatic controllers and pneumatic pumps in the non-attainment area is 4,735 tpy.

Fugitive Emissions: In order to control fugitive emissions from O&G in Wyoming, the state rules require quarterly Leak Detection and Repair (LDAR) for all facilities greater than 4 tpy. If an across the board quarterly LDAR protocol is applied, rather than tiered approach, using the data presented by the CDPHE tables 32 and 34, abatement is estimated to be 60%. Since there is some degree of control already in place, the reduction was lowered to 50% in order to represent a more conservative value. A 50% reduction in O&G fugitive emissions applied to the non-attainment area leads to a 2,200 tpy reduction, approximately 10% of total state-wide O&G fugitive emissions.

While the Wyoming O&G rules were also designed to reduce VOC emissions only, errors in emissions reporting lead to small changes in additional species from O&G sources. Table 5 reports the total NOx emissions inventory for the unchanged 2025 EPA case and the 2025 Baseline case as well as the changes in NOx emissions between the two. The total decrease in NOx emissions as a result of the application of the Wyoming O&G rules is about 1% of the total O&G NOx emissions.

Table 5. Wyoming oil and gas NOx emissions by category for the 2025 EPA and the 2025 Baseline inventories (tons/year), plus the absolute and percentage difference between the two inventories.

(tons/year)	2025 EPA	2025 Baseline	Difference	% Difference
Dehydrator	576	372	204	35%
Fugitive	5	5	0	1%
Pneumatic Controller	148	15	133	90%
Tanks	650	613	37	6%
No Additional Controls	31917	31917	0	0%
Total	33296	32922	373	**1%**

2025 "Zero-Oil&Gas" Emissions Inventory

A second emissions inventory is created to represent national emissions in 2025 assuming that all emissions associated with the O&G production sector have been eliminated. All emissions from the O&G sector are removed from the inventory, while all other emissions sectors remain unchanged from the 2025 Baseline case. Therefore, by comparing the modeled ozone and fine particulate matter concentrations of the 2025 Baseline case to the 2025 Zero-Oil&Gas scenario, the model estimated air quality and human health impacts of the entire O&G sector can be calculated. Figure 2 shows a map of the modeling domain with the difference in total VOC (tpy) emissions between the Baseline and the

[7] 86% (reduction high to low)*78%*16%+100% (reduc. high to zero)*20%*16%+54% (reduc. inter to low)*78%*80%+100% (reduc. inter to zero)*20%*80%=74% reduction

Zero-Oil&Gas scenario inventories. Values shown in Figure 2 represent all modeled VOC emissions (annual totals) associated with the O&G sector in 2025. Table 6 shows total tons per year of VOC emissions by state for both the entire emissions inventory and the anthropogenic (human caused) inventory (EPA, 2015b). The anthropogenic inventory in Table 6 excludes emissions from biogenic sources, prescribed fires and wild fires. All other sectors as listed in Table 1 are included in the anthropogenic inventory. Table 6 also shows the percentage of both the total and anthropogenic VOC inventories made up by O&G VOC emissions. In all states, biogenic sources are the largest source of VOC emissions. In 11 states, the O&G sector is the largest source of anthropogenic VOC emissions.

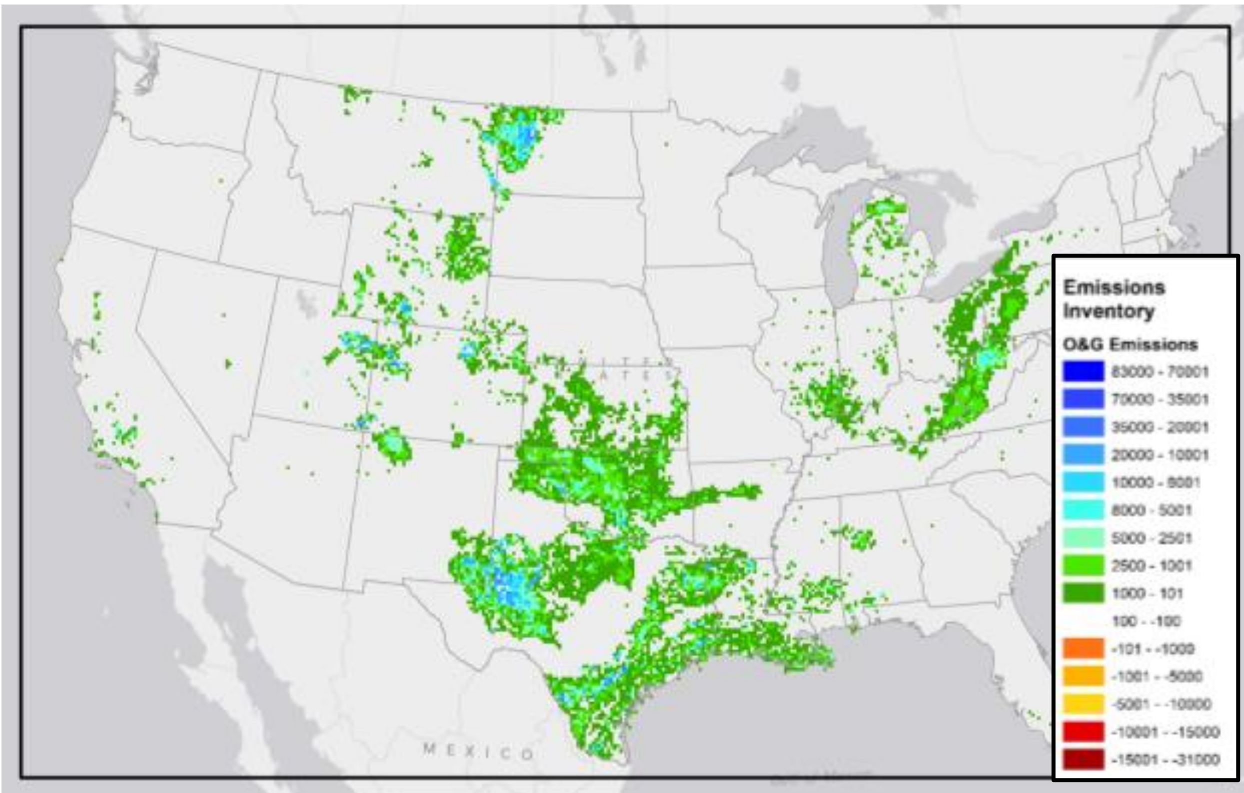

Figure 2. Baseline case total VOC emissions minus Zero-Oil&Gas Scenario total VOC emissions (tons/year). The modeling domain is outlined in black.

