Completing the Bridge to Nowhere: Prioritizing Oil and Gas Emissions Regulations in Western States

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"Natural gas provides a cost-effective bridge to . . . a low-carbonfuture."[1]
—*Ernest J. Moniz*

"Natural gas is a bridge to nowhere."[2]
—*Robert W. Howarth*

1. *MIT Study on the Future of Natural Gas: Hearing Before the S. Comm. on Energy and Natural Res.*, 112th Cong. 19 (2011) (testimony of Ernest J. Moniz, Sec'y of Energy).

2. Robert W. Howarth, *A Bridge to Nowhere: Methane Emissions and the Greenhouse Gas Footprint of Natural Gas*, 2 ENERGY SCI. & ENGINEERING (2014) (forthcoming in print), *available at* http://tinyurl.com/lzxek45.

"[N]atural gas[,] [i]f extracted safely, [i]s the bridge fuel that can power our economy with less of the carbon pollution that causes climate change."[3]

—Barack Obama

"Without . . . off-ramps or escape routes . . . natural gas may . . . prove to be a bridge too far to reach a safe climate."[4]

—Patrick Parenteau and Abigail Barnes

"If natural gas is to be a "bridge" to a more sustainable energy future, it is a bridge that must be traversed carefully: Diligence will be required to ensure that leakage rates are low enough to achieve sustainability goals."[5]

—Adam R. Brandt et al.

I. INTRODUCTION

America's energy portfolio is rapidly changing. The hydraulic fracturing boom has spurred domestic oil and gas production. Though the media has focused largely on issues related to water quality, the boom's greatest environmental impact may be on air pollution and the climate.[6] Whether that impact is positive or negative is hotly contested.[7] Abundant natural gas is championed as a "bridge fuel" away from coal and into a low-carbon energy future. For example, President Obama's March 2014 Climate Action Plan relies on reducing coal use, and assumes that natural gas has climate benefits over coal.

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3. Barack Obama, President, State of the Union Address 2014 (Jan. 28, 2014), http://tinyurl.com/k6jjrls.

4. Patrick Parenteau & Abigail Barnes, *A Bridge Too Far: Building Off-Ramps on the Shale Gas Superhighway*, 49 IDAHO L. REV. 325, 365 (2013).

5. Adam R. Brandt et al., *Methane Leaks from North American Natural Gas Systems*, 343 SCI. 733, 735 (2014).

6. *See* Jim Wedeking, *Up in the Air: The Future of Environmental Management for Hydraulic Fracturing Will Be About Air, Not Water*, 49 IDAHO L. REV. 437, 438 (2013).

7. *See, e.g.*, Howard A. Latin, *Climate Change Mitigation and Decarbonization*, 25 VILL. ENVTL. L.J. 1, 35 (2014); Bruce M. Pendery, *Generating Electricity with Natural Gas: It's Plentiful and Cheap, but Regulation is Needed to Prevent Environmental Degradation*, 32 UTAH ENVTL. L. REV. 253, 260-66 (2012); Beren Argetsinger, Comment, *The Marcellus Shale: Bridge to a Clean Energy Future or Bridge to Nowhere? Environmental, Energy and Climate Policy Considerations for Shale Gas Development in New York State*, 29 PACE ENVTL. L. REV. 321, 337-38 (2011).

But this assumption is far from certain. Scientific knowledge about the oil and gas sector's emissions, specifically about how much methane the sector emits and how it contributes to ozone formation, has boomed as rapidly as hydraulic fracturing itself. A review of the many studies published since 2009 shows that the oil and gas sector is contributing to ozone problems throughout the western United States. It also shows agreement among scientists that oil and gas production emits significantly more methane, a greenhouse gas much more powerful than carbon dioxide, than previously thought. Scientists remain divided over which timeframe is most relevant for the climate. Natural gas lacks climate benefits over coal in a shorter, twenty-year timeframe, but likely has climate benefits over coal in a longer, hundred-year timeframe. America has stepped onto the natural gas bridge, unsure if it is a bridge to a low-carbon future, or a bridge to nowhere.[8]

But that uncertainty will soon be alleviated, if not eliminated. On January 14, 2015, the Obama Administration announced a new goal to cut oil and gas sector methane emissions by 40-45% from 2012 levels by 2025, as well as several proposed actions that would allow the nation to achieve this ambitious goal.[9] According to the White House's press release, by the summer of 2015 the Environmental Protection agency (EPA) will update existing standards for volatile organic compound (VOC) emissions from new and modified oil and gas sector sources, and also propose a new standard for methane emissions from those sources.[10] The EPA will also focus on assisting states in reducing ozone precursor emissions from existing oil and gas infrastructure in areas that fail to meet the agency's ozone standards.[11]

These forthcoming changes in federal regulations will also require states to act. Some states have already begun to do so. In early 2014, Colorado took the lead and became the first state to directly regulate the oil and gas sector's methane emissions.[12] The forthcoming federal regulations will require other states to follow

8. *See* Parenteau & Barnes, *supra* note 4, at 334-38.

9. Press Release, The White House, Fact Sheet: Administration Takes Steps Forward on Climate Action Plan by Announcing Actions to Cut Methane Emissions (Jan. 14, 2015), *available at* http://tinyurl.com/kbpnwf8.

10. White House, supra note 9.

11. Id.

12. Bruce Finley, *Colorado Adopts Tougher Air Rules for Oil, Gas Industry,* DENV. POST, (Feb. 23, 2014, 7:06 PM), http://tinyurl.com/qzn7b4p.

Colorado's lead. Many of these actions will focus on implementing whatever regulations the EPA develops to reduce methane emissions from the oil and gas sector and to further reduce the sector's VOC emissions. But some states, especially western states, may have to go beyond that baseline in order to address ozone precursor emissions. Notably, the EPA recently designated areas in Colorado, Wyoming, Utah, and Texas in nonattainment with its ozone standard, in part due to oil and gas development.[13] On November 26, 2014, the EPA announced that it will strengthen its ozone standards, which will likely mean that even more areas will be in nonattainment. State regulators may thus have to craft additional strategies to address the oil and gas sector's ozone precursor emissions.

Of course, state and federal regulatory efforts focused on reducing ozone precursor emissions will also reduce methane emissions. Oil and gas equipment and processes leak mixed streams of hydrocarbons, including both methane and other hydrocarbons regulated as ozone precursors. Regulations targeting ozone precursors will plug the same holes from which methane also leaks.

There is no doubt that over the next few years, states will have to engage in extensive rulemaking to reduce methane and ozone precursor emissions from the oil and gas sector. This Article seeks to aid stakeholders in western states interested in crafting those regulations by providing the relevant scientific, legal, and engineering background. It focuses on eight western states, where the majority of oil and gas development occurs: North Dakota, Montana, Wyoming, Utah, Colorado, New Mexico, Oklahoma, and Texas.[14] The Article begins by discussing the science behind the oil

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13. *See* Air Quality Designations for the 2008 Ozone National Ambient Air Quality Standards, 77 Fed. Reg. 30,088, 30,110, 30,147, 30,151, 30,157 (May 21, 2012); EPA, COLORADO AREA DESIGNATIONS FOR THE 2008 OZONE NATIONAL AMBIENT AIR QUALITY STANDARDS 6 (2012), *available at* http://tinyurl.com/l9nvnwl; EPA, TECHNICAL SUPPORT DOCUMENT, DALLAS-FORT WORTH, TEXAS FINAL AREA DESIGNATIONS FOR THE 2008 NATIONAL AMBIENT AIR QUALITY STANDARDS 6-8, 23 (2012), *available at* http://tinyurl.com/kvcn523; EPA, TECHNICAL SUPPORT DOCUMENT, WYOMING AREA DESIGNATIONS FOR THE 2008 OZONE NATIONAL AMBIENT AIR QUALITY STANDARDS 24 (2012), *available at* http://tinyurl.com/l8rzz7t; Letter from James R. Martin, EPA Region 8 Reg'l Adm'r, to Gary R. Herbert, Utah Governor 2 (Dec. 8, 2011), *available at* http://tinyurl.com/lvs8whn.

14. Cumulatively, these eight states accounted for 61% of domestic onshore oil production in 2013 and 55% of domestic onshore natural gas production in 2012 (the most recent year in which data is available). *See* U.S. ENERGY INFO. ADMIN., CRUDE OIL PRODUCTION (2015), *available at* http://tinyurl.com/k4guy83 (calculations on file with

and gas sector's hydrocarbon emissions, translating findings from several recent studies into a form more digestible to policymakers. Next, it summarizes the current statutory and regulatory landscape governing oil and gas sector emissions at the federal and state level. Third, it describes the various equipment and processes within the oil and gas sector that emit ozone precursors and identifies technological solutions to cost-effectively reduce their emissions. Finally, it recommends specific regulations that state policymakers can and should adopt to reduce the oil and gas sector's ozone precursor emissions. These recommendations will also be valuable to federal policymakers as they engage in crafting federal standards to meet the Administration's proposed goal of reducing oil and gas sector methane emissions to 40-45% below 2012 levels by 2025. This Article thus provides a valuable source of information to federal and state policymakers and other stakeholders as they engage in the complex yet crucial task of "completing the bridge" to a lower-carbon future.

II. SCIENCE: AIR POLLUTION AND CLIMATE IMPACTS OF OIL AND GAS SECTOR EMISSIONS

A. *Background: Summarizing Oil and Gas Air Pollution Concerns*

The oil and gas sector emits a variety of pollutants. These include reactive hydrocarbons (RHCs) and nitrogen oxides (NOx), both of which contribute to tropospheric ozone formation.[15] Tropospheric ozone, often referred to as smog, negatively impacts human health at the local level (unlike stratospheric ozone, which makes life on earth possible by blocking harmful ultraviolet radiation).[16] The EPA classifies some RHCs, which are directly harmful to human health, as Hazardous Air Pollutants (HAPs).[17] And one RHC, methane, the principal component of natural gas, is an extremely potent greenhouse

author); U.S. ENERGY INFO. ADMIN., NATURAL GAS GROSS WITHDRAWALS AND PRODUCTION, (2015), *available at* http://tinyurl.com/meyea4h (calculations on file with author).

15. *See* EPA, GROUND LEVEL OZONE: BASIC INFORMATION, http://tinyurl.com/4x3xrto (last visited Jan. 31, 2015).

16. *See* EPA, GROUND LEVEL OZONE: HEALTH EFFECTS (2014), *available at* http://tinyurl.com/l6eslo; EPA, OZONE LAYER PROTECTION: BASIC INFORMATION (2014), http://tinyurl.com/6jabp3.

17. 42 U.S.C. § 7412(a)(6) (2012) (defining "hazardous air pollutants"); *id.* at § 7412(b)(1) (listing hazardous air pollutants); 40 C.F.R. § 61.01(a) (2014) (listing additional hazardous air pollutants defined by the EPA).

gas.[18] This section discusses in turn the oil and gas sector's emissions of these three forms of RHCs: ozone precursors, greenhouse gases, and HAPs.[19]

Before doing so, a brief terminology clarification is necessary. Many different terms are used to refer to hydrocarbon emissions. Different sources may use the same terms to mean different things. For example, some scientists use the term VOCs to "denote the entire set of vapor-phase atmospheric organics excluding CO and CO_2."[20] But the EPA defines VOCs as only those carbon-containing compounds that participate in atmospheric photochemical reactions.[21] The EPA's definition excludes compounds that the EPA has found to have "negligible photochemical reactivity," which include methane, ethane, and a variety of other fluorinated and chlorinated alkanes.[22] However, as explained in more detail below, at high concentrations, methane and ethane do contribute to ozone formation.[23] Thus, the terms non-methane hydrocarbons (NMHCs)[24] and reactive organic gases (ROGs) refer to a set of organic gases which includes ethane, but excludes methane.[25] Given this confusing set of definitions, this Article uses the term "reactive hydrocarbons" (RHCs) to refer to all photochemically reactive atmospheric hydrocarbons, including

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18. *See* Drew T. Shindell et al., *Improved Attribution of Climate Forcing to Emissions*, 326 SCI. 716, 717 (2009) (calculating methane's global warming potential).

19. The sector also emits three pollutants and/or their precursors in low quantities, which are thus not discussed in this Article: hydrogen sulfide, sulfur dioxide (SO_2), and particulate matter. *See generally* EPA REGION 8, AN ASSESSMENT OF THE ENVIRONMENTAL IMPLICATIONS OF OIL AND GAS PRODUCTION at ES-3, ES-4, 3-2 (2008), *available at* http://tinyurl.com/mufjkbd (discussing sulfur dioxide); SIERRA CLUB ET AL., COMMENTS ON NEW SOURCE PERFORMANCE STANDARDS: OIL AND NATURAL GAS SECTOR; REVIEW AND PROPOSED RULE FOR SUBPART OOOO, DOCKET NO. EPA-HQ-OAR-2010-0505 11-12 (2011) (discussing particulate matter); OCCUPATIONAL HEALTH & SAFETY ADMIN., OIL AND GAS WELL SERVICING E-TOOL: GENERAL SAFETY AND HEALTH: HYDROGEN SULFIDE GAS, http://tinyurl.com/q5l4cqk (last visited May 2, 2014).

20. JOHN H. SEINFELD & SPYROS N. PANDIS, ATMOSPHERIC CHEMISTRY AND PHYSICS: FROM AIR POLLUTION TO CLIMATE CHANGE 43 (2d ed. 2006).

21. 40 C.F.R. § 51.100(s) (2014); *see also* EPA, VOLATILE ORGANIC COMPOUNDS: TECHNICAL OVERVIEW (2012), *available at* http://tinyurl.com/lq7gb2d (explaining how the EPA defines VOCs).

22. 40 C.F.R. § 51.100(s)(1) (2014).

23. Marc Mansfield et al., *Emissions Inventory Report*, *in* UTAH DEP'T OF ENVTL. QUALITY, 2012 UINTAH BASIN WINTER OZONE & AIR QUALITY STUDY: FINAL REPORT 175, 175 (Seth Lyman & Howard Shorthill eds., 2013).

24. *Id.*

25. MARK Z. JACOBSON, AIR POLLUTION AND GLOBAL WARMING: HISTORY, SCIENCE AND SOLUTIONS 89 (2d ed. 2012).

those with lower reactivity, such as methane and ethane. When quoting a source using a different term, or discussing a subset of RHCs (for example, methane alone or NMHCs), this Article uses the appropriate term for the applicable subset. Finally, because multiple definitions of a "VOC" exist, when this Article uses the term "VOC," it refers to the EPA's formally codified definition of a VOC.[26]

B. *Tropospheric Ozone*

1. *Scientific background on tropospheric ozone formation*

Ozone is a trace gas in the atmosphere, with average concentrations of only thirty-five parts per billion (ppb) in the troposphere, but, despite its low concentrations, it has many negative impacts.[27] Its human health impacts include, but are not limited to, asthma, respiratory distress, hospital and emergency room visits, missed school days, and premature mortality.[28] Ozone also suppresses vegetation and crop growth rates,[29] and in a warming world can cause unpredictable shifts in plant composition, potentially enhancing weed growth and negatively impacting native vegetation.[30]

Tropospheric ozone formation requires both RHCs and NOx. Ozone forms when RHCs are broken down in the presence of sunlight, a process catalyzed by NOx.[31] The amount of ozone produced depends on the *ratio* of RHC emissions to NOx emissions.[32] Ozone isopleths illustrate how this ratio influences ozone formation.[33] When NOx concentrations are low, increasing RHC concentrations produce no additional ozone, meaning the system is "NOx limited."[34] When NOx concentrations are high

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26. 40 C.F.R. § 51.100(s) (2014).

27. SEINFELD & PANDIS, *supra* note 20, at 138, 204.

28. *See* EPA, National Ambient Air Quality Standards for Ozone, 75 Fed. Reg. 2938, 2948 (Jan. 19, 2010).

29. Fitzgerald Booker et al., *The Ozone Component of Global Change: Potential Effects on Agricultural and Horticultural Plant Yield, Product Quality and Interactions with Invasive Species*, 51 J. INTEGRATIVE PLANT BIOLOGY, 337, 342-43 (2009).

30. Donald R. Zak et al., *Forest Productivity Under Elevated CO_2 and O_3: Positive Feedbacks to Soil N Cycling Sustain Decade-Long Net Primary Productivity Enhancement by CO_2*, 14 ECOLOGY LETTERS 1220, 1224-25 (2011).

31. SEINFELD & PANDIS, *supra* note 20, at 205.

32. *Id.* at 236-37.

33. *See id.* at 237; JACOBSON, *supra* note 25, at 89.

34. SEINFELD & PANDIS, *supra* note 20, at 236-38.

and VOC concentrations are low, decreasing NOx concentrations can actually increase ozone by freeing up OH radicals to break down RHCs, meaning the system is "RHC limited."[35] In general, more urbanized areas are RHC limited, whereas more rural areas (which have little NOx but RHC emissions from vegetation) are NOx limited.[36]

One thus might expect rural oil and gas fields to be NOx limited, so adding RHCs will not produce much ozone. But the oil and gas sector emits NOx from flares, on-site engines operating drill rigs and compressors,[37] and truck traffic.[38] Accordingly, one study in Utah's rural Uintah Basin found that because there are relatively few OH radicals present, and despite a high RHC to NOx ratio, the system remained RHC limited.[39] A modeling study by renowned atmospheric chemists William Carter and John Seinfeld of four major ozone events in Wyoming's Upper Green River Basin (UGRB) found that the system was RHC limited in three of the events, and NOx limited in only one.[40] A more recent study took measurements during high-ozone events and found that the UGRB was NOx limited early in the day, but transitioned towards being more RHC limited later in the day.[41] These studies show that oil and gas sector NOx emissions can make even rural areas RHC sensitive. And in more urbanized oil and gas fields, NOx emissions from urban sources likely make the system RHC limited as well. Thus, it appears that regardless of where oil and gas production occurs, increasing RHC emissions increases ozone formation.

Location is also important to ozone formation, because ozone can only form in the presence of sunlight, so physical features like snow that amplify sunlight increase ozone production. Snow and

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35. *Id.*

36. *Id.* at 238-39; JACOBSON, *supra* note 25, at 97-98.

37. Eduardo P. Olauger, *The Potential Near-Source Ozone Impacts of Upstream Oil and Gas Industry Emissions,* 62 J. AIR & WASTE MGMT. ASS'N 966, 976 (2012).

38. Chip Brown, *North Dakota Went Boom,* N.Y. TIMES, Jan. 31, 2013, *available at* http://tinyurl.com/l3omyrx (noting that North Dakota estimates that each well requires an average of 2000 truck trips).

39. P.M. Edwards et al., *Ozone Photochemistry in an Oil and Natural Gas Extraction Region During Winter: Simulations of a Snow-Free Season in the Uintah Basin, Utah,* 13 Atmospheric Chemistry & Physics Discussions 8955, 8968 (2013).

40. William P.L. Carter & John H. Seinfeld, *Winter Ozone Formation and VOC Incremental Reactivities in the Upper Green River Basin of Wyoming,* 50 ATMOSPHERIC ENVT. 255, 262 (2012).

41. B. Rappenglück et al., *Strong Wintertime Ozone Events in the Upper Green River Basin, Wyoming,* 14 ATMOSPHERIC CHEMISTRY & PHYSICS 4909, 4920 (2014).

ice reflect sunlight, a property called albedo.[42] After initially hypothesizing snow's albedo as a source of the UGRB's wintertime ozone,[43] a later model of winter-time ozone in the Uintah Basin confirmed that snow's albedo nearly doubles daily peak ozone concentrations.[44]

Snowy conditions, especially in mountain valleys, also favor ozone formation because cold temperatures cause ozone to build up. Ordinarily, during the day, the sun warms the earth's surface, which in turn warms the atmosphere from the bottom up, so temperature decreases with elevation.[45] At night, as the surface cools, the ground often ends up being cooler than the air above it.[46] This "thermal inversion" makes the air stable and limits vertical mixing.[47] During the winter, thermal inversions can form during the daytime in intermountain basins because the winter sunlight is too weak to warm the surface.[48] When inversion layers form, they prevent atmospheric mixing and trap ozone and its precursors close to the surface, causing ozone concentrations to build up rapidly.[49] Although ozone dissipates at night, RHCs do not.[50] They can build up to extremely high concentrations if an inversion persists for multiple days and nights.[51] Under normal conditions, ozone and its precursors can disperse over great distances during the day.[52] But when they are trapped close to the surface and surrounded on most sides by mountains, they cannot surmount the physical obstacles in their path. This explains why

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42. Carter & Seinfeld, *supra* note 40, at 264-66.

