Consequences of the Evolution of Oil and Gas Control and Production Technology in the Denver Ozone Nonattainment Area

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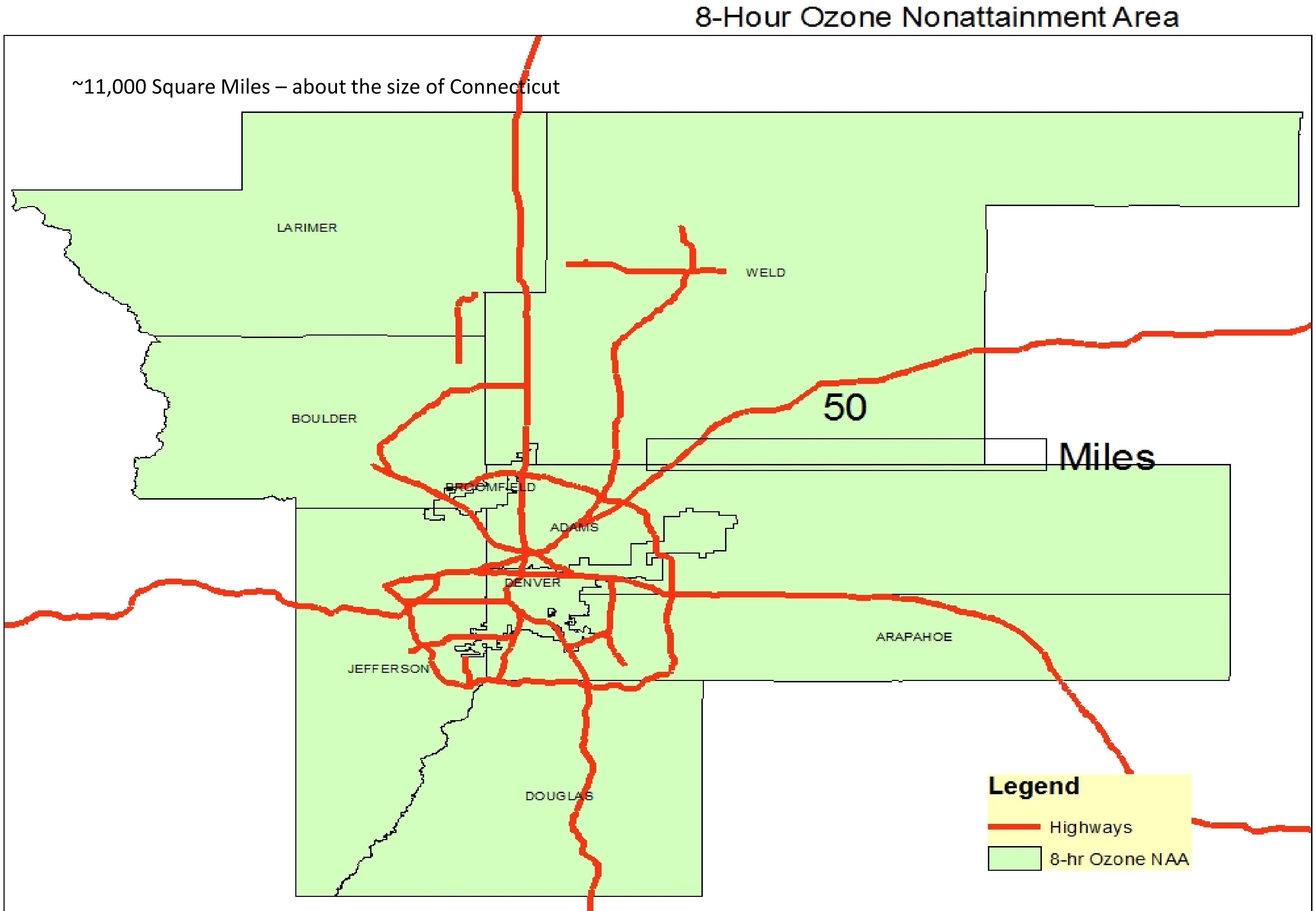
Map of Denver Metropolitan/North Front Range (DMA/NFR) Ozone Nonattainment Area (NAA)



Early Inventory Development:

The NAA would have been designated as nonattainment in 2004, but an Early Action Compact (EAC) was implemented.

EAC required 47.5% control of tank emissions.
The Area failed to attain the standard, and a SIP was required in 2007,.
Condensate tanks were the second largest source of VOC at 143 tons per day.

The 2008 ozone SIP used a base year of 2006 to project attainment of the 80 ppb ozone NAAQS by 2010. On February 13, 2008, the EPA partially approved the SIP with a 75% system-wide reduction of condensate tank VOC emissions.

VOC condensate tank emissions (tpd) for 2006 base and 2010 projection years

Emissions	Tons per Day
2006 Base Year	126.5
2010 Projection Year	129.6

Emissions Inventory Guidance for Implementation of Ozone and Particulate Matter National Ambient Air Quality Standards (NAAQS) and Regional Haze Regulations, EPA-454/B-17-002

- The general equation for emissions estimation is:

$$Emissions = A \times EF \times (1 - ER/100)$$

- A = activity total
- EF = emission factor
- ER = overall emission reduction efficiency (%)

The ER term is related to emissions controls and rules that reduce emissions (all are percentages less than 100)

Control Data Elements

- Control efficiency: the efficiency by which a control device or measure reduces emissions for a particular pollutant.
- Control Capture efficiency: portion of an exhaust gas stream actually collected for routing to a set of control devices.
- Control Effectiveness: amount time or activity throughput that a control approach is operating as designed, including the capture and reduction devices.
- Rule penetration: amount of a nonpoint source category activity that is covered by the reported control measures.
- Rule effectiveness: a rating of how well a regulatory program achieves all possible emissions reductions.

The 2010 SIP inventory included rule effectiveness and rule penetration, but not capture efficiency.

- Post-SIP inverse modeling indicated there were VOC emissions missing.
- Condensate tank inspections discovered open hatches and other leaks.
- Forward Looking Infrared Camera (FLIR) images showed leaking tanks.
- Separate Studies by NOAA and EPA in 2011 indicated emissions from oil and gas were underestimated.
- Engineering judgment was used to arrive at a capture efficiency of 75%

Revised 2008 condensate tank emissions

Emissions	tpd
Uncontrolled	351
Reported	58
Adjusted	168

Visible

IR Camera

EPA photo

Inventory Development for the 2017 Ozone SIP:
2011 Base Year Inventory

Condensate Tanks

Equation (2) Emissions (lbs) = 2011 Oil Production (bbls) X 13.7(lbs/bbl) X $(1 - (90\% \times 97.7\% \times 80\% \times 75\%))$

Base Year 2011 oil and gas condensate tank emissions			
	2011 (tpd)		
Pollutant	VOC	NOx	CO
Condensate Tank Emissions	216.0	1.1	2.3