Table 6. Total tons per year VOC emissions by state, total VOC and anthropogenic only VOC, plus O&G VOC emissions percent of total and anthropogenic VOC.

State	Total	Anthropogenic	O&G % of Total	O&G % of Anthropogenic
Alabama	2,083,795	148,480	1.1%	15.2%
Arizona	2,418,193	109,164	0.0%	0.2%
Arkansas	1,813,337	121,707	0.8%	12.3%
California	2,922,690	460,541	0.8%	5.0%
Colorado	1,380,940	354,312	25.4%	71.2%
Connecticut	115,307	50,607	0.0%	0.1%

Delaware	38,434	14,884	0.0%	0.0%
District of Columbia	7,066	5,983	0.0%	0.0%
Florida	2,215,575	397,825	0.1%	0.6%
Georgia	2,174,045	223,818	0.0%	0.1%
Idaho	934,757	56,263	0.0%	0.1%
Illinois	700,604	268,928	4.2%	10.9%
Indiana	452,186	178,594	2.5%	6.4%
Iowa	422,082	117,239	0.0%	0.0%
Kansas	955,428	174,933	7.0%	38.5%
Kentucky	805,313	165,234	3.9%	18.9%
Louisiana	1,948,609	342,767	7.4%	42.1%
Maine	352,466	35,050	0.0%	0.1%
Maryland	237,466	84,105	0.1%	0.3%
Massachusetts	193,926	93,483	0.0%	0.1%
Michigan	764,799	258,706	4.4%	12.9%
Minnesota	946,934	163,231	0.0%	0.0%
Mississippi	1,760,581	138,369	1.6%	20.7%
Missouri	1,496,195	138,578	0.0%	0.1%
Montana	1,292,876	99,361	5.1%	66.9%
Nebraska	448,001	64,097	0.7%	4.8%
Nevada	1,056,621	43,652	0.1%	1.6%
New Hampshire	121,196	26,468	0.0%	0.0%
New Jersey	243,970	128,440	0.0%	0.1%
New Mexico	1,945,271	205,446	8.3%	78.6%
New York	665,783	275,228	1.3%	3.1%
North Carolina	1,324,217	216,620	0.0%	0.2%
North Dakota	597,935	343,885	50.8%	88.3%
Ohio	585,224	255,538	1.8%	4.2%
Oklahoma	1,848,344	399,638	16.6%	76.6%
Oregon	1,290,744	85,894	0.0%	0.1%
Pennsylvania	713,898	243,916	4.2%	12.3%
Rhode Island	31,229	13,962	0.1%	0.1%
South Carolina	1,044,306	120,201	0.0%	0.1%

South Dakota	474,058	50,160	0.8%	7.3%
Tennessee	1,023,900	167,324	0.2%	1.2%
Texas	8,382,207	2,151,240	18.7%	72.7%
Utah	935,528	222,118	17.8%	75.1%
Vermont	85,621	13,322	0.0%	0.0%
Virginia	1,037,266	180,925	0.7%	3.7%
Washington	744,373	146,494	0.0%	0.0%
West Virginia	567,989	142,306	17.7%	70.7%
Wisconsin	617,721	155,761	0.0%	0.1%
Wyoming	1,026,428	194,281	16.0%	84.4%
Total	55,245,432	10,049,078	6.4%	35.4%

Figure 3 shows a map of the modeling domain with the difference in total NOx (tpy) emissions between the Baseline and the Zero-Oil&Gas scenario inventories. Values shown in Figure 3 represent all modeled NOx emissions (annual totals) associated with the O&G sector in 2025. Table 7 shows total tons per year of NOx emissions by state for both the entire emissions inventory, including all sectors as listed in Table 1, and the O&G inventory only (EPA, 2015b).

