



Unconventional Oil and Gas Development: Lessons from Extensive Ambient Air Monitoring in the Barnett Shale

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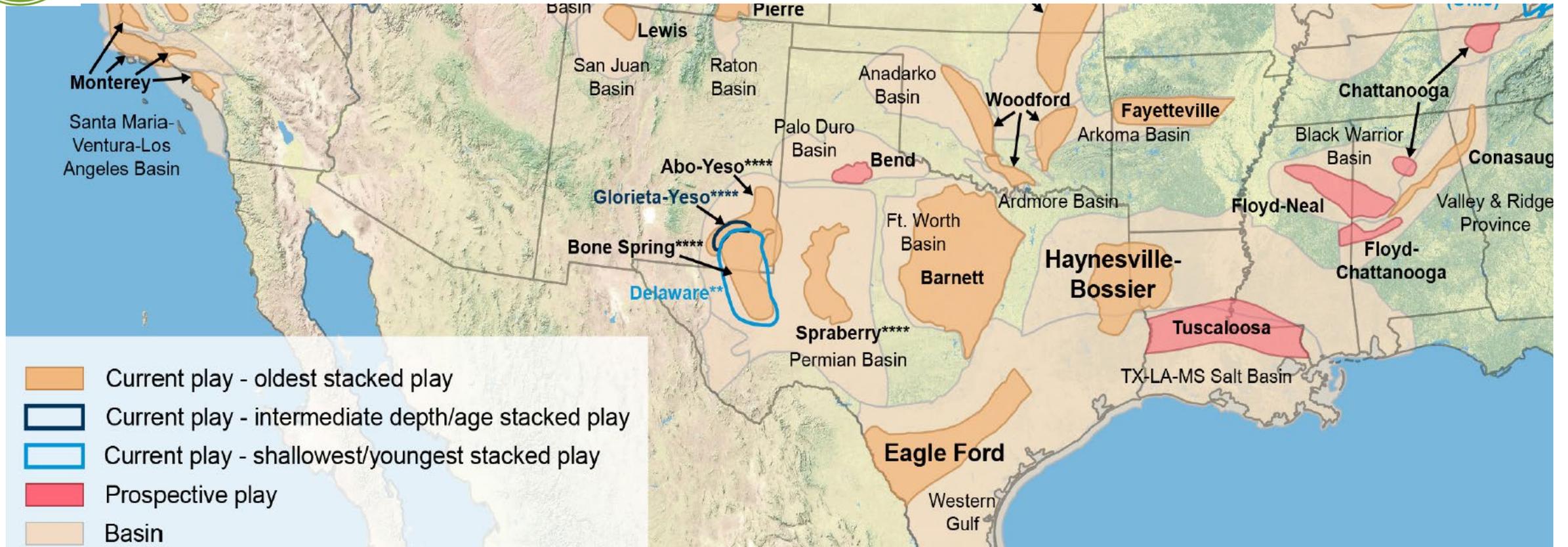
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Outline

- Background information about the Barnett Shale play
- Production stages and chemicals associated with natural gas (NG) development
- Ambient air monitoring in the Barnett Shale
- Research on the impact of NG production on air quality in the Barnett Shale