2011 oil and gas well pad source emissions

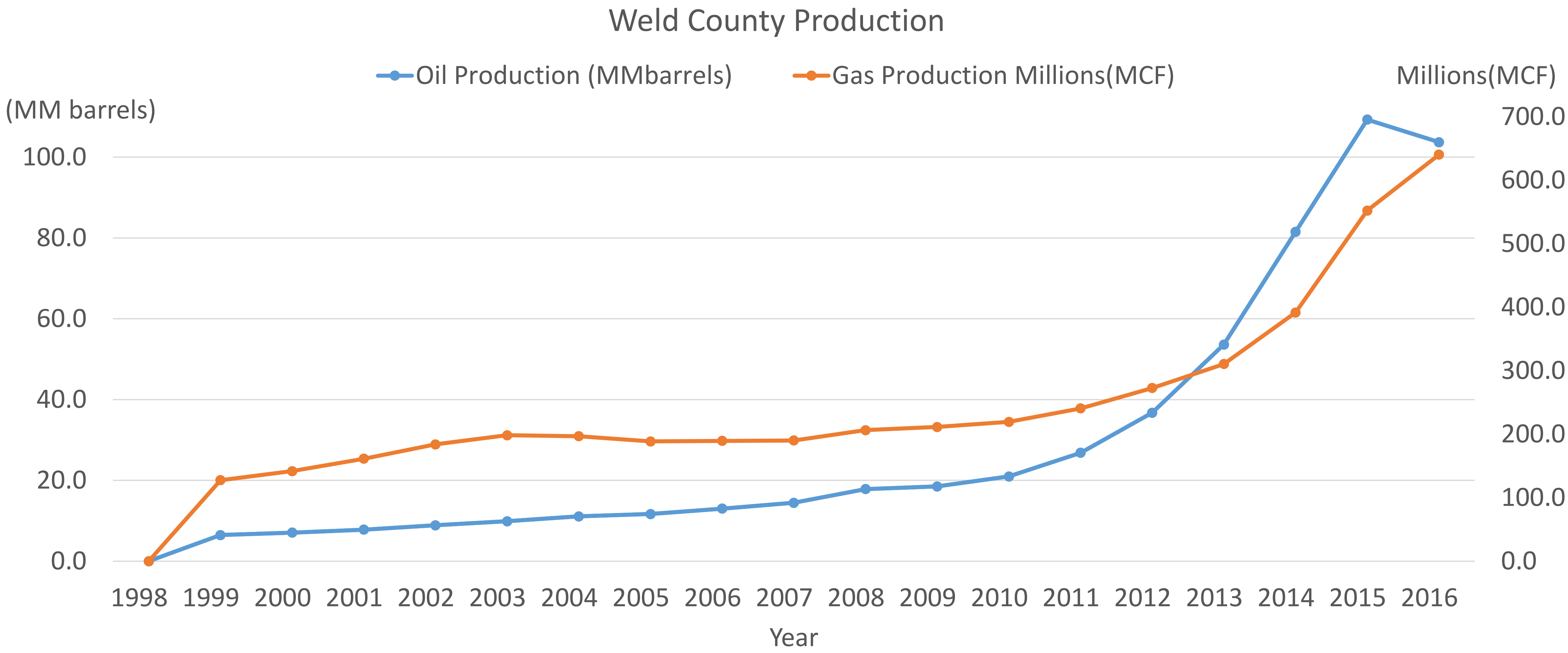
Table 4. 2011 oil and gas well pad source emissions			
	2011 (tpd)		
Oil and Gas Area Sources	VOC	NOx	CO
Oil and Gas Area Sources			
Drill rigs	0.7	11.3	5.9
Exempt engines	0.6	8.1	5.2
Fugitives	21.3		
Heaters	0.1	1.6	1.3
Misc. (spills, workover rigs, etc.)	0.5	1.3	0.5
Pneumatic devices	11.8		
Pneumatic pumps	2.4		
Truck loading of condensate liquid	3.8		
Venting - blowdowns	4.6		
Venting - initial completions and recompletions	3.2		
Water tank losses	0		
Subtotal	48.9	22.2	12.9

2011 oil and gas point source emissions

2011 (tpd)		
VOC	NOx	CO
14.8	18.1	17.0

Attainment Year Inventory

Until 2013, most of the oil and gas production in the NAA had been from vertical wells drilled in the sandstone formations. Since 2013, almost all of the new production has been in the Niobrara Shale formations, utilizing horizontal drilling and hydraulic fracturing (fracking).



Development of Attainment Year Inventory

- APCD and Regional Air Quality Council staff met numerous times with the top 6 oil producers.
- These producers provided their 2014 activity and emission data for all of their well pad facilities, and projected oil production to the 2017 attainment year.
- We accepted the non-condensate tank data as submitted.
- We modified the 2017 condensate tank emissions based on Equation (1) .
- We developed uncontrolled emission factors for each of the following configuration of wellpads based on the 2014 data:
    - Tankless
    - Vertical Wells
        - 1 stage of separation
        - 2 stages of separation
    - Horizontal Wells
        - 1 stage of separation
        - 2 stages of separation
        - 3 stages of separation

2017 VOC emissions inventory - oil and gas condensate Tanks

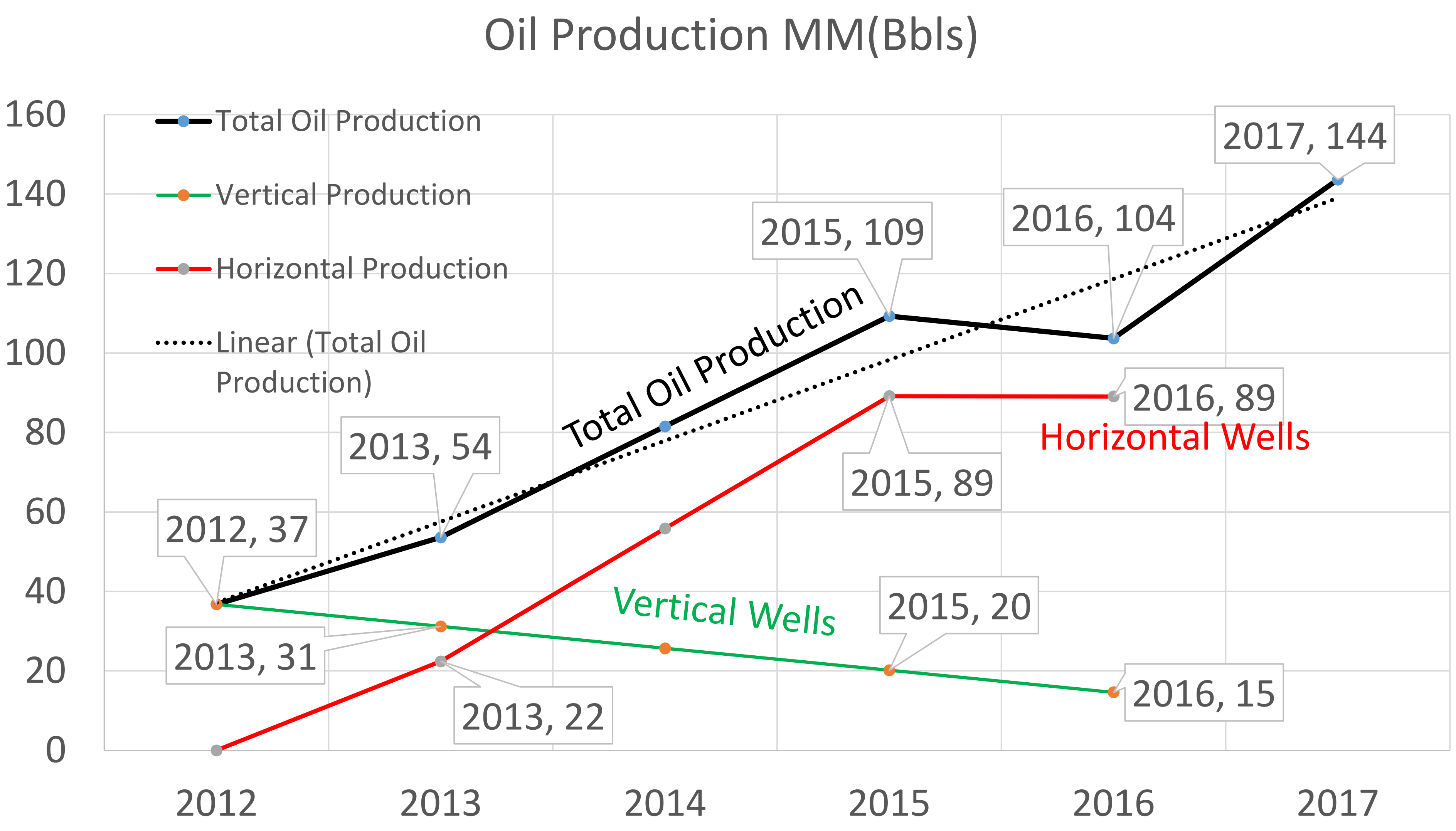
	Well Type	Stages of Separation	2014 Oil Production (MMbbl)	2017 Oil Production (MMbbl)	2014 Uncontrolled Emissions Factors (lbs/bbl)	2017 Uncontrolled Emissions (tpd)	Control Rate (%)	2017 Controlled Emissions (tpd)
All Producers in 9-County Area	Horizontal	1	13.4	9.9	7.27	98.1	74.70%	24.8
		2	**20.2**	46.7	2.01	128.9	77.40%	29.1
		3	**26.4**	26.7	0.96	35.2	77.40%	8
		Total	**70.2**	135.5		262.2		61.9
	Vertical	1	**7.8**	6.1	9.67	80.8	74.70%	20.4
		2	**3.0**	2.0	7.71	21.6	77.40%	4.9
		3	**0.0**	0.0	--	0	77.40%	0
		Total	**10.8**	8.1		102.4		25.3
	TOTAL		**81.0**	143.7		364.6		87.2