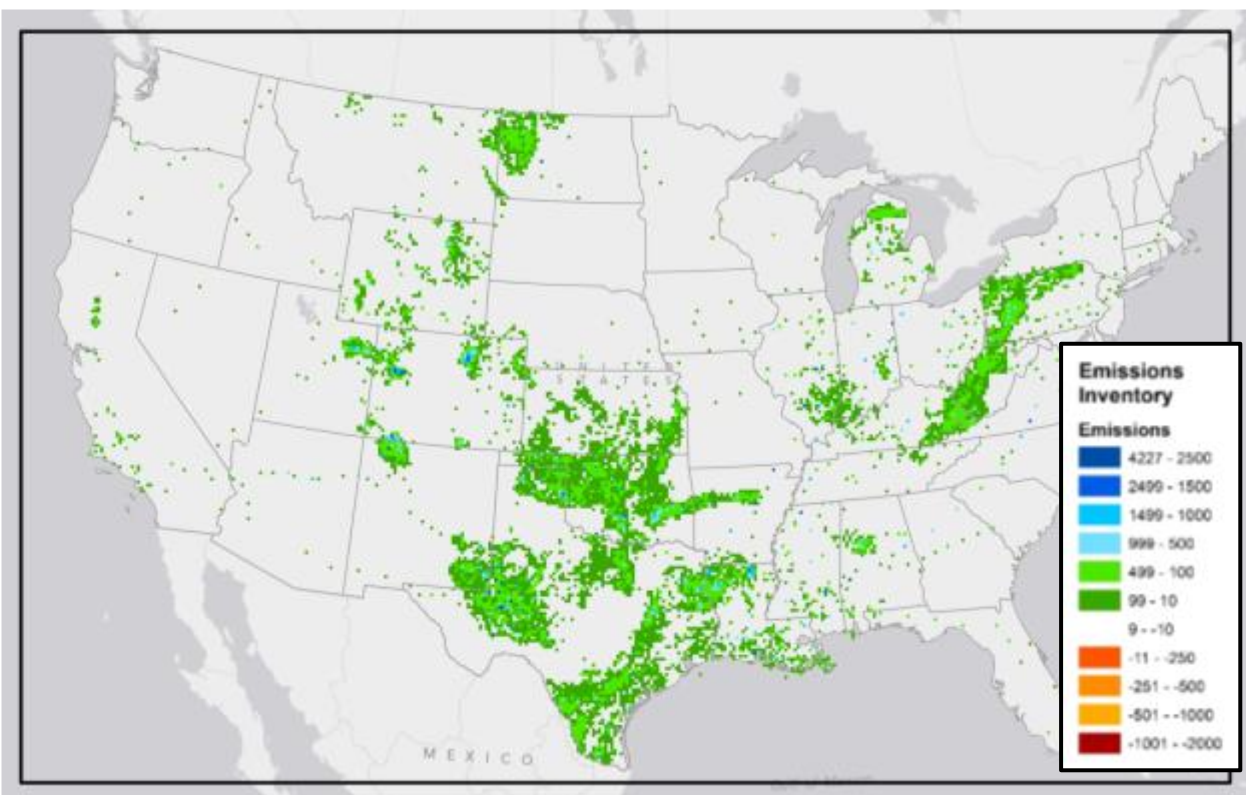

Figure 3. Baseline case total NOx emissions minus Zero-Oil&Gas scenario total NOx emissions (tons/year). The modeling domain is outlined in black.

Table 7. Total tons per year NOx emissions by state for all sectors, total NOx from O&G only, plus O&G NOx emissions percent of total.

(tons/year)	2025 Total (All Sectors)	2025 Baseline (O&G only)	% of Total NOx
Alabama	901,507	21245	2%
Arizona	1,730,874	1541	0%
Arkansas	993,970	25339	3%
California	1,551,598	7515	0%
Colorado	682,588	97557	14%
Connecticut	38,751	216	1%
Florida	1,366,992	2267	0%
Georgia	1,295,768	3193	0%
Idaho	856,642	1134	0%
Illinois	370,542	27636	7%
Indiana	309,921	18256	6%
Iowa	208,189	536	0%
Kansas	1,220,790	28228	2%
Kentucky	406,295	31281	8%
Louisiana	1,733,181	88016	5%
Maine	50,603	56	0%
Maryland	120,618	1188	1%
Massachusetts	81,205	236	0%
Michigan	313,703	25684	8%
Minnesota	1,015,727	157	0%
Mississippi	514,753	21566	4%
Missouri	848,477	416	0%
Montana	1,212,895	7286	1%
Nebraska	264,693	1560	1%
Nevada	168,426	257	0%
New Jersey	116,742	403	0%
New Mexico	1,215,404	62890	5%
New York	249,814	1974	1%
North Carolina	317,331	2769	1%
North Dakota	421,053	35997	9%
Ohio	314,060	9548	3%

Oklahoma	1,377,353	137459	10%
Oregon	1,624,352	769	0%
Pennsylvania	391,857	60395	15%
Rhode Island	13,225	26	0%
South Carolina	339,626	871	0%
South Dakota	571,321	233	0%
Tennessee	304,557	6452	2%
Texas	3,375,084	345692	10%
Utah	243,548	21118	9%
Virginia	343,310	11288	3%
Washington	452,652	307	0%
West Virginia	234,303	37339	16%
Wisconsin	188,472	587	0%
Wyoming	1,076,942	32922	3%

III. Photochemical Modeling

Once the emissions inventories are developed and processed using SMOKE as described, the simulations are then run using the Comprehensive Air Quality Model with extensions (CAMx) (www.camx.com). CAMx is a 3-Dimensional, Eularian photochemical model that simulates the emission, transport, chemistry and removal of chemical species in the atmosphere (ENVIRON, 2015). CAMx was selected for this study because it is one of the photochemical models recommended and often used by the U.S. EPA for regulatory air quality modeling purposes (EPA, 2015e) and is the model used in support of both the 2008 and 2017 Denver, Colorado ozone State Implementation Plans.[8]

CAMx version 6.2 was used for this study with the Carbon Bond 6 (cb6) chemical mechanism. The modeling domain, shown in Figure 1, is the 12US2 domain and covers the continental U.S. and all grid cells within the domain have 12 km by 12 km resolution. Individual grid cells are not shown in Figure 1; instead, the outline of the domain is shown. Within the 12 km domain, there are 396x246 grid cells that are 12 km on each side.

The meteorological inputs (including temperature, wind speed and direction, pressure, water vapor, cloud/rain, vertical diffusivity, and albedo) were developed by the EPA using the National Center for Atmospheric Research's (NCAR) Weather Research and Forecasting modeling system Advance Research WRF (WRF-ARW).[9] The meteorological inputs remain the same for each of the four simulations described and represent conditions as they occurred on the episode dates in 2011. By comparing meteorological model output to measurements made at meteorological stations throughout the US in 2011, a model performance evaluation (MPE) was conducted by the EPA for the 2011 meteorological modeling simulation and the results were found to perform within the recommended performance criteria (EPA, 2014b). The reader is referred to the EPA MPE document for additional information about

[8] http://www.colorado.gov/airquality/documents/deno308/
[9] http://www2.mmm.ucar.edu/wrf/users/docs/arw_v2.pdf

the model set-up and options chosen for meteorological modeling for the 2011 modeling platform (EPA, 2014b). Boundary and initial conditions for the simulations conducted for this study were generated by the U.S. EPA using output from the Goddard Earth Observing System 3-D chemical transport model (GEOS-CHEM: EPA, 2015b). The resulting concentrations of pollutant species modeled by CAMx were compared to corresponding measured concentrations in order to evaluate the performance of the 2011 modeling platform. The model performance statistics fell within the range of values reported by other recent model platform evaluations (EPA, 2015f).