The US has many oil and gas formations



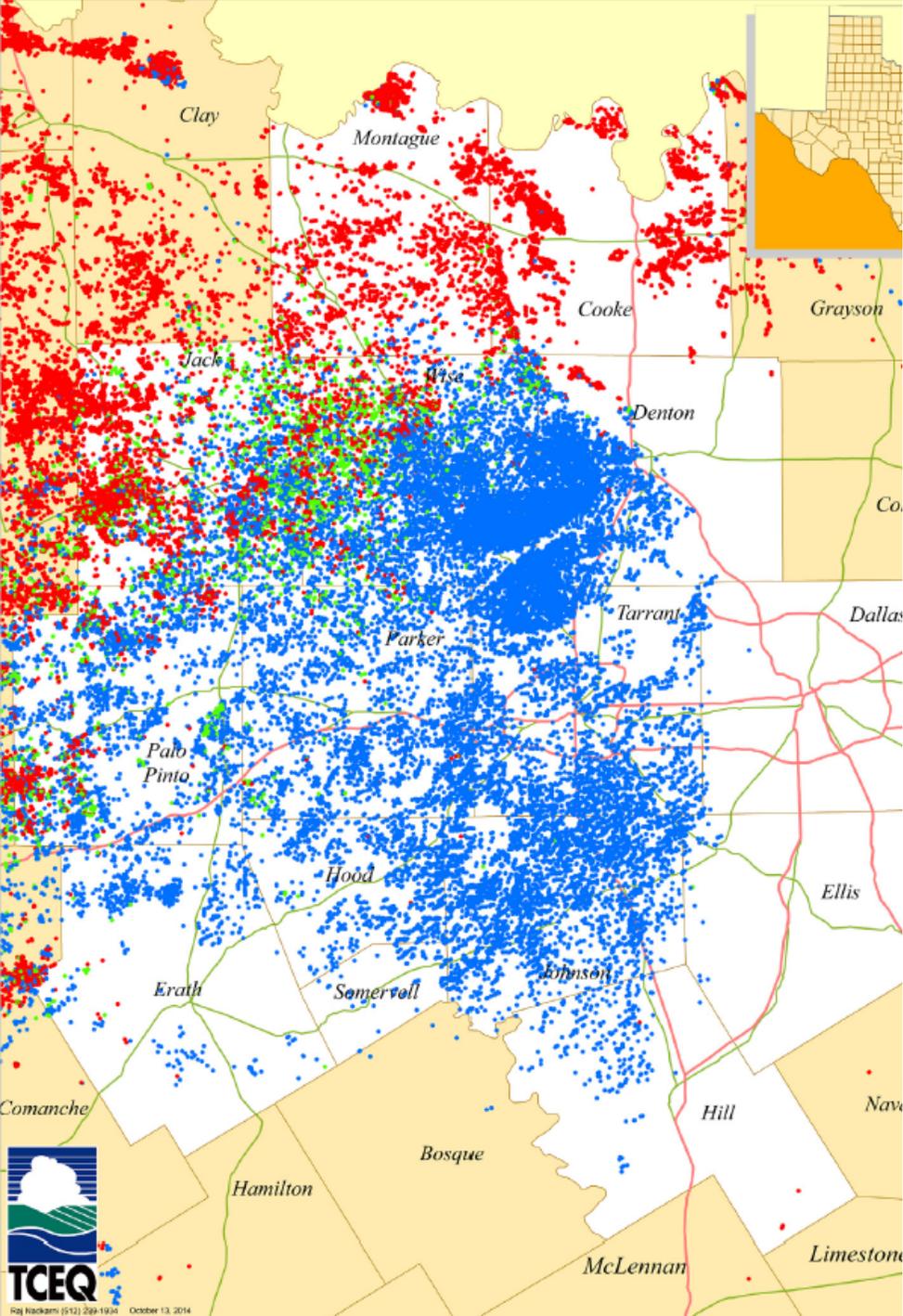
Source: US Energy Information Administration, June 2016

- Across the United States, there are a number of geological formations that contain oil and natural gas
- A subset of these formations are characterized by shale rock and they contain natural gas – these are called shale plays, and include the Eagle Ford and Barnett shales in Texas



Development of natural gas shale plays expanded in the mid-2000's

- Before the 21st century, the natural gas in shale formations was difficult to access and so there was little development of the natural gas shale plays
- Since about the mid-2000's, unconventional oil and gas development (horizontal drilling and hydraulic fracturing or “fracking”) technology advanced rapidly
- The Barnett Shale play was the first major field to be developed, as the technology was primarily developed there
- The Barnett Shale and other shale formations in Texas are among the largest in the world