43. Russell C. Schnell et al., *Rapid Photochemical Production of Ozone at High Concentrations in a Rural Site During Winter*, 2 NATURE GEOSCIENCE 120, 122 (2009).

44. Edwards et al., *supra* note 39, at 8967.

45. SEINFELD & PANDIS, *supra* note 20, at 729.

46. *Id.* at 721-22.

47. *Id.* at 730.

48. Marc Mansfield & Courtney Hall, *The Potential for Ozone Production in the Uintah Basin: A Climatological Analysis*, *in* UTAH DEP'T OF ENVTL. QUALITY, 2012 UINTAH BASIN WINTER OZONE & AIR QUALITY STUDY: FINAL REPORT 251, 253 (Seth Lyman & Howard Shorthill eds., 2013).

49. Till Stoeckenius et al., *Synopsis of Results*, *in* UTAH DEP'T OF ENVTL. QUALITY, 2012 UINTAH BASIN WINTER OZONE & AIR QUALITY STUDY: FINAL REPORT 1, 2 (Seth Lyman & Howard Shorthill eds., 2013).

50. Edwards et al., *supra* note 39, at 8968

51. D. Helmig et al., *Highly Elevated Atmospheric Levels of Volatile Organic Compounds in the Uintah Basin, Utah*, 48 ENVTL. SCI. & TECH. 4707, 4714 (2014).

52. *See, e.g.*, EPA v. EME Homer City Generation, L.P., 134 S. Ct. 1584, 1594-95 (2014) (explaining how ozone and its precursors in upwind states can contribute to ozone nonattainment in downwind states).

ozone spikes in intermountain valleys in winter daytime inversions.[53]

2. *Evidence that the oil and gas sector contributes to ozone formation*

Even though snowy western mountain valleys are physically ideal locations for ozone buildup, historically the oil and gas sector's role in ozone formation in the western United States received little attention because ozone is traditionally considered an urban pollutant. Only one major peer-reviewed study was published before 2007.[54] By then, high ozone concentrations throughout the West were piquing scientists' curiosity.[55] Initial studies were hesitant to identify the cause, but hinted that it might be the oil and gas sector.[56] In 2009, a modeling study concluded that conditions throughout the West were prime for the oil and gas sector to contribute significantly to ozone formation.[57] Recently, many studies have actually measured ozone formation in Western oil and gas fields. This section reviews studies from Wyoming, Utah, Colorado, and Texas, before considering other western areas where oil and gas likely causes ozone issues.

a. *Wyoming's Upper Green River Basin*

Wintertime ozone spikes in Wyoming's rural UGRB were the first of these phenomena to attract scientific attention.[58] In 2009, a team led by National Oceanic and Atmospheric Administration (NOAA) scientists reported that, during the winter of 2008, it measured hourly average ozone concentrations above 140 ppb, which averaged out to 122 ppb over an eight-hour period.[59] The Basin exceeded the National Ambient Air Quality Standards

53. *See* Carter & Seinfeld, *supra* note 40, at 255.

54. *See* Aaron Katzenstein et al., *Extensive Regional Atmospheric Hydrocarbon Pollution in the Southwestern United States*, 100 PROC. NAT'L ACAD. SCI. 11,975, 11,975 (2003).

55. Dan Jaffe & John Ray, *Increase in Surface Ozone at Rural Sites in the Western US*, 41 ATMOSPHERIC ENVT. 5452, 5452 (2007).

56. *Id.* at 5461.

57. Marco A. Rodriguez, Michael G. Barna & Tom Moore, *Regional Impacts of Oil and Gas Development on Ozone Formation in the Western United States*, 59 J. AIR & WASTE MGMT. ASS'N 1111, 1116 (2009) (displaying map derived from model showing enhanced ozone levels throughout the western United States due to oil and gas activities).

58. *See, e.g.*, Mead Gruver, *Wyoming Plagued by Big-City Problem: Smog*, WASH. POST, Mar. 8, 2011, *available at* http://tinyurl.com/mk7gb2k; Randy Udall, *Fracking is the New Big Gun*, HIGH COUNTRY NEWS, Mar. 29, 2012, http://tinyurl.com/n7hygoa.

59. Schnell et al., *supra* note 43, at 120.

(NAAQS) fourteen times during 2008 alone.[60] The study attributed elevated ozone concentrations to NOx and VOC emissions from natural gas production activity in the area.[61]

The Wyoming Department of Environmental Quality (WDEQ) also conducted annual studies between 2005 and 2011, finding thirteen NAAQS exceedances in 2011 alone.[62] Other studies confirmed that snow cover and low inversion layers were key factors, indicated that the system was RHC-limited, and concluded that aromatics, aldehydes, and alkenes contributed more to ozone formation than alkanes.[63] The studies also confirmed that oil and gas sector RHCs were the primary source of the ozone nonattainment.[64]

Based largely on this evidence, in 2009 Governor Dave Freudenthal requested that the EPA designate the UGRB as nonattainment.[65] In 2012, the EPA granted Wyoming's request.[66] The EPA agreed with Wyoming's conclusion that the elevated ozone concentrations in the area were "primarily due to local emissions from oil and gas development activities," and that they occurred primarily in the wintertime in the presence of snow and low inversion layers in an area constrained by natural geographic boundaries.[67]

The unusual winter conditions in the UGRB prompted two well-known atmospheric chemists to model whether the system was NOx or RHC limited.[68] They found that although alkanes were the main RHC emitted by mass, other compounds, especially aromatics and alkenes, contributed more to ozone formation.[69]

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60. *Id.*

61. *Id.* at 122.

62. COURTNEY HALL ET AL., UTAH STATE UNIV. COMMERCIALIZATION & REG'L DEV., FINAL REPORT: UPPER GREEN RIVER BASIN WINTER OZONE: SUMMARY OF PUBLIC INFORMATION ABOUT THE WYOMING PHENOMENON 6 (2012), *available at* http://tinyurl.com/k5myrad.

63. *Id.* at 14-15.

64. *Id.* at 8-11, 19 (noting that "[m]ost [VOC] samples contained only a limited range of fairly common hydrocarbon species associated with oil and gas exploration") (internal quotations omitted).

65. Letter from Dave Freudenthal, Wyo. Governor, to Carol Rushin, EPA Region 8 Acting Reg'l Adm'r 2 (Mar. 12, 2009), *available at* http://tinyurl.com/phqgt9o.

66. Air Quality Designations for the 2008 Ozone National Ambient Air Quality Standards, 77 Fed. Reg. 30,088, 30,157-58 (May 21, 2012).

67. EPA, WYOMING AREA DESIGNATIONS, *supra* note 13, at 4, 24.

68. Carter & Seinfeld, *supra* note 40, at 256, 261.

69. *Id.* at 255, 265-66.

Their results suggest that reducing oil and gas sector RHC emissions will likely reduce ozone formation during the UGRB's wintertime inversions.[70]

By contrast, another recent study that took measurements during high-ozone events in the UGRB found that, during the morning, when ozone levels were below 80 ppb, the UGRB was RHC limited.[71] But in the afternoon, when ozone concentrations exceeded 80 ppb, the system shifted to being NOx limited.[72] This suggests that whether the UGRB is RHC or NOx limited may vary by location and time of day.

In 2014, scientists from NOAA and the Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Colorado in Boulder published another study, which found that because the UGRB is only enclosed on three sides, it has more air movement and is less susceptible to high ozone events than completely enclosed valleys like the Uintah Basin.[73] It also found that ozone formation in the UGRB is negatively associated with wind speed, which helped explain why 2012, a windy year, was the only year in the past nine years without high ozone events in the UGRB.[74]

A final study by University of Wyoming scientists found that proximity to different types of human activities was key to explaining sharp variations in ozone concentrations in the UGRB over time.[75] It identified oil and gas fugitive emissions as the main source of both NMHCs and methane, and also found that proximity to well drilling was associated with higher levels of aromatics.[76]

b. *Utah's Uintah Basin*

Two hundred miles south of the UGRB, Utah's Uintah Basin also has significant oil and gas development and similar ozone

70. *See id.* at 262, 266.

71. Rappenglück et al., *supra* note 41, at 4920.

72. *Id.*

73. Samuel Oltmans et al., *Anatomy of Wintertime Ozone Associated with Oil and Natural Gas Extraction Activity in Wyoming and Utah,* 2 ELEMENTA 1, 1 (2014).

74. *Id.*

75. R.A. Field et al., *Influence of Oil and Gas Field Operations on Spatial and Temporal Distributions of Atmospheric Non-Methane Hydrocarbons and their Effect on Ozone Formation in Winter,* 14 ATMOSPHERIC CHEMISTRY & PHYSICS DISCUSSIONS 24,943, 24,944 (2014).

76. *Id.* at 24,964.

problems.[77] Indeed, because "[b]oth basins experience elevated atmospheric ozone during some winters, and because of similar meteorology, climate, topography, and industrial activity, it [is] widely believed that the cause of winter ozone was essentially the same in both basins."[78] The Utah Department of Environmental Quality (UDEQ) commissioned a comprehensive Uintah Basin Winter Ozone and Air Quality Study (UBWOS), prepared by a large team of collaborators. It found that oil and gas sources emitted 98-99% of the area's VOCs and 57-61% of its NOx (to which a coal-fired power plant also contributed).[79]

In one part of the UBWOS study, a NOAA-led research team used source-signature analysis to discern whether hydrocarbons in air samples gathered throughout the Uintah Basin were attributable to the oil and gas sector.[80] Analyzing the samples they gathered, including some collected via aircraft,[81] the NOAA research team found elevated RHCs near oil and gas facilities, mostly consisting of alkanes with fewer aromatics and very few alkenes.[82] It also found that oil wells and gas wells emitted different RHCs.[83] The team traced NOx emissions to small wellpad pump motor engines.[84] Finally, because the winter of 2012 was relatively warm and dry, the study did not register any ozone exceedances.[85] But it found ozone levels above 500 ppb near a flowback pond.[86]

Although the UBWOS study did not determine whether the basin was NOx or RHC limited, its "best estimate" was that the basin was RHC limited, and that controlling RHC (especially aromatics) emissions from the oil and gas sector was the best mitigation strategy.[87] Sure enough, a later study, also lead by

77. HALL ET AL., *supra* note 62, at 7; *see also* Jessica L. Lowrey, *Sewing Up the Regulatory Hole: Preventing Winter Ozone in Utah's Uintah Basin*, 3 SEATTLE J. ENVTL. L. 295, 297-98 (2013) (describing extent of oil and gas development in the Uintah Basin).

78. HALL ET AL., *supra* note 62, at 7.

79. Stoeckenius et al., *supra* note 49, at 2.

80. Gabrielle Pétron et al., *Source Characterization, Attribution, and Ozone Distribution in the Uintah Basin Using the NOAA Mobile Laboratory*, *in* UTAH DEP'T OF ENVTL. QUALITY, 2012 UINTAH BASIN WINTER OZONE & AIR QUALITY STUDY: FINAL REPORT 197, 197-205 (Seth Lyman & Howard Shorthill eds., 2013).

81. *Id.* at 212.

82. *Id.* at 212-16.

83. *Id.* at 209.

84. *Id.* at 219.

85. Stoeckenius et al., *supra* note 49, at 5-6.

86. Pétron et al., *supra* note 80, at 221-22.

87. Stoeckenius et al., *supra* note 49, at 3.

NOAA and CIRES scientists, analyzed the same data and found that the Uintah Basin was RHC limited.[88]

One NOAA study made headlines by finding that between 6.2 and 11.7% of the natural gas produced in the Uintah Basin leaks into the atmosphere.[89] It measured methane levels on an aircraft transect in February 2012, which it translated into the percent of natural gas leaking.[90] The authors emphasized that their study represents only a "snapshot"—a picture of emissions in a single location on a single day—and the leak rate may be different in other locations.[91] Although much of the concern the study generated focused on methane emissions,[92] the high leak rate also implies that high RHC leak rates can lead to significant ozone formation.

Another follow-up study, conducted by scientists from the Institute of Arctic and Alpine Research (INSTAAR) at the University of Colorado at Boulder, compared the 2012 UBWOS data with data from the colder and snowier winter of 2013.[93] In 2013, the inversion layer trapped ozone precursors for days at a time, causing extremely high ozone concentrations.[94] Using a conservative estimate, the study found that 8.4-15.9% of the natural gas produced was leaking into the atmosphere.[95] It found that the area exceeded the NAAQS 56% of the time during the twenty-five day study period.[96]

To date, NOAA and CIRES scientists have published one final follow-up study, which concluded that changes in oil and gas production levels were not the primary factor influencing interannual variation in wintertime ozone levels.[97] Instead, meteorological factors, such as temperature and amount of snow,

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88. Edwards et al., *supra* note 39, at 8956, 8968.

89. Anna Karion et al., *Methane Emissions Estimate from Airborne Measurements over a Western United States Natural Gas Field*, 40 GEOPHYSICAL RES. LETTERS 4393, 4396 (2013); *see also* Jeff Tollefson, *Methane Leaks Erode Green Credentials of Natural Gas*, NATURE, Jan. 2, 2013, at 12, *available at* http://tinyurl.com/ktsy3hu (providing news coverage of Karion et al.'s paper).

90. Karion et al., *supra* note 89, at 4395.

91. *Id.* at 4396-97.

92. Tollefson, *supra* note 89, at 12.

93. Helmig et al., *supra* note 51, at 4707-08.

94. *Id.* at 4709-12.

95. *Id.* at 4714.

96. *Id.* at 4711.

97. Oltmans et al., *supra* note 73, at 13-14.

drove interannual variability.[98] Thus, whether or not oil and gas operations will contribute to high ozone events in areas prone to wintertime inversions depends on difficult-to-predict meteorological phenomena—phenomena that will become even more unpredictable due to climate change.

c. *Colorado's Front Range*

Just across the border from the Uintah Basin, a monitor on Colorado's Western Slope recorded ozone levels that exceeded the NAAQS for the first time in the winter of 2013.[99] But overall, wintertime ozone issues have been more of an issue in Utah and Wyoming than Colorado, where ozone problems occur in the heavily-populated Front Range. The Denver-Julesberg Basin, located in the northern area of the Front Range, has been transformed by hydraulic fracturing in the Wattenberg Shale formation.[100] Oil and gas is hardly the Northern Front Range's only ozone source: over 3,000,000 people live in the greater Denver metro area.[101] But when the EPA designated the area as nonattainment in 2012,[102] it suggested that oil and gas activities may have impacted the region's air quality.[103] Five recent studies, conducted mostly by NOAA, illuminated the magnitude of that impact.

In the first study, NOAA scientists measured RHC concentrations throughout the Front Range.[104] The study used daily samples taken from 2007-10 at the Boulder Atmospheric

98. *Id.* at 13.

99. COLO. AIR POLLUTION CONTROL DIV., 2013 SUMMER OZONE SEASON PRE-REVIEW: BRIEFING TO THE COLORADO AIR QUALITY CONTROL COMMISSION 9-11 (2013), *available at* http://tinyurl.com/kh48pl3.

100. COLO. OIL & GAS CONSERVATION COMM'N, *Reports Portal*, http://tinyurl.com/pnsxvyq (last visited Nov. 10, 2014) (documenting 742% increase in oil production between 2000 and 2013 in Weld County) (select "oil produced" under "report" and "2000" under "production year," then select "XML file with report data" and scroll to page two to view annual production figure for "Weld." Then, compare with "2013" selected for "production year") .

101. U.S. CENSUS BUREAU, POPULATION ESTIMATES: METROPOLITAN & MICROPOLITAN STATISTICAL AREAS, http://tinyurl.com/o2vyf2r (last visited May 10, 2014) (including population in the Denver-Aurora-Lakewood, Boulder, and Fort Collins geographic areas).

102. Air Quality Designations for the 2008 Ozone National Ambient Air Quality Standards, 77 Fed. Reg. 30,088, 30,110 (May 21, 2012).

103. EPA, COLORADO AREA DESIGNATIONS, *supra* note 13, at 6.

104. *See generally* Gabrielle Pétron et al., *Hydrocarbon Emissions Characterization in the Colorado Front Range: A Pilot Study*, 117 J. GEOPHYSICAL RES., no. D4, 2012, at 3.

Observatory ("BAO"), southwest of the Wattenberg Field.[105] Compared to six towers elsewhere in the West, the BAO had elevated levels of short-lived alkanes, consistent with oil and gas production.[106] The study found the main source of alkanes and benzene was northeast of the BAO and was not vehicle combustion exhaust, leaving oil and gas as the likely source.[107] To corroborate these results, the NOAA team conducted nine on-road surveys in a mobile laboratory throughout the Wattenberg Field.[108] It found higher levels of methane, shorter-lived alkanes, and benzene in areas with oil and gas activities than it found at the BAO.[109] Additional analysis confirmed that methane and other alkane levels were at least 60% above values predicted by oil and gas emissions inventories, and that benzene levels were at least double levels predicted by emissions inventories.[110]

This NOAA study, one of the first "top-down" studies to measure oil and gas emissions, garnered significant attention, including one published critique.[111] The NOAA team published a rebuttal, standing by its results and noting uncertainty around "bottom up" emissions estimates based on inventories, highlighting the need for additional "top-down" studies.[112]

The second NOAA study compared BAO measurements to two other Front Range sites with less oil and gas activity, and to other urban sites nationwide.[113] The study found elevated alkane levels, indicating that oil and gas was the main RHC source.[114] It found that 55±18% of the VOC-OH reactivity (a measure of how much a source contributes to ozone formation) in the area was attributable

105. *Id.* at 4-5.

106. *Id.* at 5-7.

107. *Id.* at 8.

108. *Id.* at 5, 9.

109. *Id.* at 10-13.

110. *Id.* at 13-17.

111. *See generally* Michael A. Levi, Comment, *Hydrocarbon Emissions Characterization in the Colorado Front Range: A Pilot Study*, 117 J. GEOPHYSICAL RES., no. D21, 2012, at 1.

112. Gabrielle Pétron et al., Reply to Comment, *"Hydrocarbon Emissions Characterization in the Colorado Front Range—A Pilot Study,"* 118 J. GEOPHYSICAL RES., no. 1, 2013, at 236, 236.

113. Jessica B. Gilman et al., *Source Signature of Volatile Organic Compounds from Oil and Natural Gas Operations in Northeastern Colorado*, 47 ENVTL. SCI. & TECH. 1297, 1298 (2013).

114. *Id.* at 1298-1300.

to oil and gas activities.[115] The study thus concluded that oil and gas production is "a significant source of [ozone] precursors."[116]

The third NOAA study sampled twelve airplane transects over Weld County in May 2012.[117] It found oil and sector methane emissions roughly double what operators had reported to the EPA, for a total leak rate of 4.1±1.5%.[118] It found the oil and gas sector emitted twice as many non-methane hydrocarbons and seven times more benzene than the state inventory reported.[119]

The fourth NOAA study used source-signature analysis to determine the origin of RHCs measured at the BAO in 2011.[120] It identified oil and gas RHC emissions by differentiating the alkane signatures of emissions northeast of the tower from urban emissions south of the BAO.[121] The study also calculated the RHC-OH reactivity, finding that the oil and gas sector accounted for 57% of total VOC-OH reactivity in the area.[122] It concluded, "natural gas emissions could have an important impact on local to regional tropospheric [ozone] formation."[123]

In the fifth study, researchers from NOAA, CIRES, INSTAAR, and other institutions examined the Carbon-14 content of samples gathered at the BAO in 2009 and 2010.[124] Carbon-14 is a short-lived carbon isotope absent from fossil fuels, so it can be used to trace an RHC's fossil fuel origin.[125] The study suggested that elevated alkane and benzene concentrations originating in the Wattenberg Field came from the oil and gas sector.[126]

Taken together, the five studies indicate that oil and gas sector

115. *Id.* at 1297.