Note: Horizontal/Vertical breakdown is according to the wellpad having any horizontal wells.

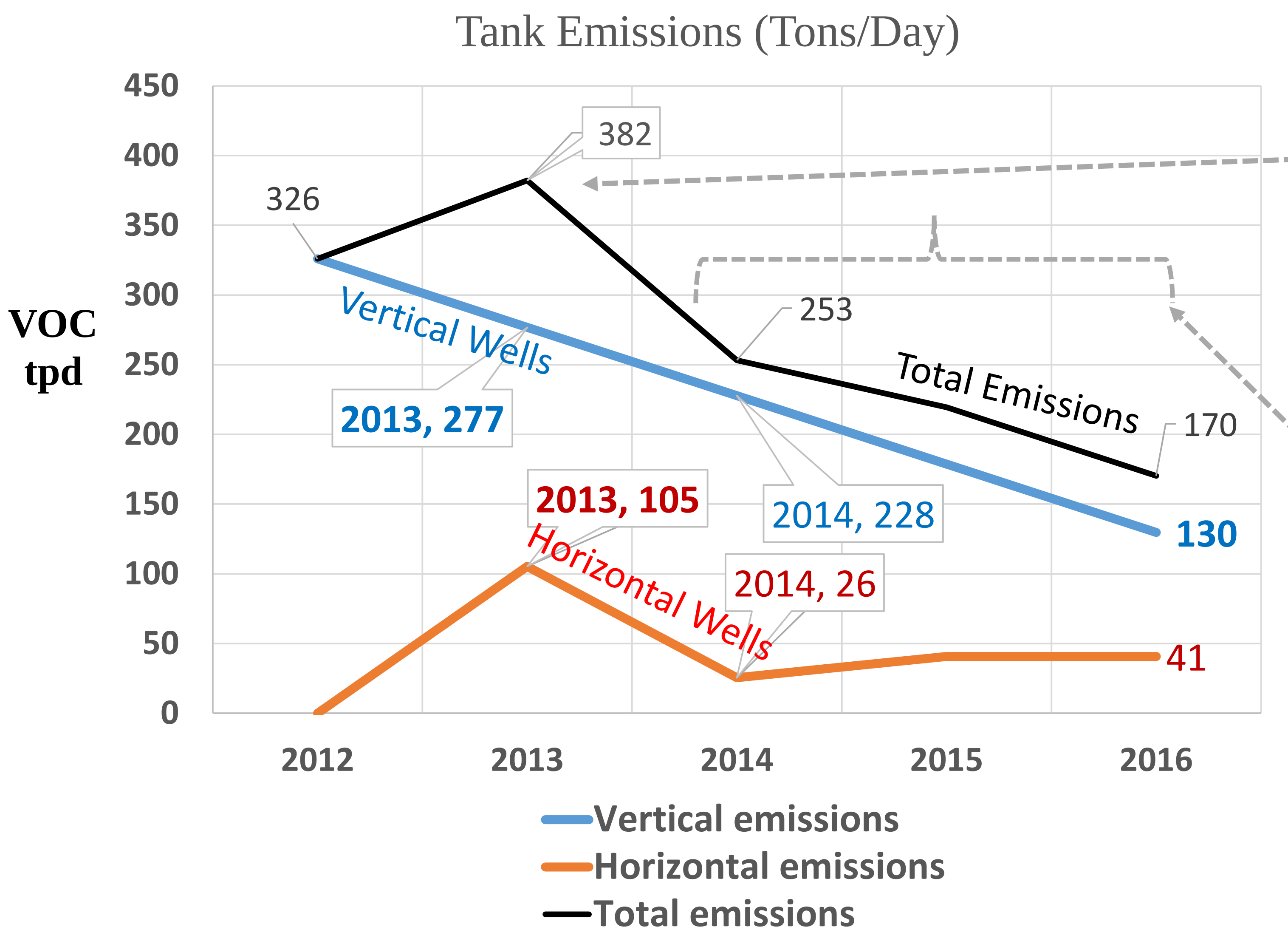
$$\mathbf{2017\ Emissions} = \mathbf{Production} \times \text{EF(lbs/bbl) X } (\mathbf{1} - (\mathbf{90\%\ X\ CE\ X\ RE\ X\ RP}))$$

For 1 Stage Of Separation CE X RE X RP = 83%, For 2 & 3 Stages of Separation CE X RE X RP = 86%

Oil production below ground breakdown for Weld County



Tank VOC emissions



2013Emissions= (22,389,762)* 7.27* (1-(90%*97.7%*80%*75%))/2000/365
+
(31,221,741)*13.7* (1-(90%*97.7%*80%*75%))/2000/365

2014 and later Emissions= [Horizontal Production]*0.33[pounds per barrel ef *derived from SIP inventory*] /2000/365 [*the total controlled emissions for horizontal wells from all producers / the total production from all producers for horizontal wells*]
+
[Vertical Production]*13.7* (1-(90%*97.7%*80%*75%))/2000/365