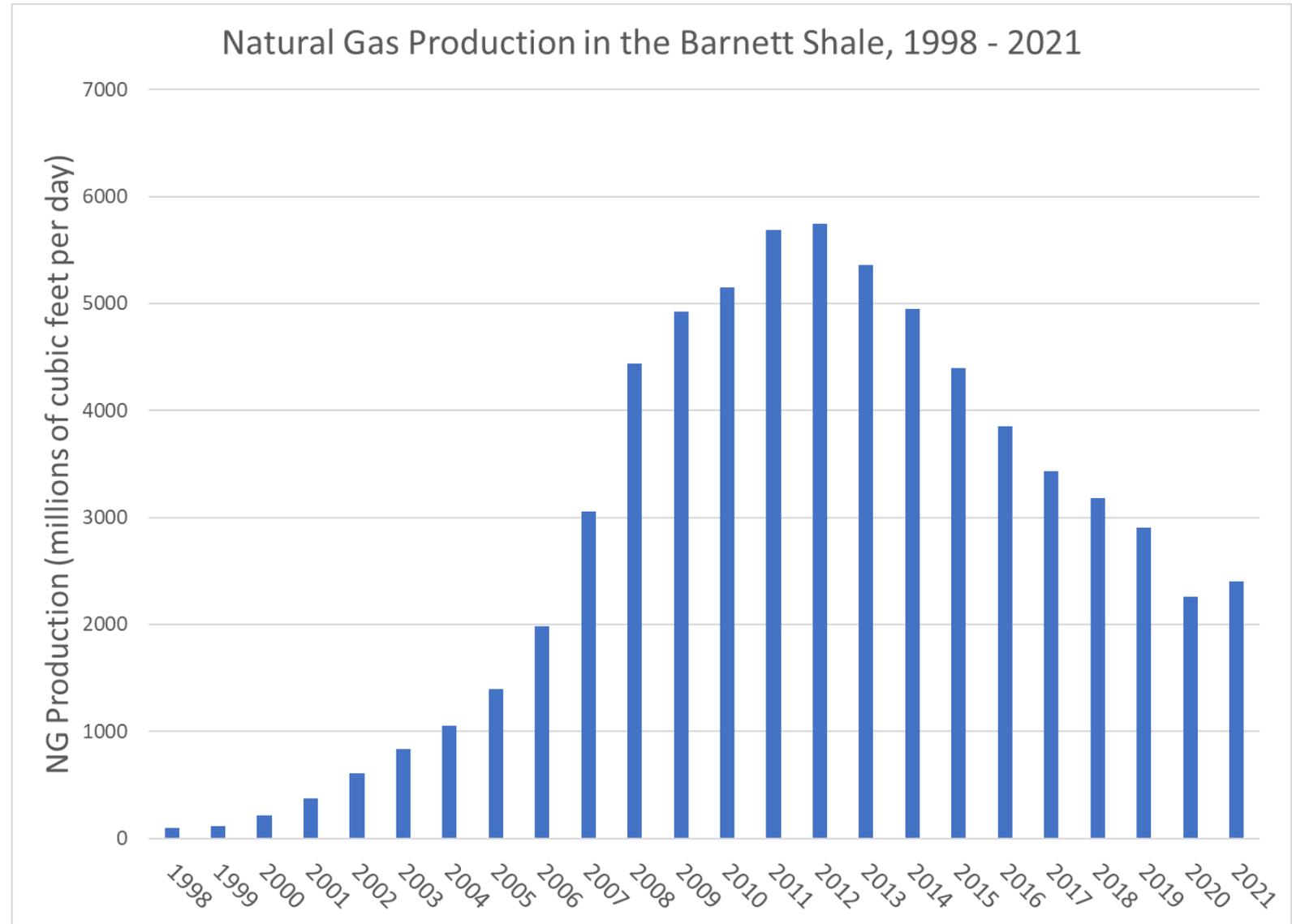
Natural gas production rapidly expanded in the Barnett Shale