116. *Id.* at 1303.

117. Gabrielle Pétron et al., *A New Look at Methane & Non-Methane Hydrocarbon Emissions from Oil and Natural Gas Operations in the Colorado Denver-Julesburg Basin*, 119 J. GEOPHYSICAL RES. 6836, 6845 (2014).

118. *Id.* at 6850.

119. *Id.* at 6836.

120. Robert F. Swarthout et al., *Volatile Organic Compound Distributions During the NACHTT Campaign at the Boulder Atmospheric Observatory: Influence of Urban and Natural Gas Sources*, 118 J. GEOPHYSICAL RES. 10,614, 10,615 (2013).

121. *Id.* at 10,620-27.

122. *Id.* at 10,632.

123. *Id.*

124. B.W. LaFranchi et al., *Constraints on Emissions of Carbon Monoxide, Methane, and a Suite of Hydrocarbons in the Colorado Front Range Using Observations of* $^{14}CO_2$, 13 ATMOSPHERIC CHEMISTRY & PHYSICS 11,1101, 11,103-05 (2013).

125. *Id.* at 11,102.

126. *Id.* at 11,113.

RHC emissions are a significant source of ozone formation in the Denver metro area. The Colorado Air Pollution Control Division (APCD) reported that the oil and gas sector accounted for 54% of statewide, anthropogenic VOC emissions in 2011.[127] It accounts for 20% of Colorado's NOx emissions.[128] It is thus unsurprising that APCD concluded, "[h]ydrocarbon emissions from oil and gas operations (among other industries) contribute to ozone formation in Colorado."[129]

d. *Texas: the Barnett, Haynesville, and Eagle Ford Shales*

Colorado's summertime ozone issues share many characteristics with ozone issues in three Texas shale formations where hydraulic fracturing has dramatically increased oil and gas production: the Barnett, Eagle Ford, and Haynesville Shales.[130] All three border urban areas (Dallas-Fort Worth; San Antonio and Austin; and Longview, Texas and Shreveport, Louisiana, respectively).[131]

A 2009 Barnett Shale study by future EPA Region 6 Administrator Dr. Al Armendariz combined oil and gas activity levels with emissions factors to calculate predicted RHC and NOx emissions by source type.[132] It projected average 2009 ozone precursor emissions of 191 tons/day, with peak summer emissions

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127. AIR POLLUTION CONTROL DIVISION (APCD), *Prehearing Statement of the Colorado Department of Public Health and Environment, Air Pollution Control Division, Regarding Revisions to Regulation Numbers 3, 6, and 7 (February 19-21, 2014 Hearing),* 3 (2014), http://tinyurl.com/m5jhe4h.

128. Sierra Club et al., *Pre-hearing Statement of the Sierra Club, Natural Resources Defense Council, Earthworks Oil and Gas Accountability Project and WildEarth Guardians Before the Colorado Air Quality Control Commission Regarding Oil & Gas Rulemaking Efforts,* 6 (2014), http://tinyurl.com/k3pdz6d.

129. APCD, *supra* note 127, at 18.

130. DAVID PORTER, R.R. COMM'N OF TEX., EAGLE FORD SHALE TASK FORCE REPORT 2 (2013); *see also* Rachael Rawlins, *Planning for Fracking on the Barnett Shale: Urban Air Pollution, Improving Health Based Regulation, and the Role of Local Governments,* 31 VA. ENVTL. L.J. 226 (2013) (discussing oil and gas related air quality issues in Texas's Barnett Shale region).

131. *Compare* TEX. DEP'T OF ENVTL. QUALITY, TEXAS ACTIVE OIL AND GAS WELLS (2014), *available at* http://tinyurl.com/p29gaz8 *with County Map of Texas,* GEOLOGY.COM, http://tinyurl.com/naqluuq (last visited Dec. 7, 2014) (providing location of counties and cities within Texas for comparison).

132. AL ARMENDARIZ, EMISSIONS FROM NATURAL GAS PRODUCTION IN THE BARNETT SHALE AREA AND OPPORTUNITIES FOR COST-EFFECTIVE IMPROVEMENTS 8-23 (2009).

of 307 tons/day,[133] exceeding precursor emissions from all on-road motor vehicles in the Dallas-Fort Worth metro area.[134]

Using that study's data and some industry-supplied data, another study modeled how emissions from these sources impact nearby ozone levels.[135] This study found that among RHCs, formaldehyde from compressor engines contributed most to ozone formation.[136] The amount of ozone produced depended on whether the system was assumed to be RHC or NOx limited.[137] Under less NOx-limited conditions, downwind peak ozone contribution by flares increased to 22 ppb.[138] Overall, the study concluded "that oil and gas activities can have significant near-source impacts on ambient ozone," and that periodic, variable emissions sources, like flaring, should be avoided to reduce ozone precursor emissions.[139]

A more recent study by scientists at the University of Texas at Austin compared RHC emissions measured at two Barnett Shale monitors to emissions predicted by the Texas Commission on Environmental Quality's (TCEQ) oil and gas emissions inventory.[140] It found that the measured emissions were higher than predicted by the TCEQ inventory, by up to 52% at one monitor.[141] It concluded that the underestimates could be corrected by updating them to reflect increased production levels and emissions from various sources.[142] Meteorological conditions, rather than sporadic oil and gas activities like liquids unloading, accounted for most of the temporal variability in the RHC concentrations.[143]

A final Barnett Shale study, also led by University of Texas at Austin researchers, modeled the impacts of increasing natural gas production on ozone formation, building in feedbacks with

133. *Id.* at 24.

134. *Id.* at 25-27.

135. Olauger, *supra* note 37, at 966-68.

136. *Id.* at 976.

137. *Id.* at 973, 975.

138. *Id.* at 975.

139. *Id.* at 977.

140. Daniel Zavala-Araiza, David W. Sullivan & David T. Allen, *Atmospheric Hydrocarbon Emissions and Concentrations in the Barnett Shale Natural Gas Production Region*, 48 ENVTL. SCI. & TECH. 5314, 5315-19 (2014).

141. *Id.* at 5318-19.

142. *Id.* at 5319.

143. *Id.* at 5320.

electricity.[144] Relying on the admittedly low TCEQ inventory, the model predicted that replacing coal with gas-generated electricity, and increasing natural gas production as a result, would decrease average regional ozone levels by 0.2-0.7 ppb.[145] Because ozone only forms during the day, increasing natural gas production, which results in roughly constant daily emissions, decreases ozone formation. This is because coal generation peaks during the late afternoon when ozone levels are already high.[146]

An early 2010 Haynesville Shale study used projected future wells and emissions inventories to predict ozone levels in 2012.[147] In a high-production scenario, it projected ozone increases over baseline levels of up to 17 ppb in southern Bossier Parish, LA.[148] As several counties in the area were already close to exceeding the NAAQS in 2008, the study predicted that shale gas activities could cause nonattainment.[149] This prediction was proven true by the area's 2012 design values.[150]

Few, if any, peer-reviewed papers study how the oil and gas sector contributes to ozone in the Eagle Ford Shale. One modeling study, which remains in press, concluded that "emissions from the Eagle Ford Shale area could affect ozone air quality in [San Antonio and Austin]."[151] An April 2014 technical report prepared by the Alamo Area Council of Government (in cooperation with the TCEQ) reported an increase in Eagle Ford NOx and VOC emissions from 66tpd and 101 tpd in 2011 to 113-188 tpd and 338-872 tpd in 2018, respectively.[152] This is worrisome for San Antonio, which already teeters on the edge of being designated as nonattainment for the federal ozone standard based on ozone

144. Adam P. Pacsi et al., *Regional Air Quality Impacts of Increased Natural Gas Production and Use in Texas*, 47 ENVTL. SCI. & TECH. 3521, 3521-22 (2013).

145. *See id.* at 3521, 3525.

146. *Id.* at 3526.

147. Susan Kemball-Cook et al., *Ozone Impacts of Natural Gas Development in the Haynesville Shale*, 44 ENVTL. SCI. & TECH. 9357, 9357-61 (2010).

148. *Id.* at 9362.

149. *Id.*

150. *See infra* notes 403-404.

151. C. Chang & K. Liao, Abstract, *Ozone Air Quality Impacts of Shale Gas Development in South Texas Urban Areas*, AM. GEOPHYSICAL UNION (Dec. 2013), *available at* http://tinyurl.com/kz5xstu; *see also* Kuo-Jen (KJ) Liao, *Personnel Profile*, TEXAS A&M UNIV. KINGSVILLE, http://tinyurl.com/ks7uf3r (last visited Jan. 31, 2015) (noting that the manuscript remains in preparation).

152. AACOG, OIL AND GAS EMISSION INVENTORY: EAGLE FORD SHALE 9-1 (2014), *available at* http://tinyurl.com/m3k3tlw.

levels that have violated federal standards on several occasions.[153]

e. *Growing ozone problems in other western oil and gas fields*

Texas, Colorado, Utah, and Wyoming are likely not alone in experiencing oil and gas-related ozone issues, but there is not enough data to say for sure, largely because the EPA does not require air pollution monitoring in rural areas. The five air monitors in the Eagle Ford Shale, an area the size of Massachusetts, are all in urban areas at the formation's fringe.[154] There are only two monitors located in the five core Bakken shale counties in North Dakota, one in a National Park outside the shale formation, and another which has not gathered data since the Bakken boom began in 2009.[155] Accordingly, a recent study concluded that "the extent to which these increased [oil and gas] emissions impact air quality, especially in highly developed shale gas regions where there are no air monitors, represents a substantial data gap and hinders effective air quality management."[156]

In December 2012, a coalition of thirty environmental and public health groups petitioned the EPA to require oil and gas operators to monitor air pollution in rural areas.[157] The EPA has not acted on the petition. In 2013, however, the EPA began recognizing data from its rural Clean Air Status and Trends Network (CASTNET) monitors as officially meeting the

153. Jim Morris, Lisa Song & David Hasemyer, *Report Offers Grim Predictions for South Texas Air Quality Amid Eagle Ford Oil Boom*, INSIDE CLIMATE NEWS (Apr. 11, 2014), http://tinyurl.com/k97bq6j.

154. *Id.*

155. *Compare The Bakken Oil Boom,* FED. RESERVE BANK OF MINNEAPOLIS, http://tinyurl.com/lsywehh (last visited Nov. 6, 2014) (providing map showing the five North Dakota counties with "core oil economic activity"), *with Design Values,* EPA, http://tinyurl.com/qywnzhd (listing active North Dakota monitors) (click on "Detailed Information" under "Ozone" in the "2012 Design Value Reports" table, and on Sheet 6 of the Spreadsheet, examine location of monitors in North Dakota, including the fact that the McKenzie County monitor is located in Theodore Roosevelt National Park ("TNRP") and that no design values are reported for the Dunn County monitor after the 2007-2009 period) (last updated Feb. 7, 2014).

156. Annmarie G. Carlton et al., *The Data Gap: Can a Lack of Monitors Obscure Loss of Clean Air Act Benefits in Fracking Areas?*, 48 ENVTL. SCI. & TECH. 893, 893 (2014).

157. PETER ZALZAL ET AL., CAL. KIDS IAQ ET AL., IN RE PETITION FOR THE U.S. ENVIRONMENTAL PROTECTION AGENCY TO 1) PROMPTLY REQUIRE OIL AND GAS OWNERS AND OPERATORS TO MONITOR FOR OZONE AND 2) TO ISSUE CONTROL TECHNIQUES GUIDELINES FOR OIL AND NATURAL GAS OPERATIONS IN NON-ATTAINMENT AREAS (2012), *available at* http://tinyurl.com/my8ge54.

requirements for regulatory ozone monitoring.[158] This is crucial, because the EPA will only gauge NAAQS compliance with data from certified monitors. For example, despite design values exceeding 75 ppb in the Uintah Basin, the EPA designated the area as "unclassifiable," rather than nonattainment, because the agency had never certified the monitors it required to be installed there as regulatory.[159] Unfortunately, few of the CASTNET monitors are located in areas with oil and gas development, and many major shale basins remain poorly monitored.[160]

"Top-down" peer-reviewed studies can help fill the gap in areas without monitors. Advances in the aircraft-based sampling techniques make monitoring large, rural areas with significant oil and gas development more feasible.[161] In the future, atmospheric scientists plan to conduct aircraft emissions surveys in the Barnett, Haynesville, and Bakken Shales, and in the San Juan Basin in Colorado and New Mexico.[162]

The Forest Service used a portable monitor to measure ozone at 23 remote sites in Utah and Colorado that cannot support year-round monitoring stations.[163] It found that 60% of the sites had design values exceeding the NAAQS, and 78% had design values above 70 ppb.[164] It found eight-hour average ozone concentrations up to 101.5 ppb, and averages above 80 ppb at eight sites.[165] All seven sites noted for being "close to or downwind from oil and gas development" had eight-hour ozone concentrations above 70

158. *See CASTNET: Ozone Monitoring*, EPA, http://tinyurl.com/kecwvf6 (last visited Nov. 6, 2014); *see also* Jason Plautz, *Oil and Gas Boom, Budget Woes Strain EPA's Monitoring Network*, E&E GREENWIRE (Mar. 31, 2014), http://tinyurl.com/jvlocpu.

159. *See* Air Quality Designations for the 2008 Ozone National Ambient Air Quality Standards, 77 Fed. Reg. 30,088, 30,151 (May 21, 2012) (designating Uintah Basin as unclassifiable); *see also Groups Seek Relief from Smog Pollution in Utah's Uintah Basin*, EARTHJUSTICE (July 23, 2012), http://tinyurl.com/n55qvgm; Martin, *supra* note 13, at 2 (explaining decision to designate Uintah Basin as unclassifiable despite evidence from unofficial monitors that its ozone levels exceeded the EPA's safety threshold).

160. *Compare* EPA, *supra* note 158 (map showing location of CASTNET monitors), *with* ENERGY INFO. ADMIN., LOWER 48 STATES SHALE PLAYS (2011), *available at* http://tinyurl.com/3uhqnh5.

161. *See, e.g.*, Karion et al., *supra* note 89; Pétron et al., *supra* note 117.

162. Anna Karion, Methane Emissions Estimates from Oil and Natural Gas Production Using Atmospheric Measurements, Presentation for Stanford School of Earth Sciences Department of Energy Resources Engineering (Apr. 14, 2014).

163. Robert C. Musselman & John L. Korfmacher, *Ozone in Remote Areas of the Southern Rocky Mountains*, 82 ATMOSPHERIC ENVT. 383, 384-85 (2014).

164. *Id.* at 386.

165. *Id.*

ppb.[166]

Until more remote studies are conducted, the EPA's design values for monitors near major oil and gas fields are the main data source.[167] The EPA's 2012 design values in the UGRB, Dallas-Fort Worth metro area, and Denver metro area remain above 75 ppb, and both the UGRG and Denver had 2012 design values higher than their 2010 and 2011 design values.[168]

Additionally, many Western areas with significant oil and gas development that are currently designated as attainment had 2012 design values exceeding the NAAQS. In the Oklahoma City and Tulsa metro areas, which have significant oil and gas development nearby,[169] nine counties had design values above 75 ppb.[170] In Texas, monitors in Bexar County, just outside the Eagle Ford Shale in the San Antonio metro area, had 2012 design values of 77 and 80 ppb.[171] In the Haynesville Shale, Gregg County, Texas, and Bossier and Caddo Parishes, Louisiana, all monitors had 2012 design values above 75 ppb.[172] And Hood County, Texas, just outside Dallas-Fort Worth in the Barnett Shale, had a design value of 77 ppb.[173] The EPA's 2012 nonattainment designations relied on design values from 2009 and 2010, years with unusually low emissions because of the recession.[174] Thus, in November 2013 the Sierra Club petitioned the EPA to redesignate as nonattainment all areas with 2012 design values above 75 ppb, including those listed above.[175]

Finally, although they did not record design values exceeding 75 ppb, monitors in many oil and gas fields, mostly in rural areas, had 2012 design values above 60 ppb (Figure 1). These results are hardly surprising. Scientists first noted elevated RHCs in Oklahoma's Anadarko Basin a decade ago and suggested that the

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166. *Id.* at 388.

167. *See* EPA, *infra* note 178; *see also* 40 C.F.R. pt. 50 app. P(3) (2014) (defining design values for ozone).

168. EPA, *infra* note 178, at Sheet 3a.

169. JOHNSON & STEBBINS, *infra* note 178.

170. EPA, *infra* note 178, at Sheet 2.

171. *Id.*

172. *Id.* (note that Bossier and Caddo Parishes had 2013 design values less than .075 ppm, and accordingly are not listed on Sheet 2 of the Design Value spreadsheet currently available from the EPA's website).

173. *Id.*

174. JOHNSON & STEBBINS, *infra* note 178, at 3, 9-10.

175. *Id.* at 1.

oil and gas sector might contribute to ozone formation there.[176] The near ubiquity of ozone concentrations above 60 ppb in rural areas near major shale plays is clearly cause for concern, and it should be a call to action for many states. Although these areas do not yet violate the eight-hour ozone NAAQs, now that the EPA has proposed to strengthen the eight-hour ozone NAAQS to within the range of 65 and 70 ppb,[177] many of these areas will likely soon be classified as being in nonattainment.

Figure 1: Western Counties with Significant Oil and Gas Development with 2012 Design Values Between 60 and 75 ppb[178]

State	**County**	**2012 Design Value**	**Oil and Gas Basin**	**Shale Formation**
Colorado	Garfield	0.066	Piceance	Williams Fork
Colorado	La Plata	0.073	San Juan	n/a
Colorado	Mesa	0.068	Piceance	Williams Fork
Colorado	Montezuma	0.068	San Juan	n/a
Colorado	Rio Blanco	0.064	Piceance	Williams Fork
New Mexico	Eddy	0.071	Permian	Barnett-Woodford
New Mexico	Lea	0.061	Permian	Barnett-Woodford
New Mexico	San Juan	0.071	San Juan	Lewis
North Dakota	Mercer	0.060	Williston	Bakken
Oklahoma	Comanche	0.075	Anadarko	Woodford
Oklahoma	Dewey	0.073	Anadarko	Woodford
Oklahoma	Kay	0.072	Anadarko	Woodford

176. Katzenstein et al., *supra* note 54, at 11,975.

177. EPA, National Ambient Air Quality Standards for Ozone (Nov. 26, 2014) (forthcoming in Federal Register), *available at* http://tinyurl.com/ozkusht.

178. Adapted by author from *Design Values*, EPA, http://tinyurl.com/qywnzhd, (click "detailed information" under "ozone," and, on downloaded spreadsheet, review county-level data on Table 4, County-Level Design Values for the 2008 8-hour Ozone NAAQS) (updated Feb. 7, 2014) (version of spreadsheet with 2012 design values on file with author); areas with significant oil and gas development identified from TCEQ, *supra* note 131; KELLY BOTT, WYO. DEP'T OF ENVTL. QUALITY, WYOMING AIR QUALITY AND NATURAL GAS DEVELOPMENT (Jan. 2008), *available at* http://tinyurl.com/k3upjbm; SETH JOHNSON & JOSHUA STEBBINS, SIERRA CLUB, PETITION TO THE ADM'R OF THE U.S. ENVTL. PROT. AGENCY TO REDESIGNATE AS NONATTAINMENT 57 AREAS WITH 2012 DESIGN VALUES VIOLATING THE 2008 8-HOUR NAT'L AMBIENT AIR QUALITY STANDARDS FOR OZONE (2013) (on file with author), at Attachment C; FED. RESERVE BANK OF MINNEAPOLIS, *supra* note 155.