Results will present the impacts of the Zero-Oil&Gas scenario on modeled concentrations of O_3. Ambient concentrations of O_3 are controlled under the NAAQS, and exposure to both species has been linked to negative human health impacts including increased mortality (Bell et al., 2004&2005; Krewski et al., 2009; Lepeule et al., 2012).

a. Photochemical Modeling Results: Ozone

The current NAAQS for ozone, finalized in 2015, is 70 ppb and attainment of this standard is determined at each air quality monitoring site in the U.S. using the three year running average of the fourth highest daily maximum 8 hour averaged ozone concentration measured at that site each year (EPA, 2016). For this study, results will be based on a single year of modeling.

In order to evaluate the impact of the scenario on O_3, the MDA8 concentration is calculated for each day of the year-long modeling period for each grid cell and each model run. Therefore, for each day and each grid cell within the modeling domain, the change in MDA8 between the Baseline case and the scenario can also be calculated. Using these daily MDA8 values, five different analyses will be conducted looking at the impacts of the scenario on five different ozone metrics.

As a first analysis, the change in the MDA8 is averaged across every day of the year, for each grid cell and for both model runs. The difference in this annual average MDA8 is calculated for the scenario by subtracting the annual average MDA8 for the scenario from the annual average MDA8 for the Baseline case (therefore positive values represent a decrease in MDA8 as a result of the scenario, and an improvement in air quality). In many cases, health impact studies have identified correlations between negative human health impacts (increased mortality for example) and ozone during warm months only (Smith et al., 2009; Zanobetti & Schwartz, 2008). For the second analysis, the average change in MDA8 will also be calculated for May – September (inclusive). This time period will be referred to as the ozone season due to increase photochemical production of ozone in the warmer temperatures and longer daylight hours. A third analysis will identify, for each grid cell, the largest single day decrease in MDA8 from the Baseline case to the scenario. This value represents the maximum modeled reduction in MDA8 for the scenario.

A fourth analysis approximates the impact of the scenario using a metric used in State and Federal regulatory modeling efforts to help determine attainment of the NAAQS. For this analysis, the ten days of the 2011 Baseline episode with the largest MDA8 values are identified for each grid cell. If those Baseline MDA8 values are greater than 60 ppb, the day is included in the analysis. Only grid cells with at least five days with MDA8 values greater than 60 ppb are used. By averaging days with the highest values for MDA8 (and only values greater than 60 ppb), the metric is assumed to capture conditions that cause the highest ozone concentrations in that area. An average MDA8 is calculated for each grid cell in the scenario using the same days used to calculate the Baseline high-day average MDA8. Finally, for the scenario, the difference in that high-day average MDA8 is calculated for each grid cell.

Similar to the high-day average MDA8 analysis, a final analysis estimates the modeled impact of the scenario on days characterized by high levels of ozone. For this final analysis, the change in MDA8 (between the Baseline case and the scenario) is averaged for all days of the year when the modeled Baseline case MDA8 is above a threshold value (threshold values of 65, 70, and 75 are evaluated). The difference between this metric and the high-day average MDA8 metric is that there is no limit to the number of days required to calculate this metric. For example, the change in MDA8 on all days greater than 75 ppb may only include a single day for some grid cells.

The following section present the results of each of these ozone impact analyses for the Zero-Oil&Gas scenario. Results for each of the five analyses are presented as a map showing the spatial distribution of changes to ozone for each metric. In addition, tables are presented showing the 20 regulatory ozone air quality monitors in the US with the largest modeled impacts on the high-day average MDA8 value.

Figure 4 shows the annually averaged change in MDA8 as a result of the Zero-Oil&Gas scenario, representing removal of all emissions from the oil and gas sector in 2025. The difference in air quality metrics between the Baseline case and the Zero-Oil&Gas scenario represent the modeled contribution of the O&G sector to air quality metrics in 2025. Widespread reductions in annually average MDA8 occur throughout much of the U.S. as a result of the Zero-Oil&Gas scenario. The maximum annual average decrease in MDA8 is 4 ppb in Texas. However, two areas of dis-benefit occur, one in Colorado and one in Pennsylvania, both as a result of large decreases in emissions of NOx from the O&G sector. In some areas, when NOx is in excess, that NOx reacts with ozone, locally reducing ozone. When that NOx is removed, ozone can increase locally. Figure 5 shows the ozone season average change in MDA8 (May – Sept) as a result of the Zero-Oil&Gas scenario. When compared to the annual season average change, the ozone season average change shows larger and more widespread impacts. Additionally, the two areas of NOx dis-benefit disappear likely because of increases in biogenic VOCs that occur during summer months. With higher VOC concentrations, it is likely that NOx is no longer in excess. The maximum change in ozone season MDA8 is 6.4 ppb, in Texas.

Figure 6 shows the maximum decrease due to the Zero-Oil&Gas scenario, on any day of the 2025 year-long modeling episode. The largest decrease in any grid cell on any day is 29 ppb in Texas. Figure 7 shows the modeled change in the average high-day average MDA8 as a result of the Zero-Oil&Gas scenario. The largest change in the high-day average MDA8 in any grid cell is 14 ppb in both Texas and Louisiana.