- The Barnett Shale is one of the largest and most active onshore natural gas fields in North America
- The productive part of the formation stretches from the city of Fort Worth towards the west and south, covering 5,000 square miles and more than 15 counties

Figure 1 from: Ethridge S, Bredfeldt T, Sheedy K, Shirley S, Lopez G, Honeycutt M. The Barnett Shale: From problem formulation to risk management. J Unconv Oil Gas Resour 2015;11:95–110.

Increase in natural gas production in the Barnett Shale

➤ Due to expanded use of unconventional production technologies, NG production increased by about 2,500% from 2000 to 2013





Fracturing of a NG well only occurs for a short time and production can last for decades



**Site selection,
pad site
preparation**

4-6 weeks



Drilling
2-4 weeks



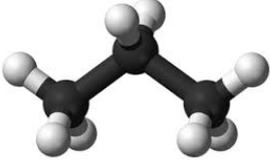
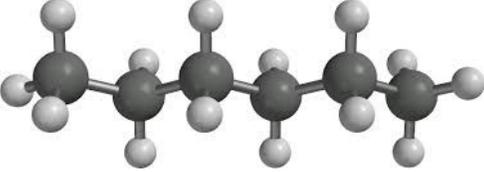
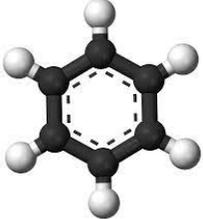
**Hydraulic
Fracturing**
3-5 days



Production
Decades



Small alkane hydrocarbons are the most abundant chemicals in NG

Chemical	% in Dry Gas	Hydrocarbon Type	
Methane	88.67	C1 alkane	
Ethane	5.03	C2 alkane	
Propane	2.13	C3 alkane	
n-Butane	0.58	C4 alkane	
Isobutane	0.38	C4 alkane	
Isopentane	0.22	C5 alkane	
n-Pentane	0.2	C5 alkane	
Heptane	0.08	C7 alkane	
n-Hexane	0.06	C6 alkane	
Methylcyclohexane	0.03	C7 alkane	
Benzene	0.02	C6 aromatic	
Toluene	0.01	C7 aromatic	
Xylenes	0.003	C8 aromatic	



NG Production activities coincided with areas where people live

- NG Production activities expanded into heavily populated areas around Fort Worth, raising concerns about the potential impact on air quality



The TCEQ increased monitoring of air quality in the Barnett Shale when NG production expanded

- While oil and NG development are largely regulated by the Railroad Commission of Texas, air emissions from these operations that occur after drilling is completed are regulated by the TCEQ
- Rapid growth of NG development near heavily populated urban areas led to increased public concern regarding impacts of air emissions on human health and welfare
- The TCEQ employed many techniques to characterize potential risk from air emissions:
 - Infrared (IR) camera and helicopter flyovers
 - Emissions inventories
 - Mobile monitoring trips
 - Field investigations
 - Fixed-site monitors