State	County	2012 Design Value	Oil and Gas Basin	Shale Formation
Oklahoma	McClain	0.075	Anadarko	Woodford
Oklahoma	Pittsburg	0.074	Arkoma	Woodford
Texas	Harrison	0.074	TX-MS-LA Salt	Haynesville
Texas	Hidalgo	0.062	Western Gulf	Eagle Ford
Texas	Navarro	0.070	Fort Worth Basin	Barnett
Texas	Nueces	0.072	Western Gulf	Eagle Ford
Texas	Smith	0.075	TX-MS-LA Salt	Haynesville
Texas	Travis	0.074	Western Gulf	Eagle Ford
Texas	Victoria	0.069	Western Gulf	Eagle Ford
Utah	San Juan	0.069	Paradox	n/a
Wyoming	Campbell	0.065	Powder River	Mowry
Wyoming	Carbon	0.064	Greater Green River Basin	Hilliard-Baxter-Mancos
Wyoming	Fremont	0.067	Greater Green River Basin	Hilliard-Baxter-Mancos
Wyoming	Uintah	0.065	Greater Green River Basin	Hilliard-Baxter-Mancos

3. *Implications of science for controlling ozone precursors*

The evidence presented above implies seven conclusions relevant to regulators.

First, oil and gas sector sources, although dispersed and individually small, cumulatively contribute to ozone formation. Despite conventional wisdom that ozone is an urban problem, this is true for oil and gas fields throughout the West, including in rural areas.

Second, although they are relatively unreactive, alkanes, including methane and ethane, contribute to ozone formation when abundant. This implies that the EPA should amend its definition of "VOC" to include methane and ethane.

Third, every oil and gas field emits different RHCs. Gas and oil fields are distinct, and natural gas composition varies in each field. Other sources, both biogenic and anthropogenic, emit different ozone precursors in each area. Some areas are more RHC-limited and others are more NOx limited (and some, like the UGRB, vary spatially and temporally as to whether they are RHC or NOx limited). Additionally, different concerns motivate reducing ozone formation in different areas. Human health is a concern everywhere, but welfare concerns vary. Ozone suppressing crop growth is more of a concern in agricultural areas. Visibility concerns are more relevant near national parks. And vulnerable populations might warrant more stringent control strategies. No two areas share an optimal ozone control strategy.

Fourth, apart from spatial variation, temporal variation can drive ozone controls. High ozone events occur only at certain times of year and under certain meteorological conditions in various locations. Temporally or meteorologically-linked control techniques, like banning well completions and liquids unloading during wintertime inversion days in the UGRB, can effectively control ozone formation without necessitating year-round controls.

Fifth, different facilities and equipment within the oil and gas sector emit ozone precursors at different rates. As discussed in Part IV below, equipment and facilities with the greatest emissions should be targeted because a small number of major emitters contribute a significant percentage of the sector's overall emissions.

Sixth, more monitors are needed in oil and gas fields throughout the West, especially in rural areas. The EPA should certify these monitors quickly so that their data can be used for NAAQS attainment designations. This is particularly true because, once the EPA updates the ozone NAAQS, many relatively rural areas will be in nonattainment. And areas already designated as nonattainment also need more monitors. There is only one ozone monitor in Weld County, Colorado, an area twice the size of Delaware, so much information about ozone formation there comes from peer-reviewed scientific studies, which cannot be conducted everywhere. As the 2012 Design Values show that oil and gas producing areas across the West are close to ozone nonattainment, more monitoring is needed everywhere to protect human health from the hazard of ozone exposure.

Finally, as discussed further in Part II(B) below, current emissions inventories (including the EPA's, TCEQ's, and Colorado's) significantly underestimate oil and gas sector emissions. These inventories must be updated to give regulators reliable data upon which to make decisions.

C. *Greenhouse Gases*

As discussed in other sections of this Article, the oil and gas sector emits several greenhouse gases and their precursors, including methane, tropospheric ozone, and nitrous oxide, but this Article focuses on methane, the main gas the sector emits.[179] Accounting for various feedbacks, the most recent International Panel on Climate Change report estimated methane's global warming potential (GWP) to be 86 times that of carbon dioxide over a 20-year time scale, and 34 times that of carbon dioxide over a 100-year time scale.[180] Although methane's 100-year GWP is much less than its twenty year GWP, the twenty year GWP is relevant because there are many catastrophic "tipping points" in the climate system, like melting the Greenland ice sheet, which, if crossed, are likely irreversible.[181] Major mitigation efforts over the next century might allow the climate system to avoid those tipping points, and immediate reduction of short-lived climate-forcing gases like methane improves the likelihood of avoiding them.[182]

1. *Efforts to quantify methane emissions*

The oil and gas sector's methane emissions are poorly understood and extremely contested.[183] Many scientists have recently attempted to quantify them. These studies show that methane emissions are well above previous estimates, specifically the EPA's national greenhouse gas emission inventory.[184] Beyond this basic agreement, the studies have found remarkably different results concerning the actual magnitude of methane emissions and whether natural gas has climate benefits over coal.[185] This Article summarizes various studies' results, strengths, and weaknesses.

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179. *See* D.L. Hartmann et al., IPCC, *Observations: Atmospheric and Surface*, *in* CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS 159, 166-67, 172-73 (T.F. Stocker et al. eds., 2013) (listing methane, ozone, and nitrous oxide as greenhouse gases).

180. Gunnar Myhre et al., IPCC, *Anthropogenic and Natural Radioactive Forcing*, *in* CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS 659, 713-14 (2013).

181. *See generally* Timothy M. Lenton et al., *Tipping Elements in the Earth's Climate System*, 105 PROC. NAT'L ACAD. SCI. 1786 (2008).

182. *See, e.g.*, Detlef P. van Vuuren & Elke Stehfest, *If Climate Action Becomes Urgent: The Importance of Response Times for Various Climate Strategies*, 121 CLIMATIC CHANGE 473, 474-75 (2013).

183. *See* David A. Dana & Hannah J. Wiseman, *A Market Approach to Regulating the Energy Revolution: Assurance Bonds, Insurance, and the Certain and Uncertain Risks of Hydraulic Fracturing*, 99 IOWA L. REV. 1523, 1578-79 (2014).

184. *See* Brandt et al., *supra* note 5, at 733.

185. *See* J.A. de Gouw et al., *Reduced Emissions of CO_2, NOx, and SO_2 from U.S. Power Plants Owing to Switch from Coal to Natural Gas with Combined Cycle Technology*, 2 EARTH'S FUTURE 75, 81 (2014) (acknowledging difficulties in ascertaining climate benefits of coal and natural gas).

Figure 2 presents each study's methane emission rate. As with ozone precursor measurement, studies measuring methane emissions split roughly into "top-down" studies which measure emissions over a large area and then attempt to attribute them to different sources, and "bottom-up" studies, which estimate the aggregate emissions of sources known to be in an area based on emissions inventories.[186]

At the broadest level, "top-down" studies aggregate data from a variety of sources into a single model. One study found that the EPA's emissions inventory underestimated U.S. methane emissions by a factor of 1.5.[187] Based on the spatial pattern of underestimates, the study concluded that the oil and gas sector was a major source of these emissions, and that regional methane emissions from oil and gas extraction and processing could be 4.9 times greater than global inventories estimate.[188] Although top-down studies allow comparisons at broad spatial scales,[189] they lose accuracy at more refined spatial scales and when attempting to distinguish between emission sources.[190] Other top-down studies use measurements taken in aircraft, vehicles, atmospheric observation towers, ground level monitors, and balloons to draw conclusions about an area's emissions profile.[191]

A recent NASA study from the Four Corners region of Colorado, New Mexico, Utah, and Arizona made headlines and highlighted the degree to which bottom-up emissions inventories can underestimate actual emissions.[192] The study used space-based observations of North American methane emissions gathered

186. *See generally* Stefan Schwietzke et al., *Global Bottom-Up Fossil Fuel Fugitive Methane and Ethane Emissions Inventory for Atmospheric Modeling*, 2 SUSTAINABLE CHEMISTRY & ENGINEERING 1992, 1992 (2014) (discussing differences between top-down and bottom-up modeling).

187. Scott M. Miller et al., *Anthropogenic Emissions of Methane in the United States*, 110 PROC. NAT'L. ACAD. SCI. 20,018, 20,018 (2013).

188. *Id.*

189. *See* Scott M. Miller, Anna M. Michalak & Steven C. Wofsy, *Reply to Hristov et al.: Linking Methane Emissions Inventories with Atmospheric Observations*, 111 PROC. NAT'L ACAD. SCI. E1321, E1321 (2014) (defending study's methods and explaining their advantages in response to a published article critiquing the study's findings regarding livestock methane emissions).

190. *See* Michael Wines, *Emissions of Methane in U.S. Exceed Estimates, Study Finds*, N.Y. TIMES, Nov. 25, 2013, *available at* http://tinyurl.com/plqmw3h (interview with study's principal authors describing its limitations).

191. *See* Brandt et al., *supra* note 5, at 734 (describing such studies).

192. *See* Jonathan Thompson, *NASA Finds Methane Hot Spot over Four Corners*, HIGH COUNTRY NEWS, Oct. 12, 2014, http://tinyurl.com/md4glfv.

between 2003 and 2009.[193] It found that the EPA emissions inventory underestimated emissions by a factor of 1.8.[194] The Four Corners region alone would account for 10% of American methane emissions if the EPA emissions inventory was accurate.[195] The study attributed the extreme methane concentrations to natural gas, coalbed methane, and coal extraction in the region, and cautioned that the growth of hydraulic fracturing in the region made accurate baseline emissions inventories even more important.[196]

Another recent study also used data gathered from the same satellite and other space-based instruments between 2002 and 2012 to estimate methane emissions in North Dakota's Bakken Shale and Texas' Eagle Ford Shale.[197] It compared emissions in 2006-08, before drilling had started in earnest in either region, with emissions in 2009-11, after the advent of both regions' drilling booms, and found a 66% emissions increase in the Bakken Shale and a 62% emissions increase in the Eagle Ford Shale.[198] This translated into a 10.1% leakage rate in the Bakken and a 9.1% leakage rate in the Eagle Ford, well above the EPA's 1.2% estimate.[199]

Bottom-up studies multiply known sources by emissions factors from emissions inventories.[200] A 2009 Barnett Shale study, using the TCEQ emissions inventory, found that 1.5% of natural gas produced in the Barnett Shale leaks into the atmosphere before it reaches a power plant, corresponding to 1.3% of methane leaking into the atmosphere.[201] Rather than using pre-determined emissions inventories, some bottom up studies survey operators about emissions from specific equipment and effectively create

193. Eric A. Kort, et al., *Four Corners: The Largest US Methane Anomaly Viewed from Space*, 41 GEOPHYSICAL RES. LETTERS 6898, 6899 (2014), *available at* http://tinyurl.com/p6lyesr.

194. *Id.* at 6900.

195. *Id.*

196. *Id.* at 6902.

197. Oliver Schneising et al., *Remote Sensing of Fugitive Methane Emissions from Oil and Gas Production in North American Tight Geologic Formations*, EARTH'S FUTURE 1, 2-4 (2014), *available at* http://tinyurl.com/pwwv5vu.

198. *Id.* at 6-7.

199. *Id.* at 8.

200. Armendariz, *supra* note 132, at 8-27.

201. JEFFREY LOGAN ET AL., JOINT INST. FOR STRATEGIC ENERGY ANALYSIS, NATURAL GAS AND THE TRANSFORMATION OF THE U.S. ENERGY SECTOR: ELECTRICITY 3, 30 (2012).

their own emissions inventories, which may provide an accurate picture of emissions in the area being studied based on common practices among operators in the area.[202]

One early bottom-up study, Howarth et al. 2011, made headlines.[203] Using methane emissions measured during flowback and well completion and estimates of both intentional and unintentional leaks, it calculated life-cycle leakage rates for conventional and unconventional natural gas production.[204] It found that 3.6% to 7.9% of methane from unconventional natural gas production leaked into the atmosphere, compared to 1.7% to 6% from conventional production.[205] One critic argued that this study overestimated fugitive emissions by underestimating the rate at which reduced emission completions (RECs) were used.[206] The team published a rebuttal, defending its initial findings with comparisons to later studies.[207] Howarth recently published another paper concluding that the "emissions estimates we published . . . are surprisingly robust, particularly for conventional natural gas[,]" and that top-down studies "indicate our estimates for unconventional gas may have been too low."[208]

A study funded by the Environmental Defense Fund (EDF), several oil and gas companies, and various other groups reached very different results.[209] Scientists were given unprecedented access to 190 natural gas production sites.[210] The study concluded that well completion emissions were lower than those reported in the

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202. AMNON BAR-ILAN ET AL., A COMPREHENSIVE EMISSIONS INVENTORY OF UPSTREAM OIL AND GAS ACTIVITIES IN THE ROCKY MOUNTAIN STATES 8 (2012), *available at* http://tinyurl.com/m5krp8r; Mansfield et al., *supra* note 23, at 181-82.

203. Robert W. Howarth, Renee Santoro & Anthony Ingraffea, *Methane and the Greenhouse-gas Footprint of Natural Gas from Shale Formations*, 106 CLIMATIC CHANGE 679, 681-85 (2011).

204. *Id.* at 681-85.

205. *Id.* at 685.

206. Lawrence M. Cathles III et al., *A Commentary on "The Greenhouse-Gas Footprint of Natural Gas in Shale Formations," by R.W. Howarth, R. Santoro, and Anthony Ingraffea*, 113 CLIMATIC CHANGE 525, 526 (2012).

207. Robert W. Howarth, Renee Santoro & Anthony Ingraffea, *Venting and Leaking of Methane from Shale Gas Development: Response to Cathles et al.*, 113 CLIMATIC CHANGE 537, 538-42 (2012).

208. Howarth, *supra* note 2, at 4-6. Like the initial 2011 study, Howarth's most recent study also made headlines. *See, e.g.*, Bobby Magill, *'Catastrophe' Claim Adds Fuel to Methane Debate*, CLIMATE CENTRAL, May 15, 2014, http://tinyurl.com/qjoaba2.

209. David T. Allen et al., *Measurements of Methane Emissions at Natural Gas Production Sites in the United States*, 110 PROC. NAT'L ACAD. SCI. 17,768, 17,773 (2013).

210. *Id.* at 17,769.

2011 EPA inventory, likely due to operators using RECs.[211] It also found that other equipment, including pneumatic controllers, had much higher emissions than the EPA inventory indicates.[212] Overall, the study found a methane leak rate of 0.42% from the natural gas production process.[213] It did not address oil and co-producing wells (which produce both oil and gas).[214] Howarth criticized it for only studying wells pre-approved by the industry, which likely represent the "best possible performance[.]"[215]

Figure 2: Recently Measured and Calculated Methane Emissions and Leak Rates[216]

Paper	**Method**	**Location**	**Sectors**	**Methane Emissions**	**Gas Leak Range (%)**	**Gas Leak Value (%)**
Miller	Tower, aircraft	TX, OK, KS	Oil & Gas	3.7	n/a	n/a
Katzen-stein	Vehicle	Anadarko Basin, TX, OK, KS	All	3.8	n/a	n/a
Karion	Aircraft	Uintah Basin, UT	Oil & Gas	0.4814	6.2 - 11.7	8.9±2.8
Helmig	Tower, Balloon	Uintah Basin, UT	Oil & Gas	n/a	8.4-15.9	n/a
Pétron 2012	Tower, Vehicle	Weld County, CO	Oil & Gas	.071-.252	2.3-7.7	4

211. *Id.* at 17,772.
212. *Id.*
213. *Id.* at 17,773
214. *Id.*
215. Howarth, *supra* note 2, at 52.
216. Calculations by author are based on the following sources: LOGAN ET AL., *supra* note 201; Dana R. Caulton et al., *Toward a Better Understanding and Quantification of Methane Emissions from Shale Gas Development*, PROC. NAT'L. ACAD. SCI. (2014); Helmig et al. *supra* note 51; Karion et al., *supra* note 89; Katzenstein et al., *supra* note 54; Miller et al., *supra* note 189; Pétron et al. (2014), *supra* note 117; Pétron et al. (2012), *supra* note 104; Schneising et al., *supra* note 197.

Pétron 2014	Aircraft	Weld County, CO	Oil & Gas	0.169	2.6-5.6	4.1±
Caulton	Aircraft	Southwest PA	Gas	0.177-1.24	2.8-17.3	n/a
Logan	Bottom up	Barnett shale, TX	Gas	n/a	n/a	1.5
Allen	On-site measures + Bottom up	Nationwide	Gas	2.3	n/a	0.42**
Howarth	Bottom up	Nationwide	Shale Gas	n/a	3.6-7.9*	n/a
Brandt***	Bottom up	Nationwide	Gas	n/a	3.6-7.1	5.4
Schneising	Satellite	Bakken, ND	Oil & Gas	n/a	2.8-17.4	10.1
Schneising	Satellite	Eagle Ford, TX	Oil & Gas	n/a	2.9-15.3	9.1

*Methane only, not full natural gas stream.

** Methane only, and production process only (not storage, processing, or transmission)

*** Not reported in study; values based on calculations from data in Brandt et al.'s supplementary materials, as reported in Howarth 2014.

2. *Implications of methane leak rates*

Scientists have reached a wide range of conclusions about the oil and gas sector's methane leak rate. Figure 2 shows how studies using different methods at different scales and locations have found very different methane leak rates. Two major studies published in early 2014 have attempted to draw conclusions from the studies published to date. Ultimately, both conclude that methane leak rates are higher than previously realized, indicating a need for regulatory action. But they disagree about whether natural gas is indeed a "bridge fuel" to a low carbon future or a "bridge to nowhere." This is because of their different normative judgments about the timeframe in which the oil and gas sector's emissions are most relevant, with one focusing on methane's twenty-year GWP, and the other on its 100-year GWP.

The first study, Brandt et al., reviewed many of the top-down and bottom-up studies discussed above, along with sector-specific studies quantifying specific equipment's emissions.[217] It concluded that actual natural gas sector emissions are approximately 1.5 times greater than the EPA emissions inventory indicates.[218] The study identified three likely explanations for this: (1) the EPA's emissions factors are based on production techniques that predate hydraulic fracturing; (2) the high cost of developing emissions factors resulted in undersampling; and (3) emissions distributions have "heavy tails," meaning that a small fraction of leaky sources emit a very large percentage of the sector's total emissions.[219] The study noted that the "greatest challenge" of top-down studies "is attribut[ing] observed [methane] concentrations to multiple potential sources (both anthropogenic and natural)."[220] Accordingly, it concluded that high leak rates found by top-down studies are likely unrepresentative, because, if scaled up, natural gas sector emissions would exceed total anthropogenic methane emitted by all source categories.[221]

Second, Howarth's aforementioned study agrees that the EPA's current emissions inventory, as revised in 2011, is too low, especially given Miller's nationwide methane measurements.[222] He agrees with Brandt that top-down studies may be unrepresentative of nationwide methane emissions, and that bottom-up studies often underestimate emissions because they leave out key system components.[223] Overall, Howarth authenticated his 2011 bottom-up calculation that the natural gas sector's methane leak rate is between 3.6% and 7.9%.[224] This range is similar to a leakage rate range Howarth calculated based on data provided in Brandt's

217. Brandt et al., *supra* note 5, at 733-34; *see also* A.R. Brandt et al., *Supplementary Materials for Methane Leaks from North American Natural Gas Systems*, 343 SCIENCE 1, 4-22 (2014), http://tinyurl.com/p84lv2n.

218. Brandt et al., *supra* note 5, at 734.

219. *Id.*

220. *Id.*

221. *Id.* at 735.

222. Howarth, *supra* note 2, at 52.

223. *Id.* at 51.