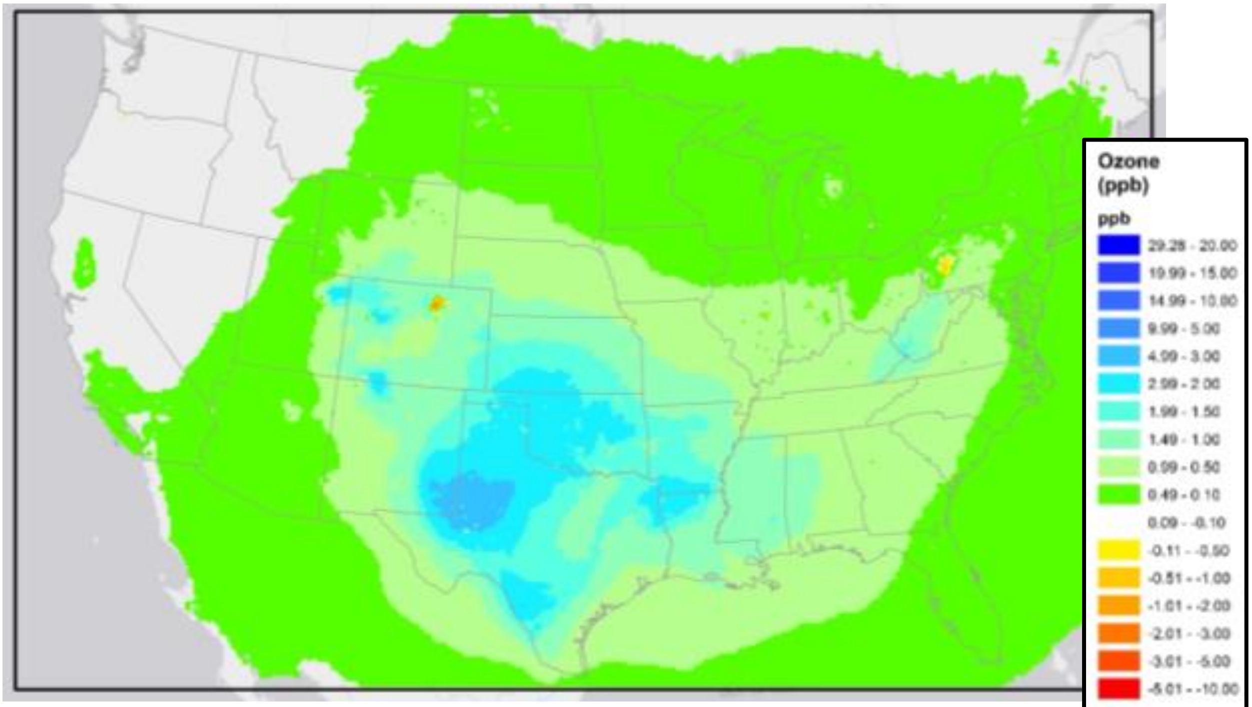

Figure 4. Change in the Modeled Annual Average MDA8 (ppb) as a result of the Zero-Oil&Gas Scenario (Baseline - Zero-Oil&Gas).

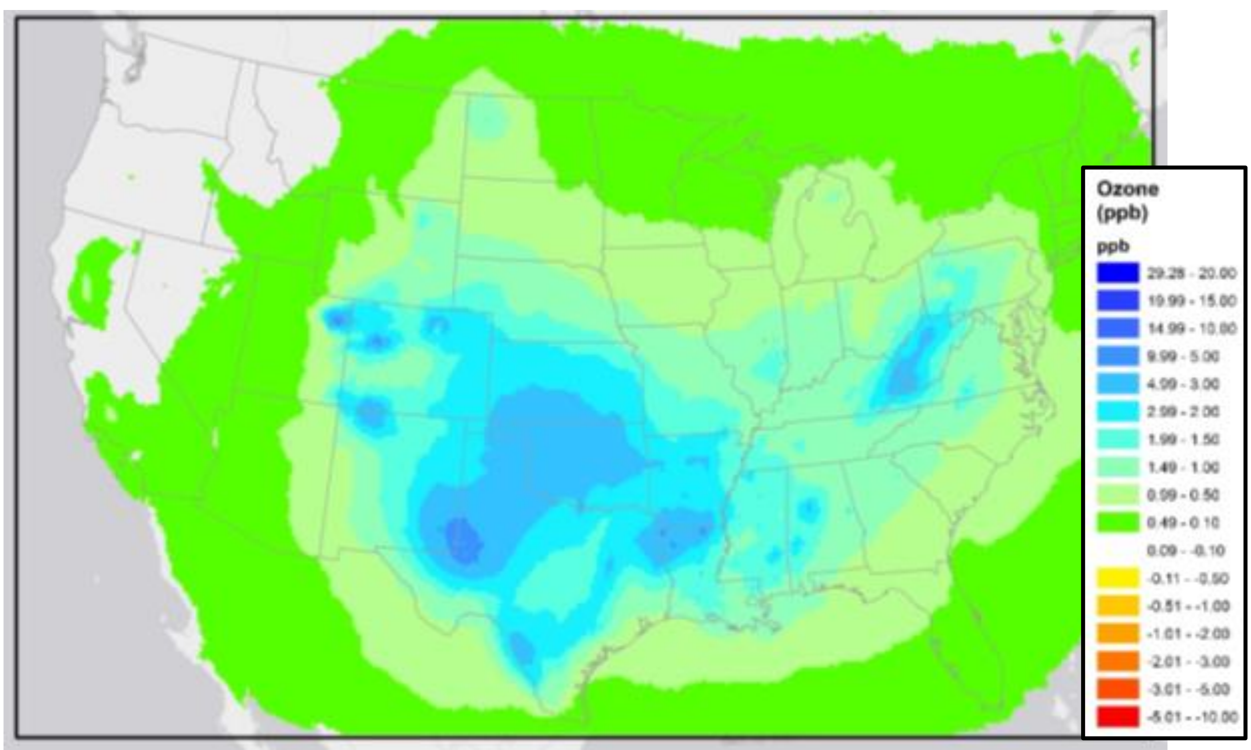

Figure 5. Change in the Modeled Ozone Season Average MDA8 (May – Sept, ppb) as a result of the Zero-Oil&Gas Scenario (Baseline - Zero-Oil&Gas).