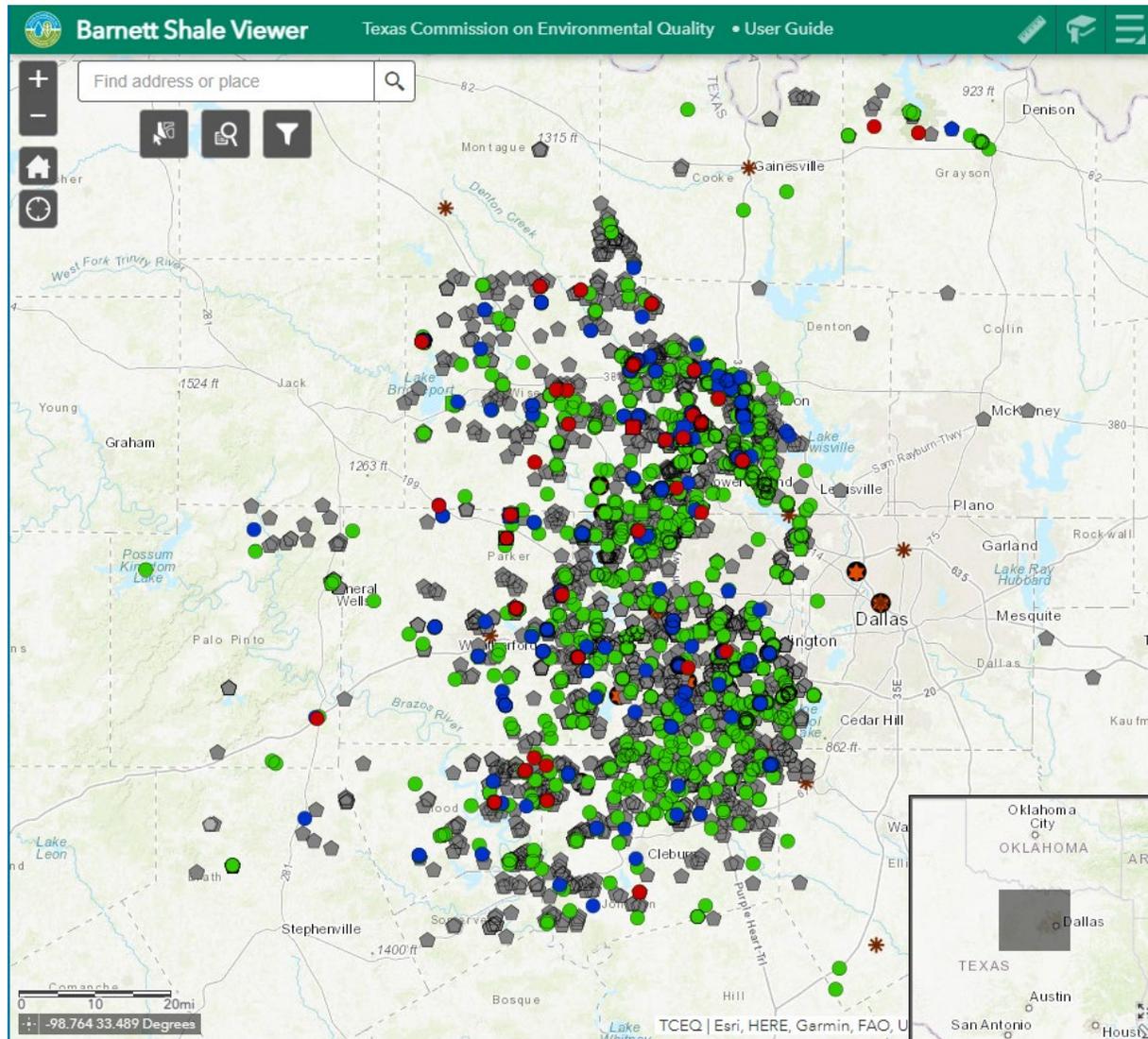
Helicopter Mounted IR Camera: Source Detection/Identification

- Comprehensive flyovers have been conducted over the area, leading to identification (and repair) of emission sources
- E.g., the 2010 flyover resulted in images of over 5,000 individual storage tanks and identification of 88 sources of significant hydrocarbon emissions.