224. *Id.* at 49-52.

supplementary material (3.6%-7.1%, with a mean of 5.4%).[225]

Despite their similarities, Brandt and Howarth reach different conclusions about the climate benefits of using natural gas as an electricity source. Using leakage rates from several studies, Brandt updated earlier natural gas sector life cycle greenhouse gas assessments which relied on the EPA's inaccurate inventory. He concluded that natural gas still has "robust climate benefits" over coal for use in electricity generation, but that such climate benefits were uncertain or unlikely if substituting natural gas for gasoline in light-duty vehicles or for diesel in heavy-duty vehicles.[226] Brandt's study looked at a "typical 100-year assessment period."[227] And it emphasized that the conclusion "may undercount" natural gas's climate benefits because some of the emissions estimates included methane emitted from oil and co-produced wells.[228]

Howarth reached the opposite conclusion. He used Brandt's data for the mean and range of natural gas sector methane emissions, and found that natural gas had a larger greenhouse gas footprint than coal for the purpose of electricity generation, and that it had a larger greenhouse gas footprint than both diesel and coal for home heating.[229] Howarth used methane's 20-year GWP, which he described as the "appropriate timescale given the urgent need to control methane emissions globally."[230] He pointed out that nearly all life cycle analyses which have found natural gas to have climate benefits over coal, including Brandt's, used hundred-year timescales.[231] Using methane's twenty-year GWP, Howarth found natural gas lost its climate benefits over coal as a vehicular fuel source at a leakage rate of 2.8%.[232] Accordingly, he concluded that replacing coal with natural gas is unwise, and advocated instead transitioning to renewable energy.[233]

Both Brandt and Howarth conclude that methane leak rates are higher than previously realized, indicating a need for regulatory action. But they disagree about whether natural gas is

225. *Id.* at 52.

226. Brandt et al., *supra* note 5, at 735.

227. *Id.*

228. *Id.*

229. Howarth, *supra* note 2, at 55-56.

230. *Id.*

231. *Id.* at 56.

232. *Id.*

233. *Id.* at 57 (citing Mark Z. Jacobson, *Review of Solutions to Global Warming, Air Pollution, and Energy Security*, 2 ENERGY & ENVTL. SCI. 148 (2009)).

indeed a "bridge fuel"[234] to a low carbon future or a "bridge to nowhere."[235] This divergence is rooted in the authors making different normative judgments about the timeframe in which the oil and gas sector's emissions are most relevant, with one focusing on methane's twenty-year GWP, and the other on its hundred-year GWP. Authors who focus on methane's twenty-year GWP are much more likely to find that natural gas lacks climate benefits over coal, and those who focus on methane's hundred-year GWP are much more likely to find that natural gas has climate benefits over coal.[236]

There is no denying that, although contested, the methane leakage rate matters, especially because President Obama's climate plan assumes that natural gas has climate advantages over coal.[237] But more relevant than the exact leakage rate is the shared conclusion of scientists from all perspectives that operators should reduce the sector's leakage rate.[238]

D. *Hazardous Air Pollutants*

HAPs, or air toxics, are pollutants which "present . . . a threat of adverse human health effects (including, but not limited to, substances which are known to be, or may reasonably be anticipated to be, carcinogenic, mutagenic, teratogenic, neurotoxic, which cause reproductive dysfunction, or which are acutely or chronically toxic) or adverse environmental effects[.]"[239] HAPs emitted by the oil and gas sector include benzene, toluene, ethyl benzene, and xylene (collectively BTEX), which are known or suspected carcinogens.[240]

Identifying human exposure to HAPs is complex, because toxic harms often take years to manifest, different HAPs often share symptoms, and humans are exposed to many HAPs, making

234. Moniz, *supra* note 1, at 19.

235. Howarth, *supra* note 2.

236. *See, e.g.*, LOGAN ET AL., *supra* note 201, at 23 n.28, 35-37 (concluding, in a life-cycle analysis that uses methane's hundred-year GWP, that natural gas has climate benefits over coal).

237. *See* EPA, Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units, 79 Fed. Reg. 34,830, 34,843 (June 18, 2014).

238. *See* Brandt et al., *supra* note 5, at 735; Howarth, *supra* note 2, at 57.

239. 42 U.S.C. § 7412(b)(2) (2012).

240. *See, e.g.*, NATURAL RES. DEF. COUNCIL (NRDC), DRILLING DOWN: PROTECTING WESTERN COMMUNITIES FROM THE HEALTH AND ENVIRONMENTAL EFFECTS OF OIL AND GAS PRODUCTION v-vi (2007).

causation difficult to prove.[241] Accordingly, oil and gas sector HAPs exposure risk remains poorly understood, and additional research may take years.[242] Despite these challenges, epidemiologists and public health scientists in Colorado have conducted three major studies to identify the public health impacts of human exposure to oil and gas sector air toxics. One study found elevated cancer risks and some non-cancer health impacts for people living near wells.[243] Another more comprehensive public health study found elevated cancer rates of up to 100 cases per million people near wells in Garfield County, likely due to benzene exposure.[244] A third study found higher rates of congenital heart defects and neural tube defects among babies born to mothers living within a ten-mile radius and near higher densities of natural gas wells.[245]

Better information about the impacts of oil and gas sector HAPs exposure will likely continue to build over time. For now, it is clear that exposure to oil and gas sector HAPs poses some risks. Given public concern over toxicity associated with hydraulic fracturing, highlighting these risks may be an important source of public support for efforts to regulate oil and gas sector emissions, regardless of which pollutant the regulations ostensibly target.

III. LAW: THE STATUTES AND REGULATIONS GOVERNING A CHANGING REGULATORY LANDSCAPE

The Obama Administration's January 14, 2015 announcement that it plans to cut methane emissions from the oil and gas sector will require significant changes to oil and gas emissions regulations at both the federal and state level. This section provides an overview of the federal and state laws that are currently in place, and explains how and why they will require states to update their

241. *See generally* PETER H. SCHUCK, AGENT ORANGE ON TRIAL: MASS TOXIC DISASTERS IN THE COURTS (1986) (documenting, in the context of Agent Orange litigation, the difficulty of proving the causal connection between symptoms which may occur for many different reasons and exposure many years before to a specific chemical known to cause those symptoms).

242. Bernard D. Goldstein et al., *The Role of Toxicological Science in Meeting the Challenges and Opportunities of Hydraulic Fracturing*, 139 TOXICOLOGICAL SCI. 271, 275-77 (2014).

243. Lisa M. McKenzie et al., *Human Health Risk Assessment of Air Emissions from Development of Unconventional Natural Gas Resources*, 424 SCI. TOTAL ENV'T 79, 80 (2012).

244. RAJ GOYAL, COLO. DEP'T OF PUB. HEALTH & ENV'T, GARFIELD COUNTY AIR TOXICS INHALATION: SCREENING LEVEL HUMAN HEALTH RISK ASSESSMENT 5-6 (2010).

245. Lisa M. McKenzie et al., *Birth Outcomes and Maternal Residential Proximity to Natural Gas Development in Rural Colorado*, 122 ENVTL. HEALTH PERSP. 412, 414 (2014).

regulations over the next few years. It also explains that because RHCs are emitted by the oil and gas sector in a single stream that includes VOCs, HAPs, and methane, regulations targeting any type of RHC emissions, especially VOC emissions, can also serve to reduce methane emissions. Additionally, because the Administration is separately engaged in the process of strengthening its ozone standards, states may have to engage in additional rulemaking for the oil and gas sector in order to meet the new, stronger ozone standards in areas that may be designated in nonattainment with the updated ozone standards.

A. *Federal Regulations*

1. *Ozone precursors*

The legal mechanisms to control ozone pollution are strong, clear, and well-established. The Clean Air Act (CAA) directs the EPA to establish NAAQS for ozone at a level "requisite to protect the public health . . . allowing an adequate margin of safety."[246] The EPA then determines whether the ozone levels in areas throughout the country exceed the NAAQS, and accordingly designates areas as "attainment" or "nonattainment."[247] If the EPA cannot determine on the basis of current data whether an area is in attainment or nonattainment, it designates the area as "unclassifiable."[248] The EPA bases its designation on each area's "design value," which is the three-year average of the fourth-highest eight-hour ozone concentration measured at a given monitoring site.[249] When making the designations for its 75 ppb eight-hour ozone NAAQS in 2012, the EPA noted that oil and gas sector emissions contributed to ozone issues in four areas that it designated nonattainment or unclassifiable: Wyoming's Upper Green River Basin (UGRB), Colorado's Denver metro area, Texas's Dallas-Fort Worth metro area, and Utah's Uintah Basin (which the EPA designated unclassifiable).[250]

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246. 42 U.S.C. § 7409(b)(1) (2012).

247. *See id.* § 7407(d)(1)(A)(i)-(ii).

248. *See id.* § 7407(d)(1)(A)(iii).

249. 40 C.F.R. pt. 50 app. P(3) (2008) (defining design values for ozone).

250. *See* sources cited *supra* note 13. Although 75 ppb remains the current eight-hour ozone NAAQS, on November 26, 2014, the EPA proposed to strengthen the ozone NAAQS to within a range of 65 to 70 ppb. EPA, NATIONAL AMBIENT AIR QUALITY STANDARDS FOR OZONE (Nov. 26, 2014) (forthcoming in Federal Register), *available at* http://tinyurl.com/ozkusht; *see also* Coral Davenport, *E.P.A. Ozone Rule Divide Industry,*

The EPA also sets technology standards, called New Source Performance Standards (NSPS), which apply to all new and modified sources emitting ozone precursors nationwide.[251] In 2012, the EPA updated the NSPS for the oil and gas sector's emissions of RHCs (which the EPA refers to as VOCs).[252] The NSPS had several major components. First, it required all new natural gas well completions and recompletions to use RECs by January 1, 2015 (with some exceptions).[253] Second, it required all storage tanks with potential to emit (pte) more than 6 tons per year (tpy) to reduce VOC emissions by 95%.[254] Third, it required low-bleed pneumatic controllers for upstream natural gas operations, and no-bleed controllers in natural gas processing facilities.[255] Fourth, it required a 95% reduction in VOC emissions from wet centrifugal compressors used in upstream natural gas operations, and designated rod packing replacement schedules for reciprocating compressors used in upstream natural gas operations.[256] Finally, it updated Leak Detection and Repair (LDAR) requirements for natural gas processing facilities.[257]

In November 2013, the EPA amended the NSPS rules for storage tanks.[258] All storage tanks in upstream oil and gas operations with pte >6 tpy of VOCs still must reduce emissions by 95%. But operators now have the option of proving that their storage tank's emissions have fallen below 4 tpy, at which point they will no longer be subject to regulation (storage tank emissions tend to decline over a well's lifetime as a well's production declines).[259] The rule also changed the phase-in timeline because the EPA incorrectly assumed in the original rule that an insufficient number of combustion devices, which most storage tanks would use to reduce emissions, would be available on the

Environmentalists, N.Y. TIMES, Nov. 26, 2014, http://tinyurl.com/ow3mgy4.

251. 42 U.S.C. § 7411(b) (2012).

252. *See* Oil and Natural Gas Sector: New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants Reviews, 77 Fed. Reg. 49,490, 49,492 (Aug. 16, 2012).

253. *Id.*

254. *Id.*

255. *Id.*

256. *Id.*

257. *Id.*

258. Oil and Natural Gas Sector: Reconsideration of Certain Provisions of New Source Performance Standards, 78 Fed. Reg. 58,416 (Sept. 23, 2013).

259. *Id.* at 58,417.

market.[260]

Although it makes significant strides to reduce the oil and gas sector's VOC emissions, the 2012 NSPS update is notable for what is *not* included.[261] First, it only applies to natural gas operations. With the exception of crude oil storage tanks, it does not apply to oil operations or to co-producing wells (wells that produce both oil and gas, which are common in many of the shale plays currently being developed).[262] Second, it regulates only emissions of VOCs, which, by the EPA's definition, does not include methane.[263] Third, it does not regulate emissions from several major equipment categories and processes, including liquids unloading. Fourth, it includes many exceptions (for example, feasibility exceptions for RECs), defines source categories narrowly (for example, regulating only pneumatic controllers as opposed to all pneumatic devices), and adopts weak standards for some source categories (for example, requiring only low-bleed, rather than no-bleed pneumatic controllers). Finally, its LDAR rules only apply in processing plants.

Although the 2012 NSPS did not cover NOx, the EPA does regulate NOx emissions through separate NSPS rules and mobile-source standards for the engines used in oil and gas fields.[264] The EPA regulates NOx emissions from compression ignition engines sometimes used to power drill rigs;[265] spark ignition engines used to power compressors, pumps, and electric generators;[266] stationary combustion turbines used to power the same

260. *Id.* at 58,417; *see also* EPA, FINAL UPDATES TO REQUIREMENTS FOR STORAGE TANKS USED IN OIL AND NATURAL GAS PRODUCTION AND TRANSMISSION 2-3 (2013), *available at* http://tinyurl.com/n2tumzm.

261. *See, e.g.*, Bob Weinhold, *The Future of Fracking: New Rules Target Air Emissions for Cleaner Natural Gas Production*, 120 ENVTL. HEALTH PERSP. A271, A275 (2012) (describing gaps in the current NSPS rule and advocating that the EPA or states close them in the future).

262. *See* JAMES BRADBURY ET AL., WORLD RES. INST., CLEARING THE AIR: REDUCING UPSTREAM GREENHOUSE GAS EMISSIONS FROM U.S. NATURAL GAS SYSTEMS 7 (2013) (noting that co-producing wells, which the source refers to as associated natural gas production, are increasingly common in oil-rich shale plays, such as North Dakota's Bakken Shale).

263. 40 C.F.R. § 51.100(s)(1) (2014).

264. *See* LEE GRIBOVICZ, ANALYSIS OF STATES' AND EPA OIL & GAS AIR EMISSIONS CONTROL: REQUIREMENTS FOR SELECTED BASINS IN THE WESTERN UNITED STATES (2013 UPDATE) 25-27 (2013), *available at* http://tinyurl.com/kbksza7.

265. *See* 40 C.F.R. §§ 60.4200-.4219.

266. *Id.* §§ 60.4230-.4248.

devices;[267]and non-road mobile source engines more commonly used to power drill rigs, hydraulic fracturing pumps, and electric generators.[268] The EPA's heavy-duty truck rules cover NOx emissions from trucks that bring water, chemicals, and workers to oil and gas wells.[269]

The CAA is a cooperative federalist statute, with the EPA setting the NAAQS, and states in charge of day-to-day implementation.[270] States must submit State Implementation Plans (SIPs) to the EPA to demonstrate how they will implement the NSPS standards, maintain attainment in attainment areas, and remedy nonattainment in nonattainment areas.[271] The CAA also requires the EPA to classify each ozone nonattainment area by how badly it exceeds the NAAQS.[272] If states fail to reduce ozone in a nonattainment area by specified deadlines, the EPA must reclassify the area as having worse ozone pollution, triggering penalties and stricter emissions restrictions.[273] States thus have incentives to reduce ozone pollution to avoid nonattainment designation, and to reduce ozone pollution in nonattainment areas to avoid increasing penalties and emissions restrictions. This incentive will get even stronger in the near future as a result of the EPA's proposal to strengthen the ozone NAAQS. Many more areas will be in nonattainment with the new, lower standard.

Ozone also reduces visibility, which the CAA governs separately from the NAAQS. In areas where visibility is an important value, such as national parks and wilderness areas, which the EPA designates as "Class I" areas, states must develop plans, subject to EPA approval, which remedy existing barriers to visibility and prevent future visibility impairment.[274] If these areas are located close to oil and gas operations, oil and gas sector emissions can be restricted if necessary to protect visibility in the Class I areas

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267. *Id.* §§ 60.4300-.4420.

268. *Id.* §§ 1039.1-.825, 1048.1-.825.

269. *See, e.g.*, *id.* § 86.004-11.

270. *See, e.g.*, David B. Spence, *Federalism, Regulatory Lags, and the Political Economy of Energy Production*, 161 U. PA. L. REV. 431, 470-71 (2013) (describing the CAA's cooperative federalist system).

271. 42 U.S.C. § 7410(a)(1) (2012).

272. *See id.* § 7511.

273. *Id.* § 7511(b) (discussing reclassification); *Id.* § 7511d (discussing enforcement in severe and extreme areas).

274. *Id.* § 7491(a)(2); *see also* 40 C.F.R. § 81.400 (2015) (listing areas in which visibility has been determined to be an important value).

2. *Hazardous air pollutants*

By contrast, there are fewer incentives to prompt state regulatory action to reduce HAPs emissions, which are regulated under facility-based performance standards.[275] Congress initially made a list of HAPs (which the EPA later added to), including pollutants emitted by the oil and gas sector, like benzene.[276] The EPA sets technology standards called National Emissions Standards for Hazardous Air Pollutants (NESHAPs) for HAPs emissions from new, modified, and existing sources with which states must comply.[277] The EPA simultaneously updated its NESHAP for the oil and gas sector alongside the NSPS in 2012.[278] It updated the NESHAP by adding glycol dehydrators with smaller emissions into its preexisting rule, and by also making them subject to LDAR requirements.[279] It is unusual for the EPA to update NESHAPs, and given that it updated the oil and gas sector NESHAP in 2012, it is unlikely to do so again in the immediate future. This is particularly true because NESHAPs apply to both new and existing sources, and the EPA has avoided regulating existing oil and gas sources to date (with glycol dehydrators as an obvious exception). The EPA seems likely to continue to avoid regulating existing sources because they are so numerous that regulating them is economically costly and politically controversial.

The EPA may also designate oil and gas wells as an "area source,"[280] which makes the wells within the area subject to stricter regulations.[281] The EPA may do so if the wells are located within a metropolitan area with over one million people, and "emissions of hazardous air pollutants from such wells present more than a negligible risk of adverse effects to public health."[282] In May 2014, sixty-four environmental and public health groups petitioned the

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275. *See generally* Kaitlyn R. Maxwell, Note, *Eroding the Public's Right to Clean Air: Examination of the Hazardous Air Pollutants Exemption for Natural Gas Drilling Under the Clean Air Act*, 21 B.U. PUB. INT. L.J. 153, 160-71 (2011) (explaining the CAA's HAPs regulatory structure and oil and gas HAPs regulations).

276. 42 U.S.C. § 7412(b)(1) (2012).

277. *Id.* § 7412(d)(3).

278. Oil and Natural Gas Sector: New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants Reviews, 77 Fed. Reg. 49,490, 49,492 (Aug. 16, 2012).

279. *Id.*

280. 42 U.S.C. § 7412(c)(3) (2012).

281. *Id.* §§ 7412(c)(1), 7412(d)(1).

282. *Id.* § 7412(n)(4)(B).

EPA to list oil and gas production wells and associated equipment as an area source in parts of six states.[283] To date, the EPA has not responded to the petition.

State SIPS must demonstrate compliance with the NESHAPs. But since the oil and gas NESHAP is unlikely to be updated again soon, and the EPA has not yet acted on the area source petition, states have little incentive to go beyond implementing the 2012 NESHAP.

3. *Greenhouse gases*

The CAA gives the EPA authority to regulate greenhouse gas emissions.[284] To date, the EPA has regulated greenhouse gas emissions from mobile sources,[285] required sources (including oil and gas sources) to report their greenhouse gas emissions,[286] required greenhouse gas emission permits for new major sources,[287] and proposed greenhouse gas emission standards for new and modified,[288] and existing[289] fossil-fuel fired power plants.

Initially, the EPA refused to regulate methane emissions from the oil and gas sector in the recent NSPS rule.[290] It emphasized

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283. EMMA CHEUSE ET AL., CAL. CMTYS. AGAINST TOXICS ET AL., PETITION FOR LISTING AND RULEMAKING UNDER SECTION 112 OF THE CLEAN AIR ACT TO ESTABLISH AN AREA SOURCE CATEGORY FOR OIL AND GAS PRODUCTION WELLS AND ASSOCIATED EQUIPMENT AND TO SET NATIONAL EMISSION STANDARDS FOR HAZARDOUS AIR POLLUTANT EMISSIONS 9 (May 13, 2014), *available at* http://tinyurl.com/lsqxo3c.

284. *See* Massachusetts v. EPA, 549 U.S. 497, 532 (2007) ("[G]reenhouse gases fit well within the Clean Air Act's capacious definition of 'air pollutant[.]'").

285. Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rule, 75 Fed. Reg. 25,324, 25,324 (May 7, 2010).