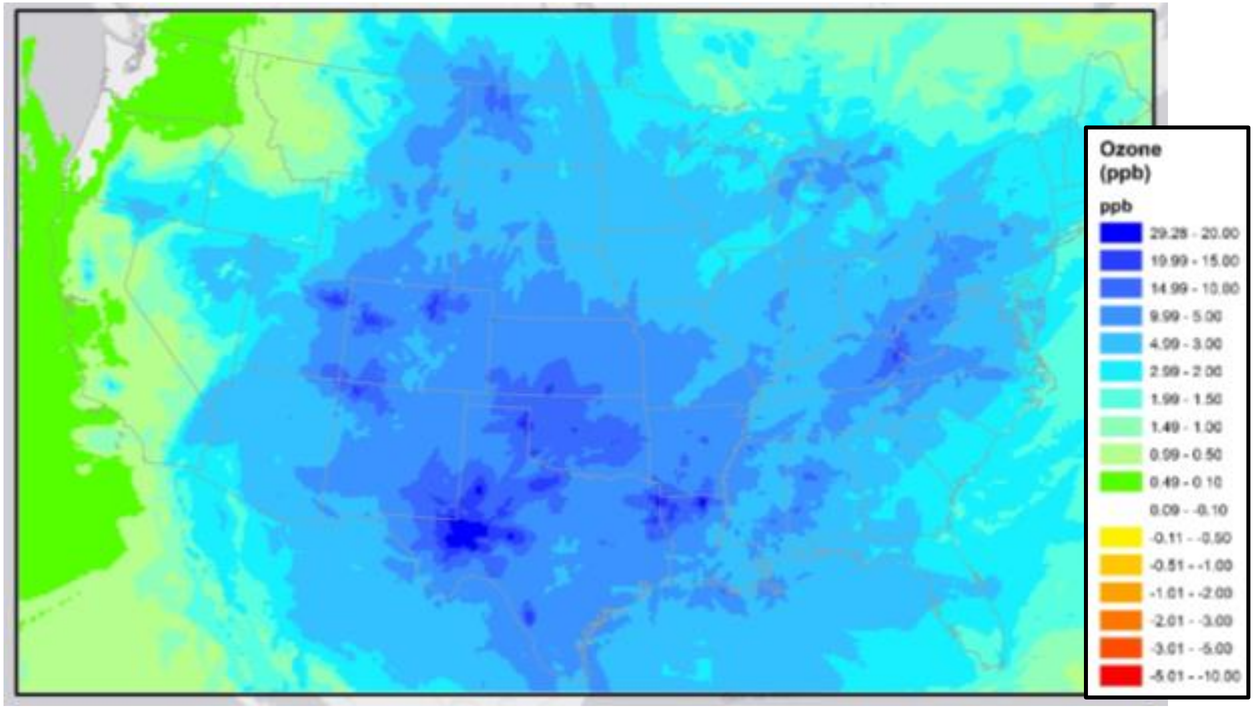

Figure 6. Maximum decrease in MDA8 (ppb) on any single day of the 2025 year-long modeling period, as a result of the Zero-Oil&Gas Scenario (Baseline - Zero-Oil&Gas).

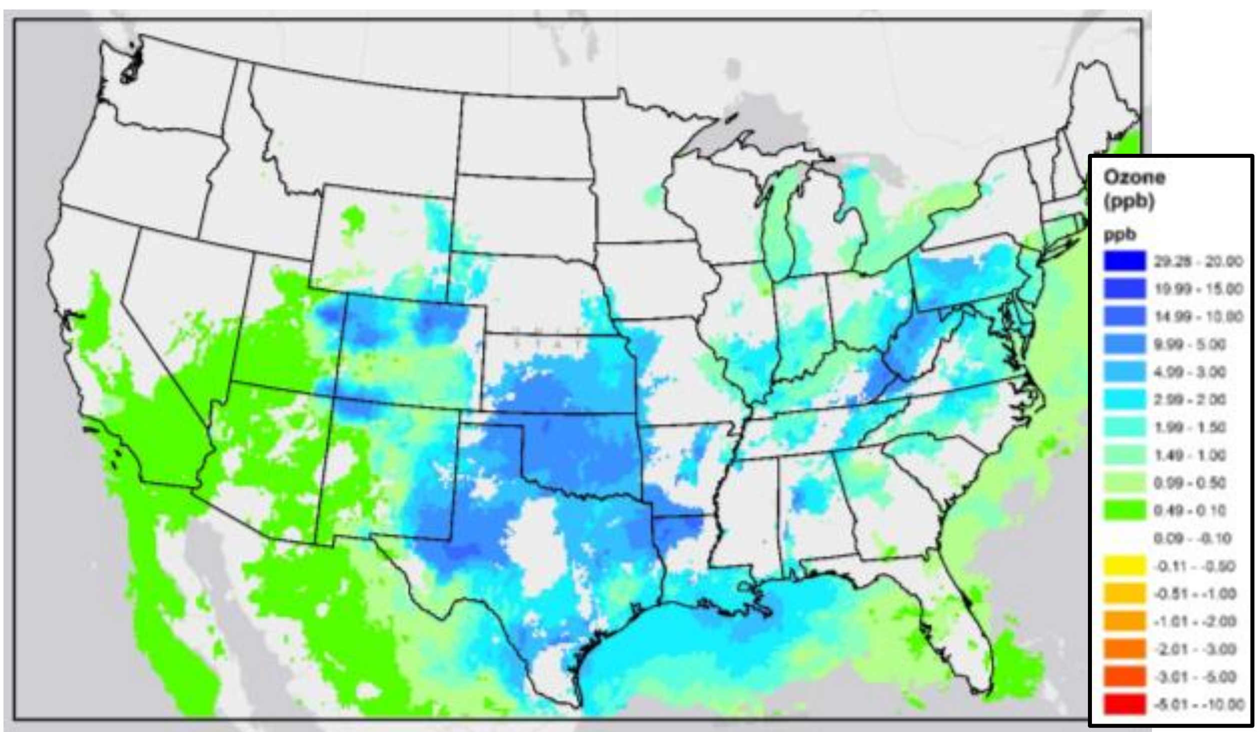

Figure 7. Change in the average "high day" MDA8 (ppb) as a result of the Zero-Oil&Gas Scenario (Baseline - Zero-Oil&Gas).