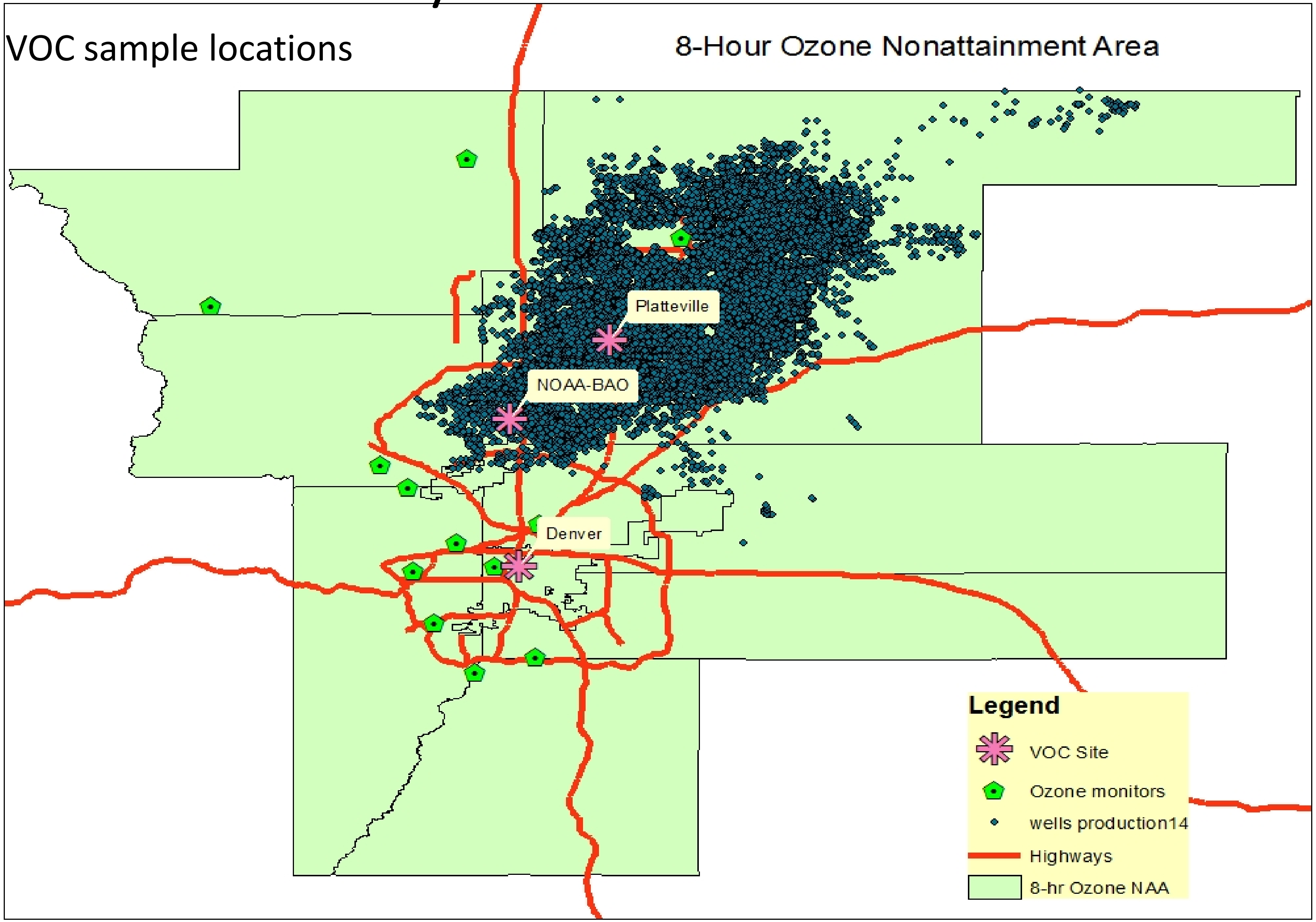
Summary of 2011 and 2017 Oil and Gas emissions (tons per day) in the ozone NAA						
Description	2017			2011		
	VOC	NO_X	CO	VOC	NO_X	CO
Oil and Gas Sources						
Point Sources Subtotal	16.3	20.6	19.7	14.8	18.1	17
Condensate Tanks Subtotal	**78.7**	0.6	2.3	**216**	1.1	2.3
Area Sources Subtotal	59	44.6	31.4	48.9	22.2	12.9
TOTAL	154	65.8	53.4	279.7	41.4	32.2

Top-Down Inventories:

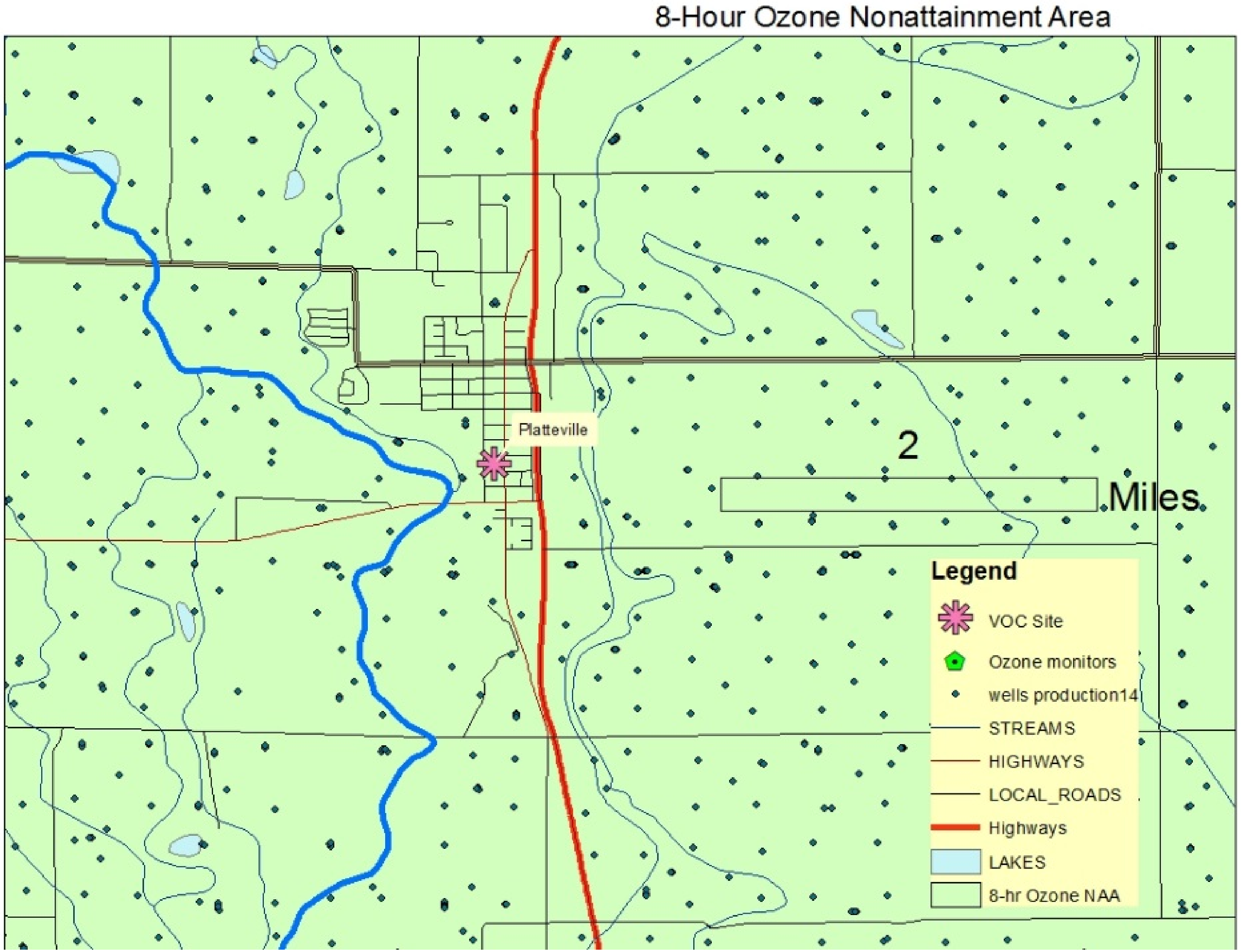
- The 2008 ozone SIP inventory was adjustedbased in part on a top-down inventory by NOAA in 2012 that indicated oil and gas VOC emissions were underestimated by about a factor of two.
- We developed a new 2008 base year inventory that had condensate tank VOC emissions that were about three times larger than those reported by industry.
- A new top-down inventory for 2012 published in 2013 by NOAA, indicates the 2017 ozone SIP base year inventory may also underestimate oil and gas VOC by a factor of two, and that benzene emissions may be underestimated by a factor of 7.
- This is concerning, but APCD has been measuring 6 to 9 AM 3-hour samples of VOC species using Summa canisters at Platteville and Denver since 2012.
- These data are good indicators of the primary VOC species emitted by local sources in these two areas since:
    - a) mixing is limited at those early hours and
    - b) the sun angle and temperatures are low so little photochemical reaction is occurring.
- An analysis of this data set is probably a more robust way to determine the accuracy of the VOC inventory.