286. Mandatory Reporting of Greenhouse Gases: Petroleum and Natural Gas Systems, 75 Fed. Reg. 74,458, 74,458 (Nov. 30, 2010) (providing the initial final rule requiring reporting of oil and gas sector greenhouse gas emissions); *see also* 2013 Revisions to the Greenhouse Gas Reporting Rule and Final Confidentiality Determinations for New or Substantially Revised Data Elements, 78 Fed. Reg. 71,904, 71,904 (Nov. 29, 2013) (providing the most recent revisions to oil and gas sector greenhouse gas reporting rule).

287. *See* Prevention of Significant Deterioration and Title V Greenhouse Gas Tailoring Rule, 75 Fed. Reg. 31,514, 31,514 (June 3, 2010) (defining threshold of greenhouse gas emissions requiring permit).

288. Standards of Performance for Greenhouse Gas Emissions From New Stationary Sources: Electric Utility Generating Units, 79 Fed. Reg. 1430, 1430 (Jan. 8, 2014).

289. *See* Coral Davenport, *Unveiling New Carbon Plan, E.P.A. Focuses on Flexibility*, N.Y. TIMES, June 2, 2014, http://tinyurl.com/ml9urv6. *See generally* Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units, 79 Fed. Reg. 34,830 (June 18, 2014).

290. Oil and Natural Gas Sector: New Source Performance Standards and

that the NSPS rule, although put in place to reduce VOC emissions, would also reduce methane emissions as a "co-benefit."[291] But not long after it released the NSPS, the EPA began considering the possibility of regulating methane directly. In March 2014, President Obama released a climate action plan for methane emissions, which focuses mostly on other sectors (landfills, coal mines, and agriculture).[292] The EPA has subsequently released a series of five white papers on methane emissions from various equipment and processes in the oil and gas sector and techniques to control those emissions, and solicited expert review and comment on its conclusions.[293] And on January 14, 2015, the Obama Administration announced that it would move forward on regulating methane directly.[294] It recognized that "a strategy for cutting methane emissions from the oil and gas sector is an important component of efforts to address climate change."[295] The Administration's plan involves actions by many agencies targeting all aspects of the oil and gas sector. Its centerpiece is strengthening the EPA's existing NSPS rule, and also directly setting methane emissions standards for the oil and gas industry, which it plans to do via a proposed rulemaking beginning in the summer of 2015, with a final rule promulgated in 2016.[296] The plan also envisions working with states to strengthen regulations in areas with ozone problems, enhancing leak detection and repair, setting strong standards for oil and gas operations on public lands, reducing emissions from the transmission and distribution phases, and funding research to improve emissions and leak control technology.[297]

Because of the CAA's cooperative federalist structure, the changes to the federal regulations will also require states to update their regulations. Notably, some states have already adopted their own rules directly targeting methane emissions. In February 2014,

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National Emission Standards for Hazardous Air Pollutants Review, 77 Fed. Reg. 49,490, 49.513 (Aug. 16, 2012).

291. Oil and Natural Gas Sector: New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants Review, 77 Fed. Reg. at 49,513.

292. THE WHITE HOUSE, CLIMATE ACTION PLAN: STRATEGY TO REDUCE METHANE EMISSIONS 2 (2014), *available at* http://tinyurl.com/obryjaw.

293. EPA, WHITE PAPERS ON METHANE AND VOC EMISSIONS (2014), *available at* http://tinyurl.com/kmeqwxa.

294. See The White House, supra note 9.

295. *Id.*

296. *Id.*

297. *Id.*

Colorado became the first state to regulate methane emissions from the oil and gas sector.[298] And in September 2014, California Governor Jerry Brown signed a bill requiring reductions in fugitive emissions from downstream pipelines. The bill also required the California Air Resources Board to develop a plan to cut methane emissions, which may include regulations targeting the natural gas sector.[299] With a federal rule forthcoming, all states with oil and gas development will have to follow Colorado's and California's lead.

B. *State Regulations*

All states must comply with the federal regulatory baseline by implementing the NSPS and NESHAP rules, meeting visibility requirements, and developing SIPs to maintain or achieve NAAQS attainment. Thus, although the federal baseline is incredibly important for establishing goals for overall emissions reductions, because states have significant flexibility in how they implement federal rules, the state level is where most oil and gas sector emissions regulations are actually put in place.[300]

1. *Colorado's RHC regulations*

On February 23, 2014, Colorado's Air Quality Control Commission (AQCC) updated its oil and gas rules, creating the nation's strongest regulations.[301] Colorado's rule adopts all federal NSPS requirements, but also goes beyond the NSPS in several ways.[302] Because methane is a powerful greenhouse gas, the rule requires operators to capture 95% of methane emissions, making Colorado the first state to directly regulate oil and gas methane

298. Stephanie Paige Ogburn, *Colorado First State to Limit Methane Pollution from Oil and Gas Wells*, SCI. AM., Feb. 25, 2014, http://tinyurl.com/lo4k58q; *see also* 5 COLO. CODE REGS. § 1001-9(II)(B) (noting that methane emissions from oil and gas operations are not exempt from regulatory provisions applying to oil and gas sector VOC emissions).

299. *See* Press Release, Envt'l Def. Fund, Governor Brown Signs Law to Find and Fix Natural Gas Leaks (Sept. 22, 2014), *available at* http://tinyurl.com/q4csh8r; *see also* Sean Cockerham, *California Looks to Curb Methane Emissions*, NEWS & OBSERVER, Oct. 20, 2014, *available at* http://tinyurl.com/mlkm3p9.

300. *See generally* Hannah J. Wiseman, *Risk and Response in Fracturing Policy*, 84 U. COLO. L. REV. 729, 803-09 (2013) (discussing oil and gas sector's air pollution impacts and surveying state regulatory responses).

301. Finley, *supra* note 12.

302. COLO. DEP'T PUB. HEALTH & ENV'T (CDPHE), REVISIONS TO COLORADO AIR QUALITY CONTROL COMMISSION'S REGULATION NUMBERS 3, 6, AND 7: FACT SHEET 1 (2014), *available at* http://tinyurl.com/q9zbk9v.

emissions.[303] The rule also requires that all newly constructed, hydraulically fractured, and recompleted gas wells capture gas during well completion, eliminating the NSPS feasibility exception.[304] Colorado's rule also creates a robust LDAR program, requiring operators to use infrared cameras in monthly, quarterly, and annual inspections for leaks at storage tanks, compressor stations, wells, and other facilities.[305] The rule requires that all new combustion devices (flares) have an auto-igniter to prevent gas from venting into the atmosphere, and it also requires existing combustion devices to install auto-igniters by May 1, 2016.[306] Bringing the state in line with the NSPS, the rule requires centrifugal compressors to reduce RHC emissions by 95%,[307] and reciprocating compressors at natural gas compressor stations to replace their rod packing every 26,000 hours of operation or every thirty-six months.[308] Finally, Colorado's rule requires no-bleed pneumatic controllers wherever electricity is available and extends a previous low-bleed pneumatic controller requirement statewide.[309]

Colorado's strong standards for storage tanks go well beyond the EPA's current requirements. First, like the federal NSPS, Colorado's rule covers only storage tanks with >6 tpy pte, but requires that operators of such tanks reduce emissions using devices rated as being capable of reducing emissions by 98%.[310] Second, Colorado's rule bans venting from storage tanks. To ensure that this is accomplished, it requires operators to develop plans to inspect storage tanks annually, quarterly, or monthly (depending on their emissions capacity), and to keep inspection records of the inspections that must be turned over to state regulators upon request.[311]

Colorado's rule also exceeds the EPA's NESHAP regulations by requiring that new glycol dehydrators with >2 tpy pte reduce

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303. *See* Colorado Air Quality Control Comm'n, *Draft Regulations No. 7*, § XIX.N 1, 23 (Feb. 23, 2014), http://tinyurl.com/lsxycuw; *see also* COLO. REV. STAT. § 25-7-109(2)(c) (2014) (granting the AQCC authority to regulate hydrocarbon emissions).

304. CDPHE, *supra* note 302, at 4.

305. *Id.* at 3-4.

306. *Id.* at 1.

307. *Id.* at 2.

308. *Id.*

309. *Id.* at 4.

310. *Id.* at 2.

311. *Id.*

emissions by 95%, using combustors with 98% rated emissions reduction potential.[312] Existing glycol dehydrators also must install the devices if they have >6 tpy pte, or >2 tpy pte if they are located 1,320 feet of an occupied building.[313]

Finally, although Colorado's rule did not designate a specific control technology for liquids unloading, it requires operators to use best management practices.[314] It also requires operators to keep at least two years of records that state regulators can use in future liquids unloading regulations.[315]

2. *Other western states' RHC regulations*

Outside Colorado, few western states have adopted such strong regulations. Indeed, few have yet adopted the NSPS requirements. But several have adopted requirements that go beyond the NSPS for various emission sources, mostly before the NSPS was released.

Wyoming was an early adopter of RECs and has required operators in part of the UGRB and other designated areas to use RECs since August 2011.[316] Montana restricts venting during well completion, by requiring flaring if gas is vented at a rate exceeding twenty thousand cubic feet (mcf) per day for more than three days.[317]

Montana requires that fugitive emissions from compressors, pneumatic controllers, glycol dehydrators, and other sources be captured and routed to a gas pipeline if one is available within a half mile, or that they be flared using an auto-ignition device.[318] Wyoming requires upstream pneumatic controllers to be low or no bleed.[319] It also requires immediate 98% emissions reductions for all new and modified glycol dehydrators in the UGRB upon start up, and phased-in controls for dehydrators with >6 tpy pte elsewhere in the state.[320] North Dakota requires glycol dehydrators to reduce emissions by 90%.[321]

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312. *Id.* at 3.
313. *Id.*
314. *Id.* at 4.
315. *Id.*
316. GRIBOVICZ, *supra* note 264, at 29.
317. *Id.*
318. *Id.* at 29-32.
319. *Id.* at 29.
320. *Id.* at 31.
321. *Id.*

Only New Mexico lacks specific storage tank regulations.[322] Montana requires all tanks with >15 tpy pte to capture their emissions, or reduce them by 95%.[323] Montana also requires submerged filling technology for storage tank loading and unloading.[324] North Dakota also requires submerged filling for tanks >1,000 gallons, requires new tanks with >20 tpy pte to reduce emissions by 98%, and tanks with <20 tpy pte to reduce emissions by 90%.[325] Utah's storage tank requirements apply only in the state's currently nonexistent ozone nonattainment areas.[326] Wyoming's rule requires 98% emissions reductions for all new and modified storage tanks.[327] It applies to all UGRB tanks, tanks with >8 tpy pte in concentrated development areas, and tanks with >10 tpy pte in other areas statewide.[328]

The de minimis emissions threshold for permits ranges from a high of >25 tpy in New Mexico and Montana to >5 tpy in Colorado and Utah. North Dakota and Wyoming require permits for all sources (although all states have various exemptions).[329] Aside from Colorado, Wyoming and Montana generally have the strongest regulations, North Dakota has middle-of-the-road regulations, and New Mexico and Utah have the weakest regulations. Notably, Wyoming and Utah have recently adopted special programs using emissions offsets designed to reduce emissions in the UGRB nonattainment area and Uintah Basin unclassifiable area, respectively.[330] In 2013, Wyoming also released a plan for implementing the CAA's nonattainment provisions in the UGRB nonattainment area.[331]

322. *Id.* at 30.

323. *Id.*

324. *Id.*

325. *Id.*

326. *Id.*

327. *Id.*

328. *Id.*

329. *Id.* at 32.

330. *See* WYO. DEP'T ENVTL. QUALITY (WDEQ), AIR QUALITY DIV., SUBLETTE CNTY. BANKING/VOLUNTARY EMISSIONS REDUCTION POLICY (Oct. 10, 2011), *available at* http://tinyurl.com/qe8pha2 (modifying Wyoming's initial offset policy to allow offset banking); Letter from David A. Finley, Adm'r, Wyo. Air Quality Div., to Sublette Cnty. Operators 2 (July 21, 2008), *available at* http://tinyurl.com/o2gsfd4 (initial Wyoming Offset Policy); Memorandum from Regg Olsen, Permitting Branch Manager, Utah Dep't Envtl. Quality, Div. Air Quality, to New Source Review Section, UDEQ Div. Air Quality 1 (Jan. 16, 2013), *available at* http://tinyurl.com/l2apqos.

331. WDEQ, AIR QUALITY DIV., UPPER GREEN RIVER BASIN OZONE STRATEGY 1 (Mar. 11, 2013), *available at* http://tinyurl.com/p5t4rjp.

3. *Comparative NOx regulations in western states*

Western states have been more consistent regarding NOx regulations. All states have adopted the EPA NSPS for compression ignition, spark ignition, and stationary gas combustion turbine engines, except Colorado, which has not adopted the EPA spark ignition standard, and has its own emissions ceiling instead.[332] Montana requires catalytic controllers or their equivalent on spark ignition engines above eighty-five horsepower.[333]

Utah, Montana, North Dakota, and New Mexico all follow the EPA standard for non-road mobile source engines, but Colorado and Wyoming both have stricter standards. Colorado requires all such engines above a certain size to obtain a special air pollution permit and comply with its conditions.[334] Although Wyoming has no statewide regulations for non-road mobile sources, in the UGRB operators who voluntarily use extra control technologies can bank future emissions credits in its offset program.[335]

C. *Underview: A Changing Regulatory Landscape*

To date, federal oil and gas emissions regulations have focused on reducing the sector's VOC and HAPs emissions. But with the Obama Administration's recent announcement, the federal government has committed to both strengthening its VOC regulations and to regulating methane emissions directly. Thus, states throughout the country, and especially in the west where most oil and gas development occurs will have to update their regulations in order to meet federal standards.

Accordingly, over the next few years there will be many state-level actions targeting both ozone precursors and methane emissions. Part V, below, provides policy recommendations for most effectively reducing oil and gas sector VOC and methane. But before describing such policies, a brief explanation of the equipment those policies should regulate is necessary.

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332. GRIBOVICZ, *supra* note 264, at 33.
333. *Id.*
334. *Id.* at 34.
335. *Id.*

IV. ENGINEERING: EQUIPMENT EMITTING POLLUTANTS AND AVAILABLE CONTROL TECHNOLOGIES

The oil and gas sector includes multiple stages, each with its own equipment that emits varying amounts of ozone precursors. The sector is generally divided into three phases: upstream (production), midstream (gathering, processing, transmission, and storage), and downstream (distribution).[336] Ozone precursors are emitted by equipment and processes throughout the oil and gas sector, but especially during upstream and midstream stages.[337]

A. *Comparing Emissions from Various Equipment and Production Phases*

Different studies have reached very different conclusions about which oil and gas equipment and processes result in the greatest amount of emissions.

The Alamo Area Council of Governments (AACOG) conducted a bottom-up analysis of emissions from different sources in Texas' Eagle Ford Shale, using emissions factors and operator surveys.[338] It found that storage tanks and loading losses dominate VOC emissions, with lower emissions from midstream sources, pneumatic devices, fugitives, and flares.[339] The main NOx sources were drill rigs, pump engines, wellhead compressors, and mid-stream sources, with lower emissions from on-road emissions, uncategorized non-road equipment, and flares.[340] It found that condensate tanks, crude storage tanks, compressor engines, fugitive emissions, and glycol dehydrators are the main midstream VOC sources, while compressor engines, heaters/boilers, and flares are the main midstream NOx sources.[341]

A similar study in Wyoming used both existing emissions inventories and operator surveys to categorize emission sources in Wyoming's three major production basins.[342] It found that emissions sources varied significantly between basins. For VOCs,

336. SUSAN HARVEY ET AL., NATURAL RES. DEF. COUNCIL (NRDC), LEAKING PROFITS: THE U.S. OIL AND GAS INDUSTRY CAN REDUCE POLLUTION, CONSERVE RESOURCES, AND MAKE MONEY BY PREVENTING METHANE WASTE 4 (2012).

337. *See id.* at 10-11 (quantifying RHC emissions by production stage); *see also* AACOG, *supra* note 152, at 1-8 to 1-9, 1-11; EPA REGION 8, *supra* note 19, at 2-8, B-1 to B-6.

338. AACOG, *supra* note 152, at iii, 1-16, 1-17.

339. *Id.* at 9-2 to 9-3.

340. *Id.*

341. *Id.* at 8-38.

342. Bar-Ilan et al., *supra* note 202, at 8-12.

pneumatic devices, venting and blowdowns, and dehydrators dominated in the Wind River Basin, while compressor engines, pneumatic devices, and unpermitted fugitives dominated in the Powder River Basin, and condensate tanks, unpermitted fugitives, and pneumatic devices dominated in the Southwest Wyoming Basin.[343] For NOx, compressor engines and drill rigs were the two largest sources in all three basins, but the overall percentages of NOx emissions varied substantially by basin.[344]

The UBWOS study, discussed above, also used a combination of existing emissions inventories, operator surveys, and production data to develop a Uintah Basin-specific emissions inventory for February 2012.[345] It found that glycol dehydrators, pneumatic devices, condensate tanks, oil tanks, and pneumatic pumps dominate RHC emissions, while compressor stations, drill rigs, and artificial lift engines dominate NOx emissions.[346]

One Barnett Shale study also used an emissions inventory to calculate relative ozone precursor emissions. [347] It used broader source categories than other studies. It found that on summer peak ozone days in 2009, condensate and oil tanks dominated VOC emissions, while compressor engines, production fugitives, well drilling and completions, gas processing, and transmission fugitives all had emissions of a similar magnitude.[348] Storage tanks dominated the inventory because the study focused on summer emissions, and, at high temperatures, increased hydrocarbon vapor pressure significantly increases storage tank emissions.[349] The study attributed 89% of NOx emissions to compressor engines, and 11% to engines used in well drilling and completions.[350]

The Colorado Air Pollution Control Division (APCD) submitted materials during the 2014 AQCC rulemaking showing the relative contribution of different oil and gas sector sources to statewide VOC emissions.[351] APCD's data shows that storage tanks account for 60% of statewide oil and gas sector VOC emissions,

343. *Id.* at 20-22.
344. *Id.*
345. Mansfield et al., *supra* note 23, at 175-86.
346. *Id.* at 176.
347. ARMENDARIZ, *supra* note 132, at 1, 24.
348. *Id.*
349. *Id.* at 22.
350. *Id.* at 24.
351. APCD, *supra* note 127, at 4.

venting and fugitives account for 20%, and pneumatics/pumps, industrial processes, evaporation, engines, and engines/rigs all account for less than 10%.[352] The APCD submission did not provide a similar emissions inventory for oil and gas sector NOx emissions.

Overall, the main VOC sources varied substantially by region. In nearly all areas, storage tanks were the top VOC emitter. After storage tanks, the next most common VOC emitters were pneumatic devices and venting and fugitive emissions, both of which were among the top three emission sources in five studies. Compressor engines, midstream sources like pipelines and compressor stations, liquids unloading, glycol dehydrators, and well drilling, completion, and workovers are all relatively less important VOC sources. These results show that emissions profiles vary by location, and that states can and should target their own emissions profile. However, overall, the studies suggest that storage tanks and venting and fugitive emissions should be top regulatory priorities in all states.

The studies presented a much clearer picture for the top NOx sources. All studies reporting NOx emissions showed that compressor engines were the top source of NOx emissions. Most of the studies showed drilling rigs to be the second highest source of NOx emissions, and heaters/boilers were the third most common NOx source. Other major sources of NOx emissions were pad construction, miscellaneous engines, and midstream sources. The implication of these consistent findings is that states should focus their regulatory efforts on reducing NOx emissions from compressor engines, followed by drill rigs and heaters/boilers.

B. *Control Technologies for Individual Emission Sources*

1. *Wellhead emissions: completions, recompletions, and flowback*

A number of different processes occur at the wellhead, including drilling exploration wells, wellpad construction, drilling production wells, hydraulic fracturing, well completion, flowback, venting, and flaring. During exploration, wellpad construction, and drilling production wells, NOx from on-site and off-site engines is the primary ozone precursor emitted.[353] Most wells today

352. *Id.* at 4.