Figure 8 (a), (b) & (c) provides the threshold analysis results corresponding to thresholds of 65, 70 and 75 ppb respectively for the Zero-Oil&Gas Scenario. The maximum modeled impact averaged over all days with a Baseline MDA8 greater than 65 ppb is 21 ppb in Texas. Wyoming, West Virginia, Virginia, Utah, Texas, Tennessee, Pennsylvania, Oklahoma, New Mexico, Missouri, Mississippi, Louisiana, Kentucky, Kansas, Illinois and Arkansas all contain at least one grid cell with a modeled impact greater than 5 ppb on all days when the Baseline MDA8 is greater than 65 ppb. The maximum modeled impact, averaged over all days with a Baseline MDA8 greater than 70 ppb is 29 ppb in Texas. West Virginia, Virginia, Utah, Texas, Pennsylvania, Oklahoma, Ohio, New Mexico, Missouri, Louisiana, Kentucky, Kansas, Colorado, Arkansas, Arizona and Alabama all contain at least one grid cell with a modeled impact greater than 5 ppb on all days when the Baseline MDA8 is greater than 70 ppb. Finally, the maximum modeled impact, averaged over all days with a Baseline MDA8 greater than 75 ppb is 29 ppb in Texas. West Virginia, Utah, Texas, Oklahoma, New Mexico, Missouri, Louisiana, Kentucky, Kansas, Colorado, Arkansas and Alabama all contain at least one grid cell with a modeled impact greater than 5 ppb on all days when the Baseline MDA8 is greater than 75 ppb.

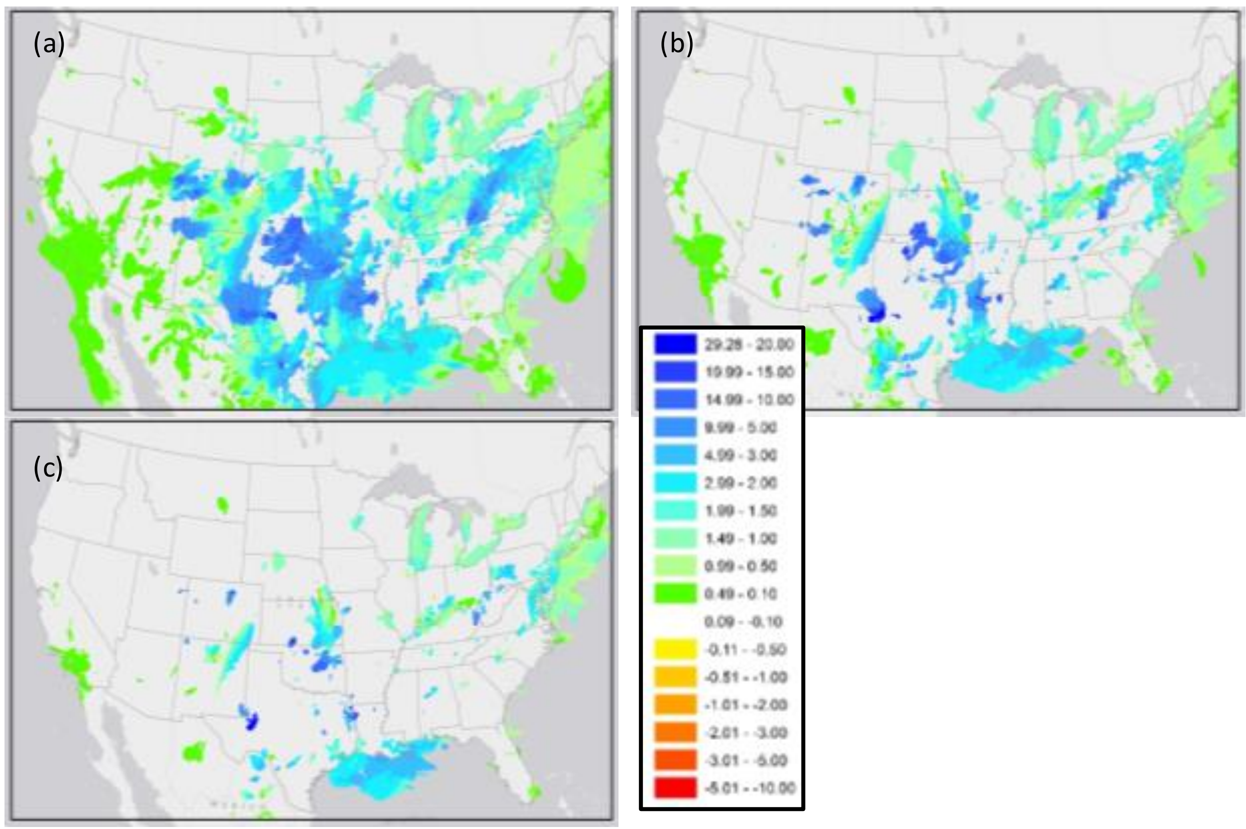

Figure 8 a-c. Threshold Analysis: Average change in MDA8 (ppb) due to the Zero-Oil&Gas Scenario on all days where the Baseline case MDA8 is greater than (a) 65 ppb, (b) 70 ppb, and (c) 75 ppb (Baseline - Zero-Oil&Gas).

Table 8 below presents the 20 regulatory ozone air quality monitors in the US with the largest modeled decrease in the high-day average MDA8 value, due to the Zero-Oil&Gas Scenario. For each monitor, the high-day average MDA8 for the Baseline run is reported, along with the number of days included in the calculation (must be at least five, and no more than 10), and the decrease in the high-day average MDA8 as a result of the Zero-Oil&Gas scenario. The contribution of emissions from the O&G sector to the Baseline case high-day average MDA8 value is represented by the value in the last column. There are 68 regulatory ozone air quality monitors in the US with a Baseline high-day average MDA8 value greater than 70 ppb, and a Zero-Oil&Gas MDA8 value for those same days less than 70 ppb (only two are shown in Table 15). This means that emissions from the O&G sector cause the high-day average MDA8 to go above the current ozone standard at 68 monitors in the US.

Table 8. Top 20 regulatory ozone air quality monitors in the US with the largest modeled decrease in the high-day average MDA8, as a result of the Zero-Oil&Gas Scenario (ppb).