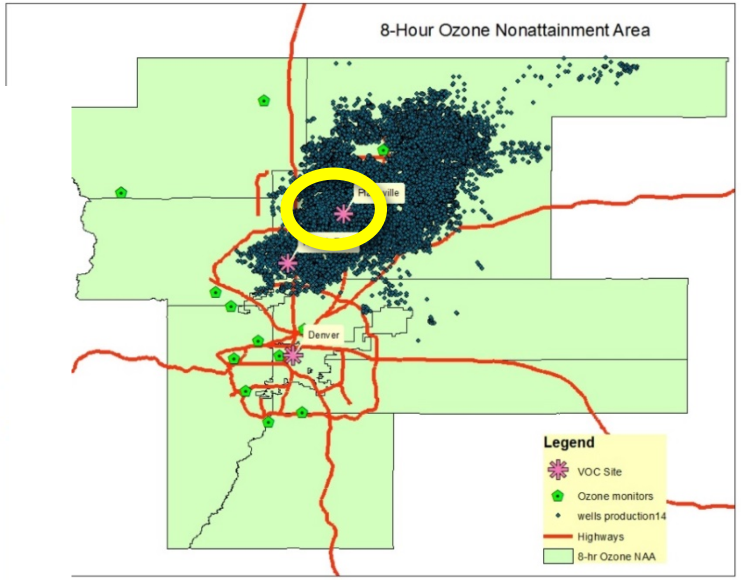
VOC Precursor Analysis:

VOC sample locations

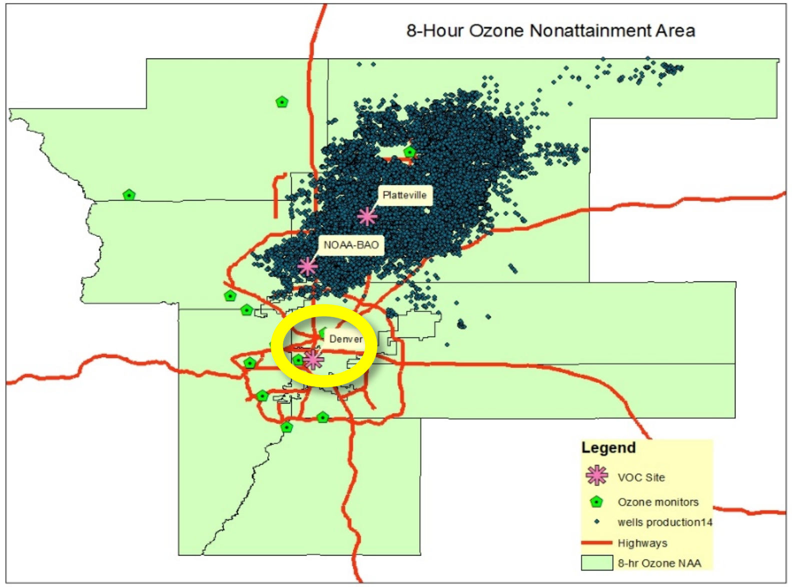


Platteville VOC site

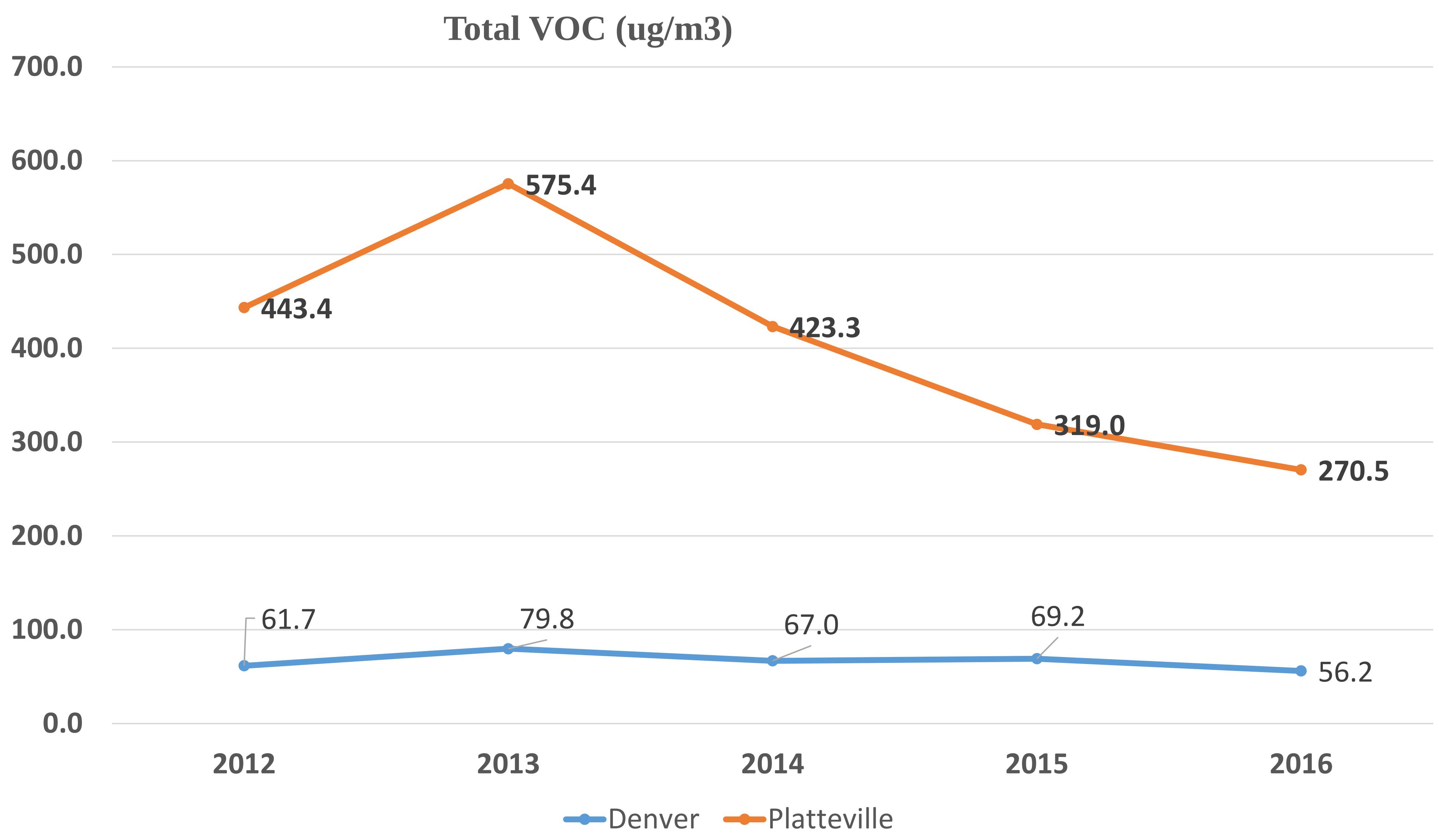




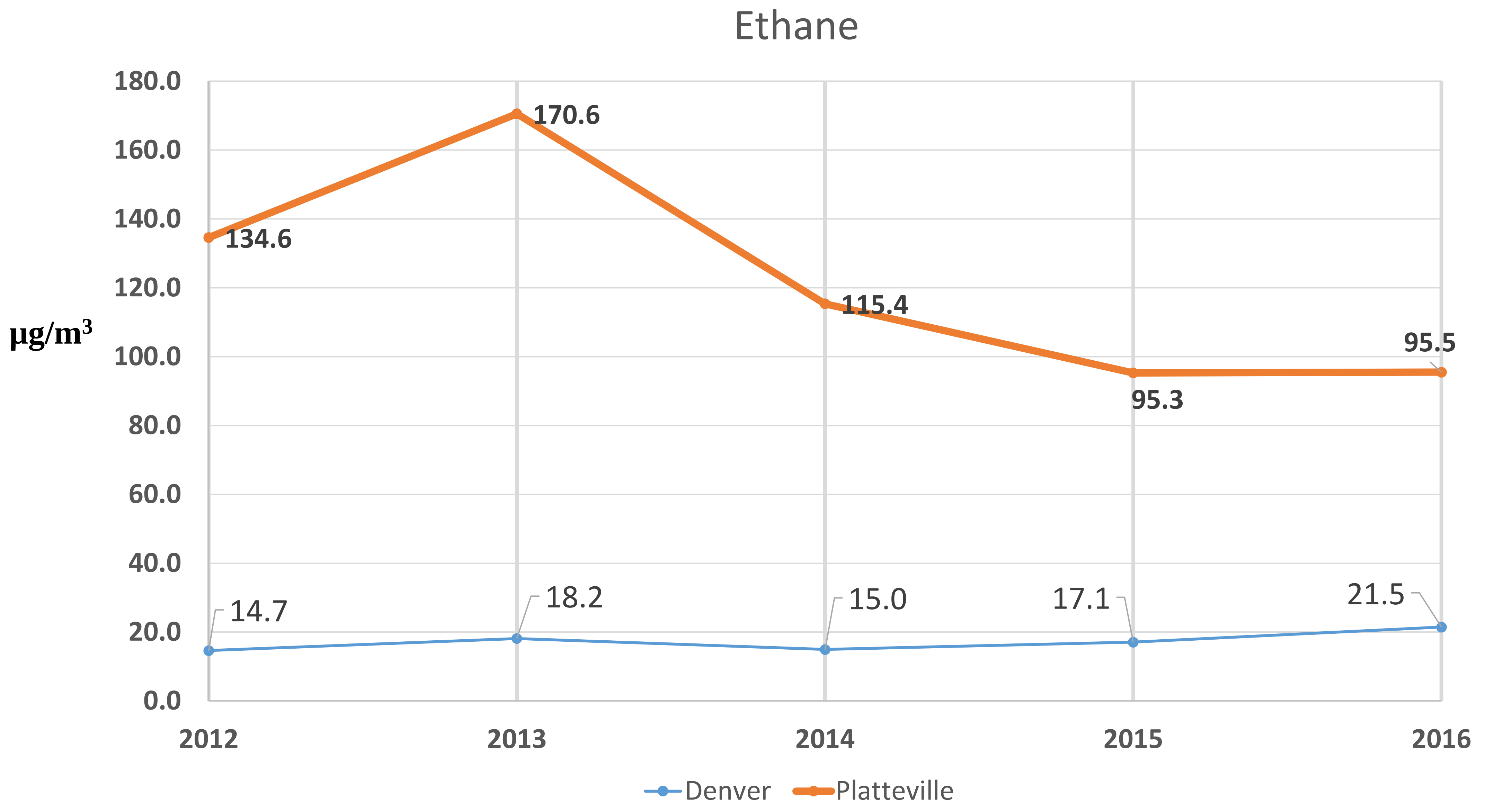
Denver VOC site



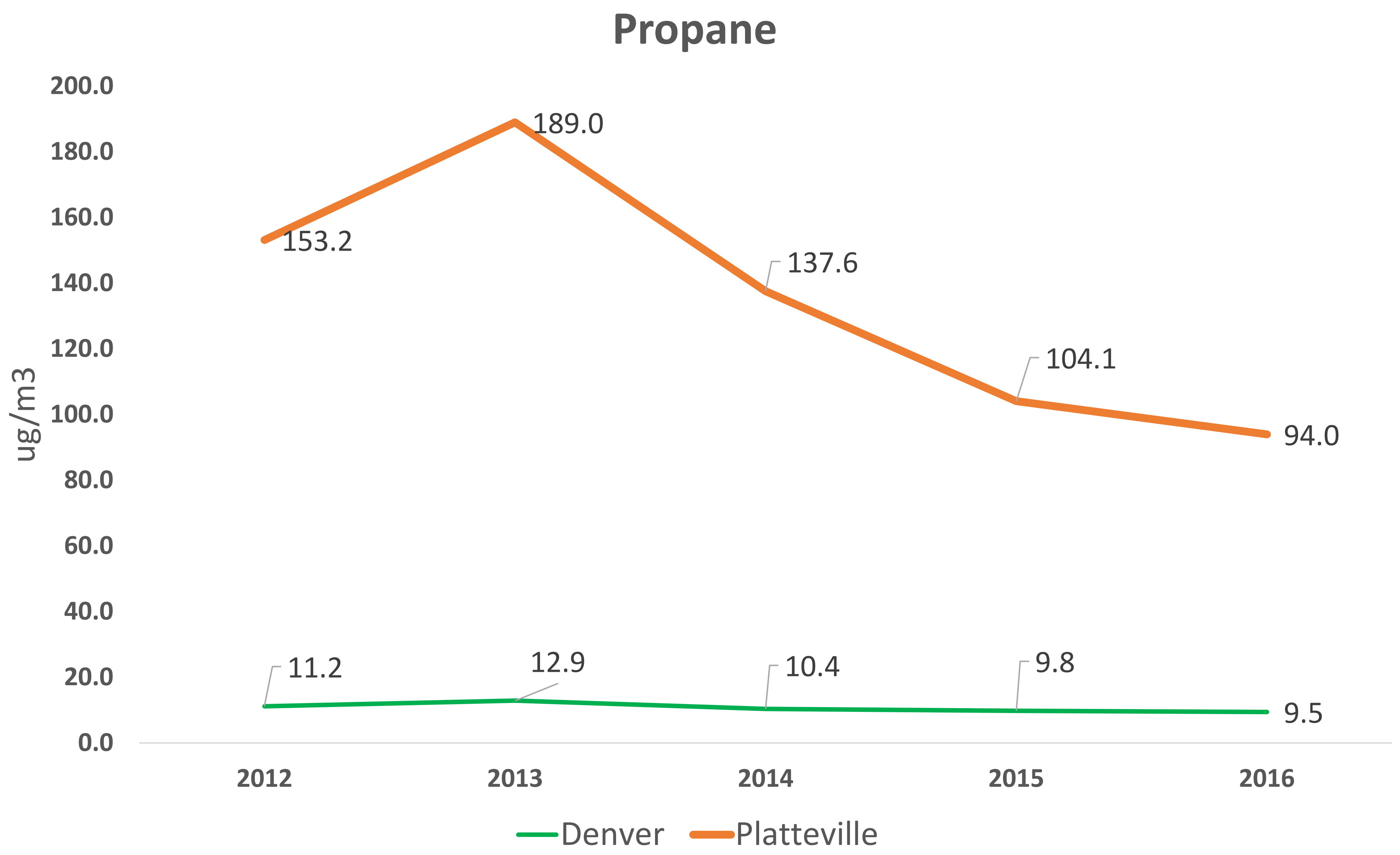
Annual average VOC at Platteville and Denver sites from 2012 to 2016



Annual average ethane (µg/m³)