353. AACOG, *supra* note 152, at 3-1 to 3-21 (describing exploration and

are hydraulically fractured, a process in which a mixture of water, sand, and chemical additives are injected at high pressure at various angles and points off of a wellbore into otherwise low-permeability formations (usually shales), creating fractures in the formation through which liquid and gaseous hydrocarbons can flow into the production well.[354] Hydraulic fracturing is a logistically complex process that entails significant NOx emissions from engines powering hydraulic fracturing pumps, pump trucks, water pumps, blender trucks, sand kings, blow out control systems, forklifts, generators, bulldozers, backhoes, high pressure water cannons, and cranes, as well as off-site truck engines.[355] NOx emissions controls are discussed below, in Part IV(B)(7).

Well completion follows hydraulic fracturing. This process includes the flowback phase, in which sand, liquid, and chemicals that are injected into a well during hydraulic fracturing are cleared out. Well completion has significant RHC emission potential if the fluids and gas brought to the surface are allowed to vent directly into the atmosphere.[356] Uncontrolled, vented emissions during well completions can vary significantly between wells. One study measured them ranging from 0.5 Megagrams (Mg) to four Mg of methane,[357] and the EPA estimates that they can range up to twenty-five million cubic feet of natural gas per well.[358] Historically, well completion fluids were most often directed into storage pits in which sand, water, produced fluid, hydrocarbon liquids, and natural gas were separated and allowed to settle, and from which gases could vent directly into the atmosphere.[359] These pits are discussed in Part IV(B)(8), below. When production begins to decline, many wells are also re-fractured and/or re-completed to stimulate production, in a process sometimes called a recompletion or a well workover, resulting in emissions similar to

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wellpad construction), 4-1 to 4-20 (describing production well drilling).

354. *Id.* at 5-1; *see also* Allen et al., *supra* note 209, at 17,768.

355. AACOG, *supra* note 152, at 5-2 to 5-27 (describing hydraulic fracturing pumps and other associated on-site engines), 5-20 to 5-24 (describing off-site, on-road engines).

356. Allen et al., *supra* note 209, at 17,769-70.

357. *Id.* at 17,769.

358. EPA, LESSONS LEARNED FROM NATURAL GAS STAR PARTNERS: REDUCED EMISSIONS COMPLETIONS FOR HYDRAULICALLY FRACTURED NATURAL GAS WELLS 2 (2011), *available at* http://tinyurl.com/mr6tsek.

359. *Id.*; *see generally*, COLO. OIL AND GAS CONSERVATION COMM'N, PIT DISCUSSION (2012), *available at* http://tinyurl.com/mtlupb8.

those stemming from an initial completion.[360]

There are two alternatives to venting that reduce emissions from well completions and flowback: flaring and capture. Capture is generally referred to as a Reduced Emission Completion (REC) or a Green Completion.[361] Flaring refers to burning off the gas that would otherwise be vented into the atmosphere with a flare, which eliminates most RHC emissions.[362] Flaring converts methane into carbon dioxide, a less-powerful greenhouse gas. Assuming a high efficiency flare, from a climate perspective there is no difference between flaring, which combusts natural gas at the beginning of its lifecycle, and capture, which combusts gas at the end of the lifecycle. In fact, if nothing is done to address downstream fugitive emissions and leaks from other equipment, flaring may actually have climate benefits over capture, since gas is burned off immediately rather than making its way through a system in which it can leak out during other stages.

But flares are far from perfect. They pose fire and safety risks, especially under windy conditions in dry areas, and their combustion process emits other pollutants (NOx, particulate matter, and carbon monoxide).[363] NOx emissions are not necessarily a bad thing. Substituting NOx emissions for RHC emissions in areas which are RHC limited will decrease overall ozone formation. Overall, though, capture is generally preferable to flaring because flares are problematic for other reasons. Their light pollution can be a nuisance if located close to houses.[364] Many flares have low RHC destruction efficiency.[365] Moreover, flared gas cannot be captured and sold, depriving operators of a potential financial opportunity.[366] Some scholars define combusting gas for no energy-generating or economic purpose as waste.[367] In the 2012 NSPS rule, the EPA required all newly

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360. EPA, *supra* note 358, at 1-2.

361. BRADBURY ET AL., *supra* note 262, at 19.

362. EPA, *supra* note 358, at 2.

363. *Id.; see also* Sierra Club et al., *supra* note 19, at 34-35.

364. *See* EPA, *supra* note 358, at 2; *see also, e.g.*, Edwin Dobb, *The New Oil Landscape*, NAT'L GEOGRAPHIC (Mar. 2013), http://tinyurl.com/a93novn (discussing the nuisance posed by flares located close to homes in North Dakota's Bakken shale); Clifford Krauss, *In North Dakota, Flames of Wasted Natural Gas Light the Prairie*, N.Y. TIMES (Sept. 26, 2011), http://tinyurl.com/pyf2jum.

365. Sierra Club et al., *supra* note 19, at 35.

366. *Id.* at 32.

367. *See, e.g.*, Michael Pappas, *Anti-Waste*, 56 ARIZ. L. REV. 741, 785-86 (2014).

completed and recompleted natural gas wells drilled between October 15, 2012 and January 1, 2015 to flare emissions from completions, and allowed wildcat, delineation, and low-pressure wells to use flares in perpetuity.[368]

Capture, or RECs, involves using a portable separation device to capture flowback fluids, which separates gas (routed into a gathering line and sold on the market), liquid hydrocarbons (stored in condensate tanks and sold), and wastewater and sand (for disposal).[369] Because both natural gas and hydrocarbon liquids are captured and can be sold, RECs are cost-effective, and generally pay for themselves in less than a year.[370] RECs are not perfect, but the EPA estimates that a typical REC reduces VOC emissions by 95%.[371] Given their cost-effectiveness and capacity to reduce emissions, it is unsurprising that in 2008, Colorado began requiring RECs at all wells where technically and economically feasible, and Wyoming required them for all wells in the Jonah-Pinedale anticline (part of the UGRB) and in designated areas of concentrated development.[372] As noted above, the EPA will require all non-wildcat, delineation, and low-pressure wells to use RECs beginning January 1, 2015.[373] Notably, the EPA estimated that even without this regulatory requirement, 51% of operators would implement RECs voluntarily by 2015 because they are so cost-effective (excluding operators in Colorado and Wyoming that were already required to do so).[374] One study found that, as a result of operators using RECs, well completion emissions nationwide were

368. Oil and Natural Gas Sector: New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants Review, 77 Fed. Reg. 49,490, 49,497, 49,499 (Aug. 16, 2012) (listing compliance deadlines for wildcat, delineation, low-pressure, and standard wells, and explaining that compliance period begins October 12, 2012, and that the rule applies to both completions and recompletions).

369. *See* EPA, OIL AND NATURAL GAS SECTOR: STANDARDS OF PERFORMANCE FOR CRUDE OIL AND NATURAL GAS PRODUCTION, TRANSMISSION, AND DISTRIBUTION: BACKGROUND SUPPLEMENTAL TECHNICAL SUPPORT DOCUMENT FOR THE FINAL NEW SOURCE PERFORMANCE STANDARDS 2-3 (2012).

370. *See* EPA, *supra* note 358, at 5-7; *see also* EPA, NATURAL GAS STAR PROGRAM, RECOMMENDED TECHNOLOGIES AND PRACTICES (2014), *available at* http://tinyurl.com/nuuu3s2.

371. EPA, *supra* note 369, at 5-1 to 5-3.

372. Sierra Club et al., *supra* note 19, at 22.

373. Oil and Natural Gas Sector: New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants Review, 77 Fed. Reg. 49,490, 49,497 (Aug. 16, 2012).

374. EPA, *supra* note 369, at 4-5 to 4-6 (calculations on file with author).

lower than the EPA's current emissions inventory predicted.[375]

As the EPA recently acknowledged in a white paper on controlling emissions from oil and co-producing completion, how many of these wells use RECs, flares, and venting remains poorly understood.[376] The EPA white paper thus drew few conclusions about optimal control technologies, and instead solicited comments on various issues.[377]

RECs may not be possible at all wells. Some wells have pressure that is too low to make RECs feasible.[378] And RECs require a gathering line into which natural gas can be routed and sent to market. Installing a gathering line can be expensive for wells located far away from existing infrastructure. This is why the EPA exempted delineation and wildcat wells from the NSPS REC requirement.[379] Some states are less concerned than the EPA about the costs of forcing operators to install gathering lines in order to use RECs. Although Colorado's 2008 rule had an economic and technical feasibility exemption,[380] Wyoming's pre-NSPS rule did not have any exceptions for wells located far away from gathering lines and other infrastructure.[381]

The lack of gathering line infrastructure is a much bigger issue for oil wells, which can produce significant amounts of natural gas, especially in North Dakota's Bakken shale.[382] Since the NSPS does not cover oil wells or co-producing wells, there is no nationwide standard requiring RECs for such wells.[383] As of 2013, the EPA remained opposed to requiring oil well and co-producing well operators in the Bakken Shale to use RECs because of the lack of

375. Allen et al., *supra* note 209, at 17,769-70.

376. EPA, OIL AND NATURAL GAS SECTOR: HYDRAULICALLY FRACTURED OIL WELL COMPLETIONS AND ASSOCIATED GAS DURING ONGOING PRODUCTION 45 (2014), *available at* http://tinyurl.com/lu46984.

377. *Id.* at 43-48.

378. *Id.* at 24.

379. *See* Sierra Club et al., *supra* note 19, at 30-32.

380. Colorado's new rule, adopted in February 2014, now requires all gas wells, even in remote locations, to either capture or flare gas, and, if using a flare, use a flare which is rated at 98% destruction efficiency and is actually combusting gas with at least 95% destruction efficiency. APCD, *supra* note 127, at 22.

381. *See* Sierra Club et al., *supra* note 19, at 31.

382. *Id.* at 32-33.

383. *Cf.* BRADBURY ET AL., *supra* note 262, at 7 (noting that co-producing wells are particularly common in several shale plays, including the Bakken Shale in North Dakota).

pipeline infrastructure in the area.[384] However, other parties have argued that requiring RECs even in relatively remote oil fields like the Bakken would ultimately be economically beneficial because of the large volume of natural gas that could be captured once infrastructure was installed.[385]

Finally, requiring RECs alone is not enough to ensure that operators actually capture their emissions during well completion. Even though both Colorado and Wyoming have required RECs for several years, both still have persistent (and worsening) ozone problems. Although well completions are not the only source of ozone precursor emissions, this implies that not all operators are using RECs as required. Enforcement is a significant problem in the oil and gas sector. There are often very large numbers of operators and emissions sources (most of which are unattended for the majority of their lifetime in use) and very few state inspectors to investigate them.[386] Inspection records show more than 200 reported violations from inspected facilities each year since 2005 in Colorado alone, although this number is likely an estimate, "because in Colorado the discovery of a violation does not necessarily lead to a [reported violation]."[387] Oil and gas emissions would surely decrease if states would use robust inspection and enforcement programs.

2. *Equipment leaks and fugitive emissions*

Leaking equipment in the oil and gas sector accounts for one of the most, if not *the* most, significant sources of emissions, and at least one report predicted that leak reduction will and must be a priority for the federal government, states, and operators alike.[388] Equipment leaks, producing what are often called "fugitive emissions" are inevitable, and are common throughout the oil and

384. Approval and Promulgation of Federal Implementation Plan for Oil and Natural Gas Well Production Facilities; Fort Berthold Indian Reservation (Mandan, Hidatsa, and Arikara Nation), North Dakota, 78 Fed. Reg. 17,836, 17,846 (Mar. 22, 2013).

385. Sierra Club et al., *supra* note 19, at 32-33.

386. *Cf.* EARTHWORKS, BREAKING ALL THE RULES: THE CRISIS IN OIL & GAS REGULATORY ENFORCEMENT: STATES ARE BETRAYING THE PUBLIC BY FAILING TO ENFORCE OIL & GAS DEVELOPMENT RULES 20 (2012), *available at* http://tinyurl.com/92b8wfo (discussing under-enforcement).

387. *Id.* at 33.

388. *See* LDAR: A Problem and a Solution for Hydraulic Fracturing, [2014] 44 Envtl. L. Rep. (Envtl. Law Inst.) 10,345, 10,347.

gas industry.[389] They represent a substantial percentage of the sector's VOC emissions.[390] Leaks can spring at a variety of valves, pumps, connections, and pressure relief devices throughout the oil and gas sector.[391] Many studies have shown that emissions distributions have "heavy tails," meaning that a small number of sources, probably leaky ones, emit a very high percentage of overall emissions.[392] This indicates that identifying and fixing those leaks may have substantial benefits.[393] The EPA's recent white paper on oil and gas leaks confirmed that a small number of facilities likely account for a large percentage of the sector's overall emissions, and focused on the use of Optical Gas Imaging (OGI) using portable infrared cameras as a method of LDAR.[394] Perhaps unsurprisingly, the Obama Administration's January 2015 announcement of its plan to reduce methane emissions specifically discusses plans to enhance leak detection.[395]

Because methane is colorless and odorless, leaks can be difficult to detect,[396] but infrared cameras make detecting them easy and cost-effective.[397] States can require operators to check for leaks at varying frequencies, based on the likelihood and magnitude of potential emissions, and repair leaks soon after their detection.[398] When proposing an infrared camera-based LDAR program, Colorado's APCD estimated emissions decreases of 40% from annual inspections, 60% from quarterly inspections, and 80% from monthly inspections.[399] Aerial optical leak imaging—flying over an area in an airplane or helicopter and identifying leaks with

389. *See* BRADBURY ET AL., *supra* note 262, at 28.

390. *See* Zavala-Araiza, Sullivan & Allen, *supra* note 140, at 5319 (finding that equipment leaks partially account for TCEQ's 2011 emissions inventory underestimating emissions).

391. HARVEY, GOWRISHANKAR & SINGER, *supra* note 336, at 7.

392. *See* Brandt et al., *supra* note 5, at 734.

393. *Id.* at 735.

394. EPA, OIL AND NATURAL GAS SECTOR LEAKS 54-55 (2014), *available at* http://tinyurl.com/orqjzze.

395. The White House, supra note 9.

396. HARVEY, GOWRISHANKAR & SINGER, *supra* note 336, at 7; *see also, e.g.*, Alun Williams, *Robotic Gasbot Detects Methane Leaks with Laser*, ELECTRONICS WKLY., June 6, 2014, *available at* http://tinyurl.com/lpv583l.

397. ENVIRONMENTAL DEFENSE FUND (EDF), IN THE MATTER OF PROPOSED REVISIONS TO COLORADO AIR QUALITY CONTROL COMMISSION REGULATIONS NUMBER 3, PARTS A, B, AND C; REGULATION NUMBER 6, PART A; AND REGULATION NUMBER 7 10-11 (2014).

398. *See* APCD, *supra* note 127, at 21-22.

399. *Id.* at 21.

an infrared camera—can facilitate leak detection at broad spatial scales, especially where pipelines and other facilities are relatively inaccessible by ground.[400]

An alternative to infrared-camera LDAR is Directed Inspection and Maintenance (DI&M), in which operators identify components most likely to leak and occasionally inspect and maintain them.[401] In its recent white paper, the EPA noted that some studies have indicated that DI&M can be effective.[402] However, unlike infrared LDAR, DI&M only detects leaks at locations where they have been previously predicted, and might miss leaks at unusual locations. Moreover, leak detection methods that rely on human senses or other indicators, such as changes in flow rate, are less likely to catch leaks than infrared cameras, which more easily detect leaks.

3. *Compressors*

Compressors prevent natural gas from escaping from gathering, transmission, and distribution lines.[403] There are two main types of compressors—centrifugal (wet or dry seal) compressors and reciprocating (piston) compressors.[404] Compressors require engines, which are often operated using natural gas from the well site, to create the force used to pressurize and compress natural gas. These engines emit substantial quantities of NOx.[405] Compressors, especially their valves and seals, are a major source of RHC leaks.[406]

The NSPS requires that wet seal centrifugal compressors reduce emissions by 95%, and that reciprocating compressors replace rods (used to prevent leaks) every thirty-six months.[407] In

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400. *See* Roger Fernandez, et al., *Aerial Optical Leak Imaging*, INTERMOUNTAIN OIL AND GAS BMP PROJECT, http://tinyurl.com/ksnzs6n (last visited Jan. 31, 2015).

401. *See Begin Directed Inspection and Maintenance (DI&M) at Remote Facilities*, INTERMOUNTAIN OIL AND GAS BMP PROJECT, http://tinyurl.com/kowm2ug (last visited Jan. 31. 2015).

402. EPA, *supra* note 394, at 55.

403. *See* HARVEY, GOWRISHANKAR & SINGER, *supra* note 336, at 30.

404. EPA, OIL AND NATURAL GAS SECTOR COMPRESSORS 3 (2014), *available at* http://tinyurl.com/nrsubsv.

405. AACOG, *supra* note 152, at 6-8.

406. HARVEY, GOWRISHANKAR & SINGER, *supra* note 336, at 30.

407. Oil and Natural Gas Sector: New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants Reviews, 77 Fed. Reg. 49,490, 49,492 (Aug. 16, 2012).

its recent white paper report on compressor methane emissions, the EPA identified periodic replacement of rod packing systems and capturing their emissions as effective control technologies for reciprocating compressors.[408]

No states currently have regulations in place which exceed the EPA's standards, although Montana applies its fugitive emissions rule and Colorado its LDAR rule to compressors.[409] The EPA has identified switching from wet seals to dry seals, which operate using mechanical forces rather than oil as a lubricant, as an emission reduction technique.[410] The EPA has found that dry seals have average leak rates of 0.5-3 standard cubic feet per minute (scf/min), compared to leak rates of 40-200 scf/min, and that dry seals are also more reliable, require less maintenance, and use less power.[411] Dry seals are also cost-effective. The EPA estimates their payback time at one to three years.[412] Unsurprisingly, the EPA white paper identified transitioning from wet seal compressors to dry seal compressors as a superior control technology for centrifugal compressors.[413]

4. *Pneumatic devices*

Pneumatic controllers regulate gas pressure, temperature, and flow throughout the natural gas industry, including in dehydrators, separators, flash tanks, processing plants, and on transmission pipelines.[414] They continuously bleed natural gas into the air to regulate internal pressure and flow.[415] Pneumatic controllers are not the only pneumatic devices used in the oil and gas sector—pneumatic pumps, snap-acting devices, and chemical injection pumps are also used.[416] Overall, pneumatic devices are one of the

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408. EPA, *supra* note 404, at 43.

409. GRIBOWICZ, *supra* note 264, at 29 (Montana); CDPHE, *supra* note 302, at 2-4 (Colorado).

410. EPA, REPLACING WET SEALS WITH DRY SEALS IN CENTRIFUGAL COMPRESSORS 1 (2006), *available at* http://tinyurl.com/qjoophb.

411. *Id.* at 3.

412. EPA, *supra* note 370.

413. EPA, *supra* note 404, at 43.

414. EPA, LESSONS LEARNED FROM NATURAL GAS STAR PARTNERS: CONVERT GAS PNEUMATIC CONTROLS TO INSTRUMENT AIR 1 (2006), *available at* http://tinyurl.com/mkhf6gz.

415. BRADBURY ET AL., *supra* note 262, at 28.

416. Sierra Club et al., *supra* note 19, at 41-42.

largest sources of RHC emissions in the oil and gas sector.[417] One recent study found that TCEQ's emission inventory underestimates actual pneumatic controller and chemical injection pump emissions.[418] Another study found that the EPA's 2011 emissions inventory slightly overestimated emissions from chemical injection pumps, but underestimated emissions from intermediate-bleed pneumatic controllers by 29% and emissions from low-bleed controllers by 270%.[419]

"High-bleed" pneumatics can be replaced with no-bleed pneumatics called instrument air devices, which substitute compressed air for pressurized gas, totally eliminating emissions.[420] Instrument air controllers are already widely adopted, especially in processing plants, where continuously leaking gas into the air is dangerous.[421] Moreover, instrument air devices capture gas which can be sold at market, and thus pay for themselves within about a year.[422] Although instrument air systems result in zero emissions,[423] they require electricity, which is not always available in remote areas.[424] But just because a site is remote does not mean it lacks electricity. Some operators have already installed solar panels to power instrument air devices, with an estimated payback of four years.[425] The EPA described this option as feasible where sufficient sunlight existed to operate the solar panels.[426] Operators can also use the natural gas they produce to provide electric power at remote well sites,[427] although this reduces the overall product they send to market, and has greater emissions than using a renewable energy source.