Code	State	County	Number Days Included	Baseline	Zero Oil&Gas Modeled Contribution.
490472003	UT	Uintah County	10	69.6732	12.0693
220730004	LA	Ouachita Parish	10	67.3755	11.1489
400430860	OK	Dewey County	10	64.1986	9.9826
211950002	KY	Pike County	10	67.5318	9.9298
80450012	CO	Garfield County	10	67.6803	9.4340
81230009	CO	Weld County	10	70.2805	9.3967
211930003	KY	Perry County	10	64.6542	9.1308
220170001	LA	Caddo Parish	10	68.3459	8.6928
482030002	TX	Harrison County	10	67.5423	8.6912
490472002	UT	Uintah County	10	68.7141	8.5665
401210415	OK	Pittsburg County	10	67.8309	8.5217
220150008	LA	Bossier Parish	10	71.5686	8.4277
350250008	NM	Lea County	10	65.0240	7.8261
80691004	CO	Larimer County	10	69.5991	7.8147
350450009	NM	San Juan County	10	66.8100	7.4439
490471002	UT	Uintah County	10	65.0598	7.1963
80770020	CO	Mesa County	10	63.8249	6.8809
350450018	NM	San Juan County	10	66.0385	6.8325
490137011	UT	Duchesne County	10	63.6175	6.7448

IV. Human Health Impacts Modeling

For the Zero-Oil&Gas scenario, the human health impacts associated with changes in ozone concentrations are estimated using the Benefits Mapping and Analysis Program Community Edition 1.0 (BenMAP). BenMAP is available for download on the US EPA's website.

The approach used to calculate benefits in this study follows the methodology of the US EPA's Regulatory Impact Analysis (RIA) developed in support of the most recent update to the NAAQS for ozone (EPA, 2015e). Calculated changes to the modeled O_3 and $PM_{2.5}$ concentrations, presented in the previous session, are overlaid with forecast US census data representing 2025 (Woods & Poole, 2012) and projected county-level 2025 baseline incidence data (EPA, 2015e), and applied to the concentration-response functions (crfs) corresponding to the specific pollutant. The incidence and monetary benefits values represent total values for health benefits realized during the year 2025. BenMAP has built in population projections (including 2025) that incorporate economic predictions of changing population spatial distributions, which could be important given that pollution is often not spatially homogeneous.

Crfs are statistical relationships between small changes in ambient concentrations of pollution and human health endpoints. The crfs used in this study are all from published, peer-reviewed literature. For some human health endpoints, the result from each crf will be presented individually. In the case of some endpoints with multiple crfs, results from each crf are pooled together using the random/fixed effect pooling method to combine the results and provide a single value from multiple studies. The fixed effects pooling method weighs each crf value by the inverse variance of that particular study, giving more weight to studies with lower variance. The random effects pooling method accounts for both the within-study variance, and the variance between studies. Detailed information about the crfs used in this study is presented in the results sections below.

BenMAP CE has built in procedures to use Monte Carlo type assessment to estimate uncertainty intervals associated with random sampling errors and variability for each of the crfs. Therefore, with each result, the 95% confidence interval associated with that result will also be presented. In the case of incidence results, the 95% confidence interval will represent the uncertainty associated with the crfs.

a. Health Impact Results: Ozone

The health responses to modeled changes in ozone concentrations are estimated using the MDA8 concentrations. BenMAP receives MDA8 inputs values for each model grid cell and each day during the ozone season (defined here as May 1st – September 30th) for each of the model runs, and calculates the difference in MDA8 between the Baseline case and the scenario. Then BenMAP applies those differences to each individual ozone crf, using the projected 2025 population by grid cell, and projected 2025 incidence values by grid cell to calculate a change in the health endpoint due to the change in ozone.

While it is generally agreed that there is no threshold concentration below which exposure to ozone is safe, no matter what time of year (EPA, 2015e), many ozone crfs have identified correlations between ozone concentrations and human health endpoints during warm months only (Smith et al., 2009). Therefore, the impacts during the ozone season only (May – Sept) are calculated and presented here. Many areas of the modeling domain have warm weather and high modeled ozone outside of the ozone season and so the human health results presented here likely represent a lower bound to the full human health impacts associated with each of the scenarios.

Table 9 lists all the ozone mortality and morbidity crfs used in this study, and the pooling approach where appropriate. Table 9 also presents the national sum of the incidence results of the individual mortality crfs, and the pooled morbidity crfs, by endpoint category. The incidence results presented in Table 9 are national sums and therefore they do not show in detail the full number of people affected by this scenario by region.

Table 9. Concentration response functions, references, pooling methods and estimated human health incidence values (with 95% confidence interval) associated with changes to ozone resulting from the Zero-Oil&Gas scenario.

Endpoint	Study	Pooling Method	Zero-Oil&Gas
Premature mortality - short-term	Smith et al. (2009)		559 (299, 817)
	Zanobetti & Schwartz (2008)		332 (162, 501)
Hospital Admissions - Respiratory	Katsouyanni et al. (2009)		618 (-145, 1,377)
Asthma-related	Glad et al. (2012)	Random/Fixed	1,910 (177,

emergency department visits	Ito et al. (2007) Mar and Koenig (2010) Peel et al. (2005) Sarnat et al. (2013) Wilson et al. (2005)	Effects Pooling	5,920)
Asthma exacerbation	Mortimer et al. (2002) Schildcrout et al. (2006)	Random/Fixed Effects Pooling	755,177 (-229,668, 1,513,503)
School loss days	Chen et al. (2000) Gilliland et al. (2001)	Random/Fixed Effects Pooling	551,592 (194,794, 1,219,110)
Acute respiratory symptoms	Ostro and Rothschild (1989)		1,547,514 (639,009, 2,450,117)

V. Summary

This report documents the development and results of two photochemical modeling runs designed to estimate the modeled impacts on U.S. air quality and human health, of all emissions associated with the O&G sector. Modeled results show widespread reductions in ozone as a result of the Zero-Oil&Gas scenario, leading to widespread reductions in mortality and morbidity human health endpoints.

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