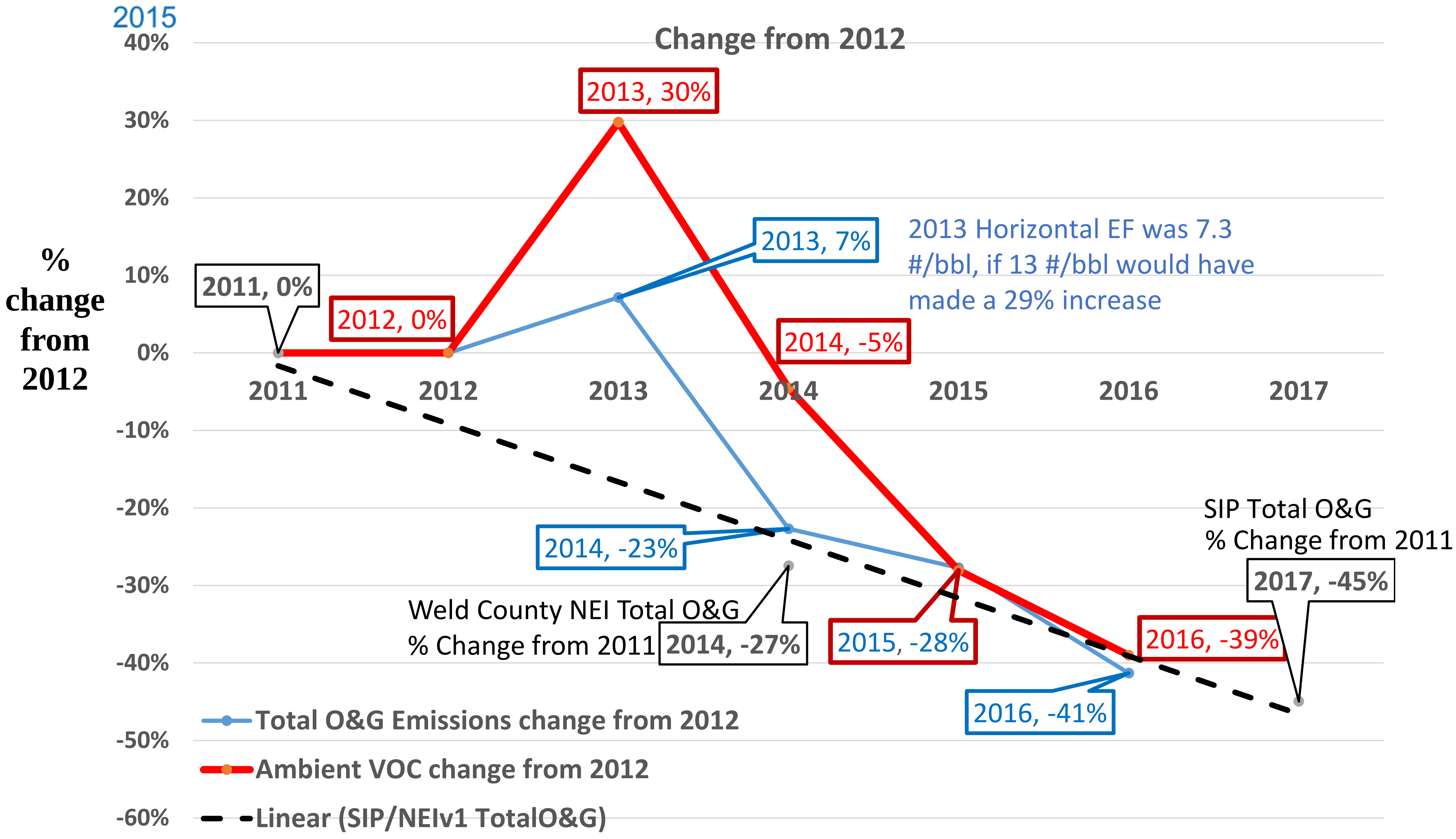


Annual average propane (ug/m3)