An alternative to instrument air devices for remote sites is mechanical devices, which use mechanical linkages to regulate gas flow and pressure.[428] Mechanical devices are somewhat more

417. *See id.*; EPA, *supra* note 414, at 1.

418. Zavala-Araiza, Sullivan & Allen, *supra* note 140, at 5319.

419. Allen et al., *supra* note 209, at 17,771-72.

420. EPA, *supra* note 414, at 1.

421. *Id.*

422. *Id.*

423. EPA, OIL AND NATURAL GAS SECTOR PNEUMATIC DEVICES 51 (2014), *available at* http://tinyurl.com/mx3d3jm.

424. *Id.*

425. Sierra Club et al., *supra* note 19, at 40.

426. EPA, *supra* note 423, at 54, 57.

427. *See* EPA, *supra* note 414, at 1.

428. EPA, PRO FACT SHEET NO. 301 FOR REDUCING METHANE EMISSIONS: CONVERT PNEUMATICS TO MECHANICAL CONTROLS 1 (2011), *available at*

expensive than compressed air devices, but the EPA conservatively estimates the payback period at only four years,[429] which is comparable to the period for installing a solar panel for an instrument air device. The EPA white paper indicated that mechanical pumps and controllers are suitable replacements for high-bleed controllers and pumps in many situations.[430]

Finally, operators can replace high-bleed and intermediate-bleed[431] pneumatics with low-bleed pneumatics.[432] Low-bleed pneumatics still continuously bleed gas, but they bleed less than other pneumatics.[433] The exact definition of a "low-bleed" pneumatic is contested, with potential values ranging from <6 scf/hr to <0.2 scf/hr.[434]

5. *Liquids unloading*

While a natural gas well is in production, over time, liquids can build up inside which impede gas flow.[435] These liquids are periodically removed, or "unloaded" (also known as a "well blowdown"), and during the unloading process gas is vented into the atmosphere.[436] WRI estimates, based on the EPA's 2011 emissions inventory, that liquids unloading will be the primary source of the natural gas sector's methane emissions once the NSPS rule is fully implemented.[437] By contrast, EDF's study concluded that the EPA's 2011 emissions inventory overestimated emissions because wells unload liquids less frequently than the EPA's estimate, and that the average emissions per event are lower than the EPA estimates.[438] The EDF study also noted that liquids unloadings vary by well in frequency, duration, and total

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http://tinyurl.com/mjoe8o3.

429. *Id.*

430. EPA, *supra* note 423, at 56-57.

431. *See* Sierra Club et al., *supra* note 128, at 27-29.

432. BRADBURY ET AL., *supra* note 262, at 28.

433. *Id.*

434. Sierra Club et al., *supra* note 19, at 40-41.

435. BRADBURY ET AL., *supra* note 262, at 28.

436. *Id.*; *see also* AACOG, *supra* note 152, at 6-39 (describing liquids unloading process in greater detail).

437. BRADBURY ET AL., *supra* note 262, at 28.

438. Allen et al., *supra* note 209, at 17,770; *see also* Zavala-Araiza, Sullivan & Allen, *supra* note 140, at 5320 (finding that measured RHC concentrations at a site in Texas' Barnett Shale were lower than would be expected given liquids unloading levels predicted in TCEQ's inventory).

emissions.[439] In response to self-reported industry findings, the EPA reduced its estimates of liquids unloading emissions by 90% in its draft 2013 greenhouse gas inventory.[440] The EPA white paper indicates that a few unloadings cause the bulk of overall emissions, and that liquids unloading accounts for 14% of the oil and gas sector's total methane emissions.[441] Given the disparities in these various reports, more research is needed to determine the actual magnitude of liquids unloading emissions.

A simple control technology—a plunger lift—can prevent the need for liquids unloading altogether by removing liquids as they build up.[442] Plunger lifts capture gas which otherwise would be vented, making them cost-effective. The EPA estimates that plunger lifts cost less than $10,000/well and that they pay off within a year.[443] Unsurprisingly, about 40% of natural gas wells already use plunger lifts.[444] The EPA white paper was thus optimistic about expanded plunger lift use.

6. *Storage tanks*

Storage tanks are likely the greatest source of oil and gas sector RHC emissions. This is likely because they are so numerous (often several per well, plus others downstream), most are designed to vent (or "flash") some emissions, and their venting rate increases during the summer ozone season as temperatures increase.[445] Unlike well completions, equipment leaks, and liquids unloading, storage tank emissions are not one-time events. They are continuous.[446]

The NSPS storage tank regulations, which require 95% emissions reductions from storage tanks with >6 tpy pte, have been hotly contested and were subject to revision. The main control technology used to reduce storage tank emissions is flaring, and the EPA was initially concerned that there were not enough flares

439. Allen et al., *supra* note 209, at 17,770-71.

440. BRADBURY ET AL., *supra* note 262, at 3.

441. EPA, OIL AND NATURAL GAS SECTOR LIQUIDS UNLOADING PROCESSES 25 (2014), *available at* http://tinyurl.com/lov4ekw.

442. BRADBURY ET AL., *supra* note 262, at 28.

443. EPA, *supra* note 370.

444. Allen et al., *supra* note 209, at 17,770.

445. ARMENDARIZ, *supra* note 132, at 22-23; *see also* Sierra Club et al., *supra* note 128, at 25 (describing flashing losses).

446. APCD, *supra* note 127, at 15-16.

on the market to cover demand, although it later realized this was incorrect.[447] Colorado's recent rulemaking focused a great deal on storage tanks, bringing the state regulation in line with the federal NSPS, but also requiring that flares have at least 95% operational efficiency, be rated at 98% destruction efficiency, and be equipped with an auto-igniter.[448] The auto-igniter is crucial because the flares at some storage tanks, like a pilot light, can blow out, resulting in gas being vented directly into the atmosphere.[449] Colorado's rule also banned venting from storage tanks, and required operators to develop plans for annual, monthly, or quarterly inspections and recordkeeping.[450]

7. *On- and off-site engines*

A variety of engines powering pumps, compressors, drilling rigs, trucks, and other devices in the oil and gas sector emit significant amounts of NOx. Compressor engines and drilling rigs are particular culprits. One study found that frac pumps were responsible for a significant amount of overall oil and gas emissions in the Eagle Ford Shale.[451]

Several technologies can reduce NOx emissions from various engines. For compressor engines, the EPA recommends installing automatic air-fuel ratio controls, which can reduce natural gas venting emissions by up to 12,000 mcf per year, and which are highly cost effective, with payback periods of less than a year depending on gas prices.[452] As described in Part II(B)(2)(c) above, most western states simply adhere to the EPA's NSPS and mobile source standards for NOx emissions from engines in the oil and gas sector. Colorado, however, sets requirements for off-road engines, which are often used to power drilling rigs. If these engines are above a certain horsepower and exceed a certain NOx emissions potential, they must obtain special emission permits.[453]

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447. *See supra* notes 258-260 and accompanying text.

448. CDPHE, *supra* note 302, at 1-2.

449. *See* Sierra Club et al., *supra* note 128, at 25, 30 (discussing the use of auto-igniters on storage tanks to ensure that emissions are continuously flared).

450. CDPHE, *supra* note 302, at 2.

451. GINNA RODRIGUEZ & CHENCHEN OUYANG, AIR EMISSIONS CHARACTERIZATION AND MANAGEMENT FOR NATURAL GAS HYDRAULIC FRACTURING OPERATIONS IN THE UNITED STATES 46 (2013).

452. EPA, INSTALL AUTOMATED AIR-FUEL RATION CONTROLS 1 (2011), *available at* http://tinyurl.com/ng2r4cu.

453. GRIBOVICZ, *supra* note 264, at 33.

8. *Storage pits*

Well completion fluids are often routed directly into storage pits, which, if not covered, can vent RHCs directly into the atmosphere. Fracturing fluid, produced water, fracking mud, and other wastewater are also sometimes stored in open pits and can have similar emissions. Covering the pits or storing fluids in storage tanks can eliminate these emissions.[454] Although no western states require this, several California counties and local air quality management districts do.[455] For example, the Santa Barbara County Air Pollution Control District requires that all pits that receive liquids after separation either be replaced with tanks or that they be covered and have a vapor recovery unit installed.[456]

9. *Glycol dehydrators*

Glycol dehydrators are used to remove water and other liquids from natural gas, mostly during natural gas processing, although they are also used at further upstream stages.[457] Glycol dehydrators are a major source of RHC emissions and of HAPs emissions in particular.[458]

Glycol dehydrator emissions can be controlled with flares. The EPA's NESHAP rule requires a 95% emissions reduction for larger glycol dehydrators, and also sets emissions limits for smaller glycol dehydrators.[459] Colorado mirrors this rule, adding its standard requirement for flaring efficiency, and setting a >6 tpy RHC floor for the 95% emissions reduction.[460] Colorado also requires 95% reductions with similar flare efficiencies for glycol dehydrators located near occupied buildings or outdoor activity areas with >2 tpy pte.[461] Wyoming requires 98% emissions reductions for all

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454. *See* Sierra Club et al., *supra* note 19, at 53-59.

455. *Id.* at 53.

456. *Id.*

457. HARVEY, GOWRISHANKAR & SINGER, *supra* note 336, at 26.

458. *Id.* (noting methane emissions); *see also* Oil and Natural Gas Sector: New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants Reviews, 77 Fed. Reg. 49,490, 49,502 (Aug. 16, 2012) (describing HAPs emissions).

459. Oil and Natural Gas Sector: New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants Reviews, 77 Fed. Reg. at 49,501-03.

460. CDPHE, *supra* note 302, at 3.

461. *Id.*

glycol dehydrators in the UGRB, with no minimum pte.[462]

V. POLICY: RECOMMENDED REGULATIONS REDUCE OIL AND GAS SECTOR OZONE PROBLEMS

Having explained the scientific basis for how the oil and gas sector emits methane and contributes to ozone formation, the legal and regulatory regime governing oil and gas sector emissions, and the control technologies available, this Article now provides recommendations about what technologies both state and federal regulators should require in order to achieve maximum emissions reductions. Figure 3, below, presents those recommendations.

The Obama Administration's January 2015 announcement commits the EPA to strengthening its existing NSPS rule, and also to regulating methane directly. Notably, several western states already have emissions standards stricter than the EPA's current NSPS standards for many devices in the oil and gas sector. Colorado's February 2014 rule exemplifies this. Colorado's 2014 rule, and rules in place in other Western states that already exceed the EPA's baseline thus provide a useful framework for assessing what sorts of regulatory standards will likely be in place after the EPA updates its rules. Figure 3 presents a summary of these standards. For some source categories, like liquids unloading, that are largely unregulated, Figure 3 includes control technologies discussed in Part IV, above, especially in the EPA's white papers.

Figure 3: Recommended Regulations for States to Adopt

Equipment/ Process	Recommendations for States to Exceed Federal Requirements	Required In
RHCs regulated	Include RHCs excluded by the EPA's VOC definition (including methane)	CO
Monitoring	Install certified regulatory monitors in every county with significant oil and gas development	none
Enforcement	Inspect one in five wells during well completion phase Inspect all oil and gas facilities annually	none

462. GRIBOVICZ, *supra* note 264, at 31.

Wellhead Emissions (completions, recompletions, and flowback)	Require RECs at all wells, including oil wells and co-producing wells Allow flaring only when necessary for safety or to reduce ozone if system is RHC limited Require all flares to operate at 95% efficiency and be rated at 98% destruction efficiency	CO, WY (no remote well exception); CO (flare efficiency)
Equipment Leaks and Fugitive Emissions	LDAR with infrared cameras at varying frequencies (depending on emissions potential) at all oil and gas sector facilities.	CO
Compressors	Replace wet seals with dry seals	None
Pneumatic Devices	No-bleed (instrument air) devices wherever electricity available Use solar electricity if feasible at sites off power grid Low-bleed devices (<.2 scfh) if electricity unavailable Apply to all pneumatic devices, not just controllers	CO, WY (no or low-bleed); CO (no-bleed if electricity)
Liquids Unloading	Mandate use of plunger lifts and ban venting during liquids unloading.	none
Storage Tanks	Mandate submerged loading and unloading Require all flares to have an auto-igniter, and to operate at 95% efficiency and be rated at 98% destruction efficiency Ban venting and require operators to develop emissions plan to ensure that no venting occurs No exception for tanks with >4 tpy emission potential	CO (auto-igniter, plan & venting ban; WY (no 4 tpy min); MT, ND (submerged filling).
On- and Off-site Engines	Special permitting for non-road mobile source (drilling rig) engines Automated air-fuel ratio controls in compressor engines	CO (engine permits
Storage Pits	Cover all pits or replace with tanks	Santa Barbara

Glycol Dehydrators	98% emissions reductions for all new, modified & existing dehydrators with no minimum emission potential threshold	WY (98%); CO (existing)

Although the EPA will adopt rules that will apply nationwide, some states may even have to go beyond the EPA's new rules in order to address their ozone problems. This is especially true because the EPA is also strengthening the ozone NAAQS. There are no one-size-fits-all solutions to reduce ozone, because each area's unique meteorology, topography, climate, and gas composition create different issues. Different areas have different reasons to reduce ozone, including human health, crop protection, and visibility. Thus, states which still exceed the EPA's ozone standards after adopting the new federal NSPS baselines can tailor their ozone regulations to their unique needs. For example, consider, the appropriate control technology for well completions. In remote and mountainous areas, building many miles of gathering lines might disrupt wildlife habitat and risk leaks during avalanches and landslides. The same is not true in the Bakken Shale's flat prairie terrain, where densely-packed wells can easily be connected to a single pipeline. Similarly, when requiring compressed air no-bleed pneumatics, states must consider if electricity is available, and whether an area has enough solar capacity that solar panels can feasibly generate power if electricity is otherwise unavailable.

Most importantly, when developing strategies to reduce ozone formation, states should consider whether the area in which they are trying to reduce ozone formation is RHC or NOx limited. If the area is NOx limited, it is important to reduce additional NOx sources, so using NOx-generating flares would be unwise, and building whatever gathering line infrastructure is necessary to capture gas at the wellhead is advisable. But if the area is RHC limited, then destroying gas with a NOx-generating flare is less harmful, especially if there are substantial downstream RHC leaks. That the best control technology depends on whether an area is RHC or NOx limited highlights the importance of states conducting thorough research to understand the degree to which their oil and gas fields are so limited. This is particularly true given that studies have shown that the NOx and RHC limitation of rural production fields like Wyoming's UGRB can vary at different locations, and even times of day.

Of course, considerations beyond ozone formation are also relevant to shaping emissions control policies. Consider, for example, the advantages of capture over flaring. For one, NOx emissions can reduce visibility more than ozone, so flares are a poor choice near Class I areas. Similarly, in areas with high fire risks, flares are especially risky. And if flares are located close to occupied buildings like houses, their light pollution can reduce quality of life, making capture preferable. The forthcoming federal rules should consider all these factors, and possibly give state agencies discretion to choose based on the individual circumstances of the area being regulated.

Accounting for unique spatial and temporal factors highlights another important way in which states should tailor their regulations to their own unique circumstances. Ozone formation is only an issue in most areas under a limited set of conditions. There are generally only a few sufficiently hot summer (or snowy, inversion-layer prone winter) days to trigger ozone problems. This matters because different sources have different temporal emissions patterns. Some, like pneumatic devices, leak gas into the atmosphere continuously. States should thus prioritize reducing emissions from such sources, because they continuously capture gas that can be sold on the market, making it more cost-effective to reduce their emissions. Other types of equipment, like storage tanks, have emissions that vary depending on temperature and other conditions, so regulations for those devices can be prioritized to reduce emissions on high-ozone-risk days, and to use especially reliable equipment (for example, an auto-igniter). Still other processes have temporally sporadic emissions. Liquids unloading emissions only occur while liquids are being unloaded, and completions emissions while a well is being completed. For these temporally sporadic processes, states can adopt additional restrictions during periods ozone formation is particularly risky—for example, banning liquids unloading on high ozone days. Of course, these process all emit the same amount of methane, regardless of when they occur, which is one reason why directly regulating methane may force greater emissions reductions than regulations targeting ozone formation alone.

Understanding when a high ozone day will occur requires more extensive monitoring than currently exists. The federal government should thus close the rural monitoring loophole, and recognize that even rural oil and gas fields can experience ozone problems. The EPA should certify these monitors, so that their data can be used for regulatory applications. Additionally, states in which oil and gas and agricultural operations co-exist should consider requiring extra monitoring, since ozone's crop suppression function can damage their economy. Moreover, monitoring means more than just having a stationary monitor in place. It means supporting both top-down and bottom-up studies, like the UBWOS study, which build a complete picture of how the oil and gas sector contributes to an area's ozone issues and the regulatory tools to address them.

Ozone aside, the EPA must determine how to create regulations that successfully reduce methane emissions. Many regulatory strategies targeted at reducing ozone precursor emissions will also successfully reduce methane emissions, but there may be some need for separate, methane-specific regulations. For example, as natural gas moves further downstream, it is gradually purified and other hydrocarbons are removed, so by the time natural gas has left the processing plant, it is mostly methane. Thus, reducing 95% of VOC emissions from a storage tank somewhere downstream of the processing phase is not the same thing as reducing 95% of total RHC emissions (which includes methane).

Finally, Figure 3 recommends the adoption of stronger leak detection and enforcement rules. All of the recommendations discussed in this Article are only effective if they are enforced, and if leaks are actually caught and plugged as quickly as possible. The scientific studies done to date have shown that a small percentage of wells account for a very large percent of emissions. Using infrared camera LDAR and frequent inspections, operators can identify and plug leaks at these wells on their own. The EPA's federal rules can set strong standards for leak detection. But states must play a role, too. Only with a real threat of robust state inspection is it realistic to assume that all operators—even those operating on a shoestring budget—will actually follow through and reduce their emissions.

VI. Conclusion

Technological advances have put natural gas at the center of America's energy future. And even though the exact climate impacts of a coal-to-gas transition remain contested by scientists, there is little scientific disagreement that methane emissions should be reduced to avoid potentially catastrophic climate impacts. The Obama Administration has recognized this, and has proposed an ambitious plan to cut those emissions. This will mean both developing new federal regulations directly regulating the oil and gas sector's methane emissions, and updating existing federal regulations targeting the oil and gas sector's ozone precursor emissions. States will thus have to revise their existing rules to comply with the new federal standards for the oil and gas sector. Additionally, the EPA's proposal to strengthen the ozone NAAQS may force some states to go even further than meeting the new federal baselines. A growing body of scientific literature shows that even in rural areas, oil and gas development can cause significant ozone problems. Thus, some western states may need to go further than the EPA's forthcoming oil-and-gas-sector-specific regulations in order to bring their ozone levels into compliance with the updated ozone NAAQS.

This Article has provided the relevant information that stakeholders in the many forthcoming federal and state regulatory processes will need in order to craft regulations that protect both the climate from methane pollution and public health from ozone pollution. It reviewed the scientific basis for how the oil and gas sector contributes to ozone pollution, even in rural areas of western states, and also how the sector's methane emissions contribute to global climate change. It explained how existing and newly proposed laws and regulations at the federal level will force states to update their own regulations. It provided an overview of the technical side of those regulations by explaining which equipment and processes in the oil and gas sector are most responsible for emissions. And it provided an overview of the policies that both federal and state governments can adopt in order to reduce those emissions.

Taking these, and other, common sense steps to cost-effectively reduce the methane leak rate is necessary to ensure that natural gas is a bridge to a more sustainable future, not a bridge to nowhere. The Obama Administration's January 2015 announcement is a critical first step towards that goal. It is now up to federal and state regulators, and the stakeholders who influence them, to put in place the specific regulations that can achieve that ambitious and crucial goal.