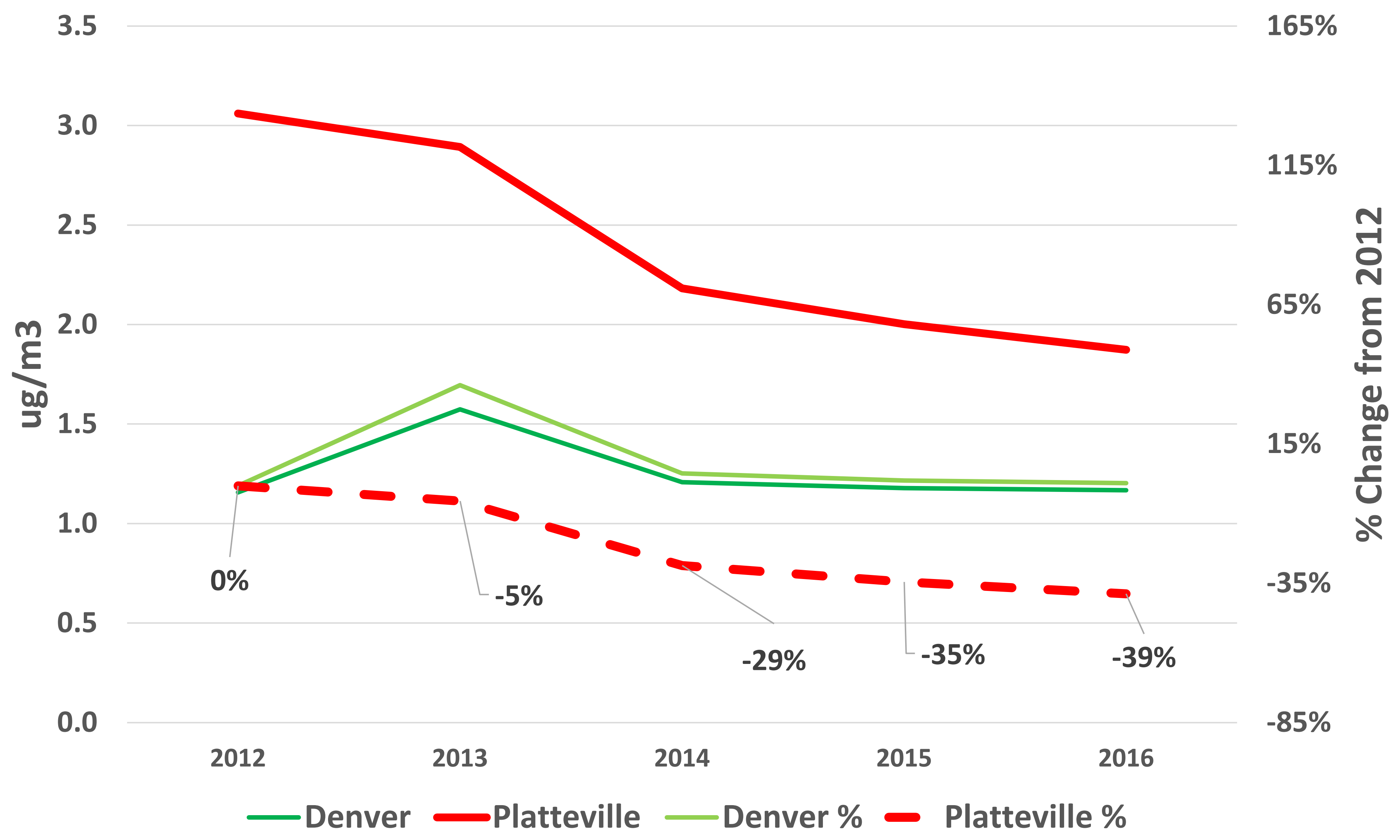


NMOC speciation profiles by weight percent				Platteville			Denver		
DJFLA	DJVNT	**NOAA BAO 2011**	Species	2012	2015	2016	2012	2015	2016
32.6%	24.7%	**22.4%**	**Propane**	**26.5%**	**25.1%**	**25.7%**	16.5%	13.2%	13.4%
26.9%	45.3%	**27.2%**	**Ethane**	**23.3%**	**23.0%**	**26.1%**	21.6%	22.9%	30.4%
15.0%	9.7%	**18.6%**	**n-Butane**	**16.1%**	**15.4%**	**15.1%**	10.7%	9.3%	9.9%
8.3%	5.1%	**8.0%**	**Isobutane**	**6.9%**	**6.3%**	**6.7%**	4.3%	4.3%	3.9%
4.6%	3.7%	7.7%	n-Pentane	6.6%	6.5%	5.9%	6.2%	6.7%	4.4%
5.9%	4.1%	6.9%	Isopentane	7.1%	5.8%	5.5%	8.2%	0.1%	3.6%
		2.5%	Methylcyclopentane	0.9%	1.2%	0.9%	1.4%	1.8%	1.3%
3.3%	7.1%	2.2%	n-Hexane	2.1%	2.6%	2.1%	2.8%	3.0%	2.3%
2.5%	0.0%	0.7%	n-Heptane	0.6%	0.9%	0.8%	1.0%	1.4%	1.3%
0.2%	0.2%	0.6%	Toluene	0.5%	0.9%	0.8%	3.5%	5.8%	4.7%
0.2%	**0.1%**	**0.5%**	**Benzene**	**0.5%**	**0.5%**	**0.5%**	1.7%	1.6%	1.7%
		0.6%	Methylcyclohexane	0.7%	1.1%	0.8%	0.9%	0.8%	0.5%
		0.6%	Cyclohexane	0.7%	0.9%	0.7%	0.9%	3.1%	2.1%
		0.5%	Acetylene	0.2%	0.4%	0.5%	2.4%	2.6%	2.9%
		0.5%	Ethylene	0.5%	0.6%	0.7%	5.0%	4.7%	4.4%
0.1%	0.1%	0.3%	m/p Xylene	0.2%	0.4%	0.3%	1.8%	2.5%	1.8%
0.1%	0.0%	0.2%	2,2,4-Trimethylpentane	0.0%	0.0%	0.1%	0.7%	1.2%	0.9%
		0.1%	o-Xylene	0.1%	0.1%	0.1%	0.7%	1.1%	0.7%
0.1%	0.0%	100.0%	n-Nonane	0.1%	0.2%	0.1%	0.3%	0.5%	0.4%
0.0%	0.0%		n-Decane	0.0%	0.2%	0.1%	0.4%	0.6%	0.4%
0.0%	0.0%		Ethylbenzene	0.1%	0.1%	0.1%	0.6%	0.9%	0.6%
0.4%	0.0%		n-Octane	0.2%	0.5%	0.3%	0.5%	0.7%	0.6%
0.0%	0.1%		Cyclopentane	0.4%	0.4%	0.3%	0.5%	0.6%	0.4%

Change in emissions compared with change in VOC concentrations



Annual average benzene (ug/m3) and percent change from 2012



CONCLUSIONS

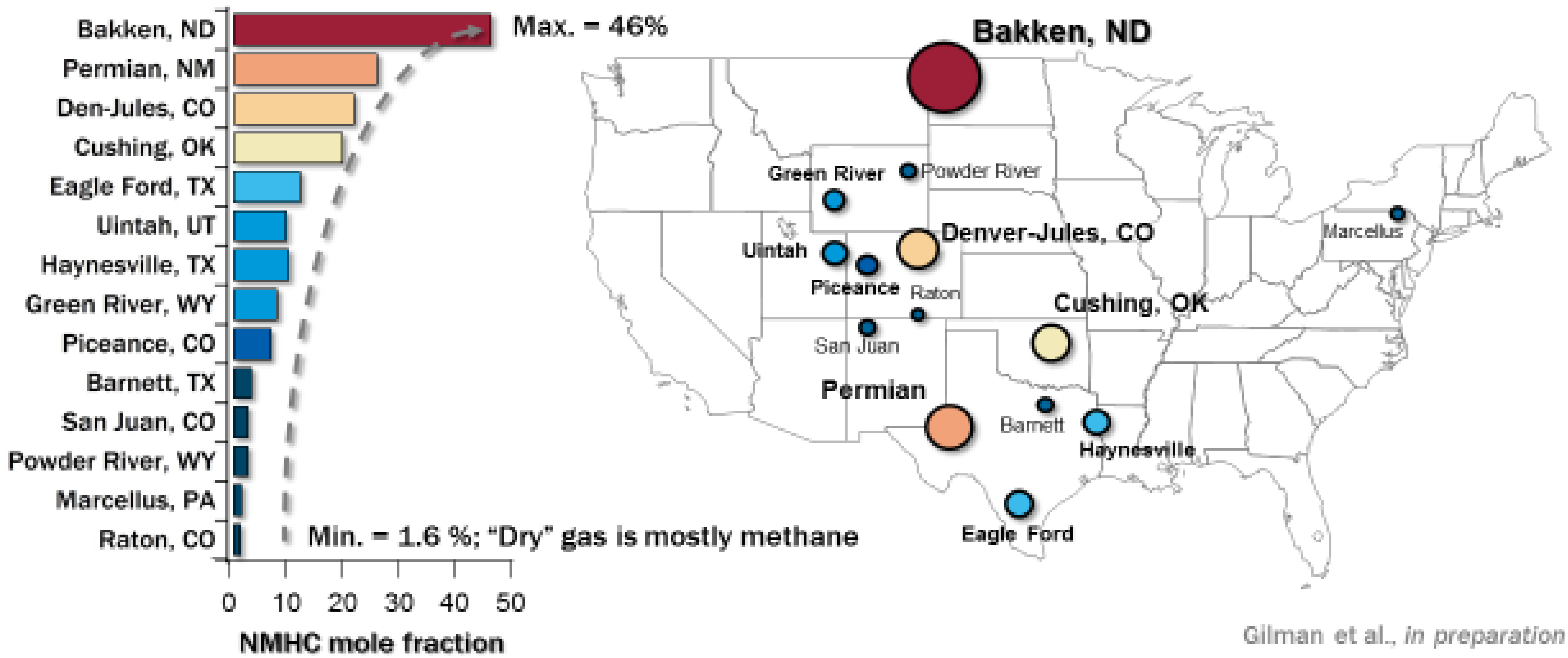
- The top-down inventory conclusions that the base year inventory may be twice as high for VOC and seven times higher for benzene do not seem to match the ambient data.
- The WRAP speciation profile for benzene in flash emissions does seem to be low by a factor of three.
- Condensate tank emissions are the largest category of VOC.
- Controlling tanks provides over 80% of the total reduction in emissions from 2011 to 2017.
- If there were some other unknown or poorly characterized source of VOC, the ambient VOC trend would not have tracked the total oil and gas emission trend as well.
- Condensate emissions are large in the NAA because both oil and gas are produced in the same wells under conditions of high gas pressure resulting in high flash emissions rates.
- Flash emissions are from gases dissolved in the oil that “flash” out of solution when the gas pressure is reduced to near ambient levels.
- The use of two or three stages of separation combined with compressors allows most of the flash gas to be removed from solution before going into storage.
- Oil or condensate in conjunction with high pressure gas is a subset of “wet gas”.

NMOC mole fractions at oil and gas shale basins.

4) NOAA airborne measurements are used to characterize VOC emissions and hydrocarbon fluxes for several of the largest oil and gas producing shale basins in the U.S.

$$\frac{\sum NMHC}{CH_4 + \sum NMHC} = \text{NMHC mole fraction}$$

A "wet" gas contains a larger fraction of non-methane hydrocarbons (NMHC)



Gilman et al., *in preparation*

CONCLUSIONS, Continued

- Basins ranking above the San Juan may have significant condensate tank emissions.
- To quantify these emissions, pressurized liquid samples should be obtained from the well pad separators to calculate a valid uncontrolled emission rate.
- Without such samples the EPA Oil and Gas Tool will not adequately represent emissions.
- Good speciation profiles are also necessary to apportion VOCs for hazardous air pollutants and photochemical models.
- Ambient Summa canister sampling is a good check on the pressurized liquid sampling , which is difficult perform.