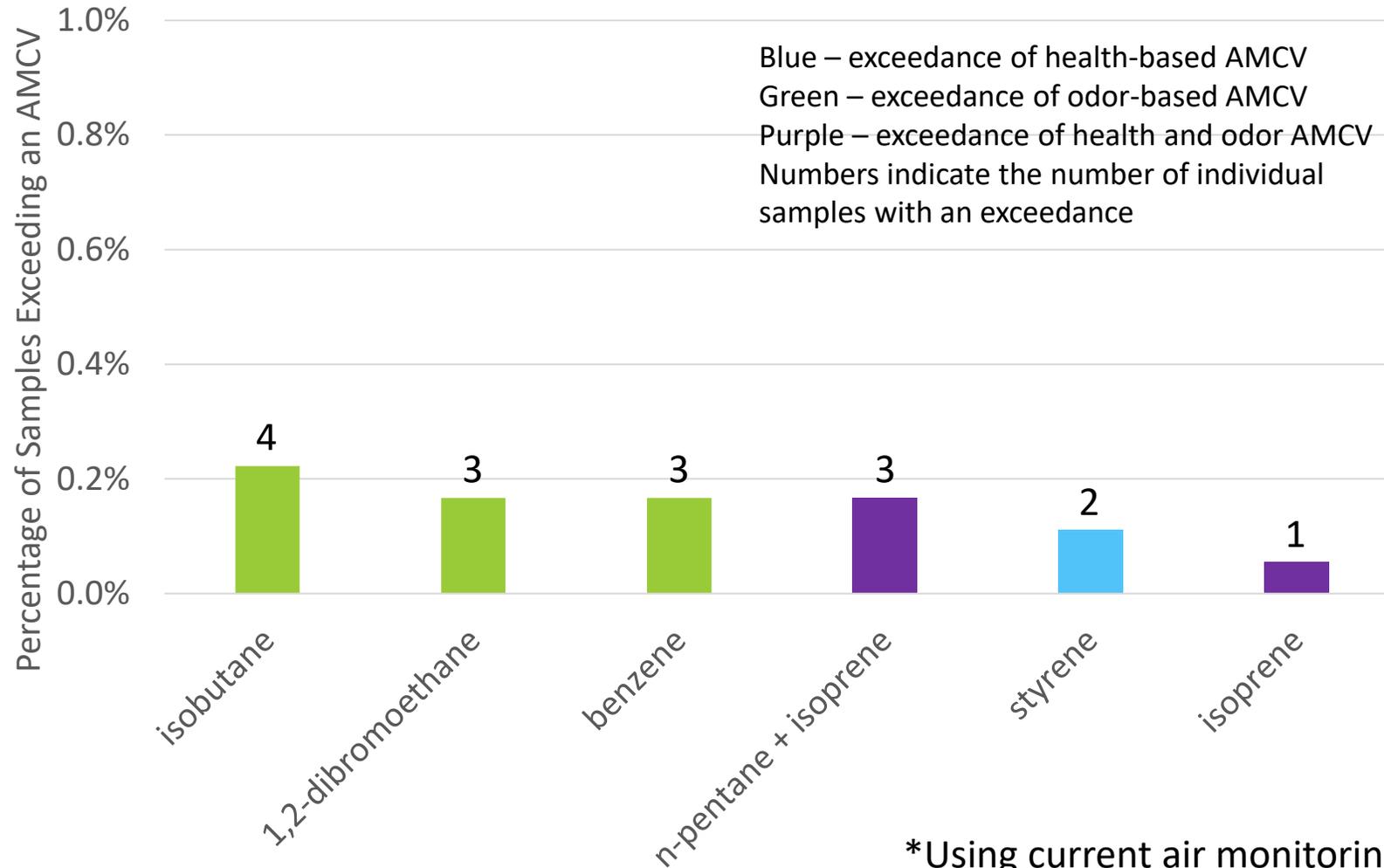
Field investigators collected many individual air samples



- Over 1700 individual canister samples were collected
 - Sampled for volatile organic compounds (VOCs) and carbonyls
 - Collected distance and source information
 - Included 30 min, grab, or stationary canister
 - Samples were collected by field investigators in the region, by staff from the central office, and by citizens
- Measured concentrations of chemicals that exceeded a health or odor-based comparison value were rare



Monitored exceedances of a comparison value were very uncommon

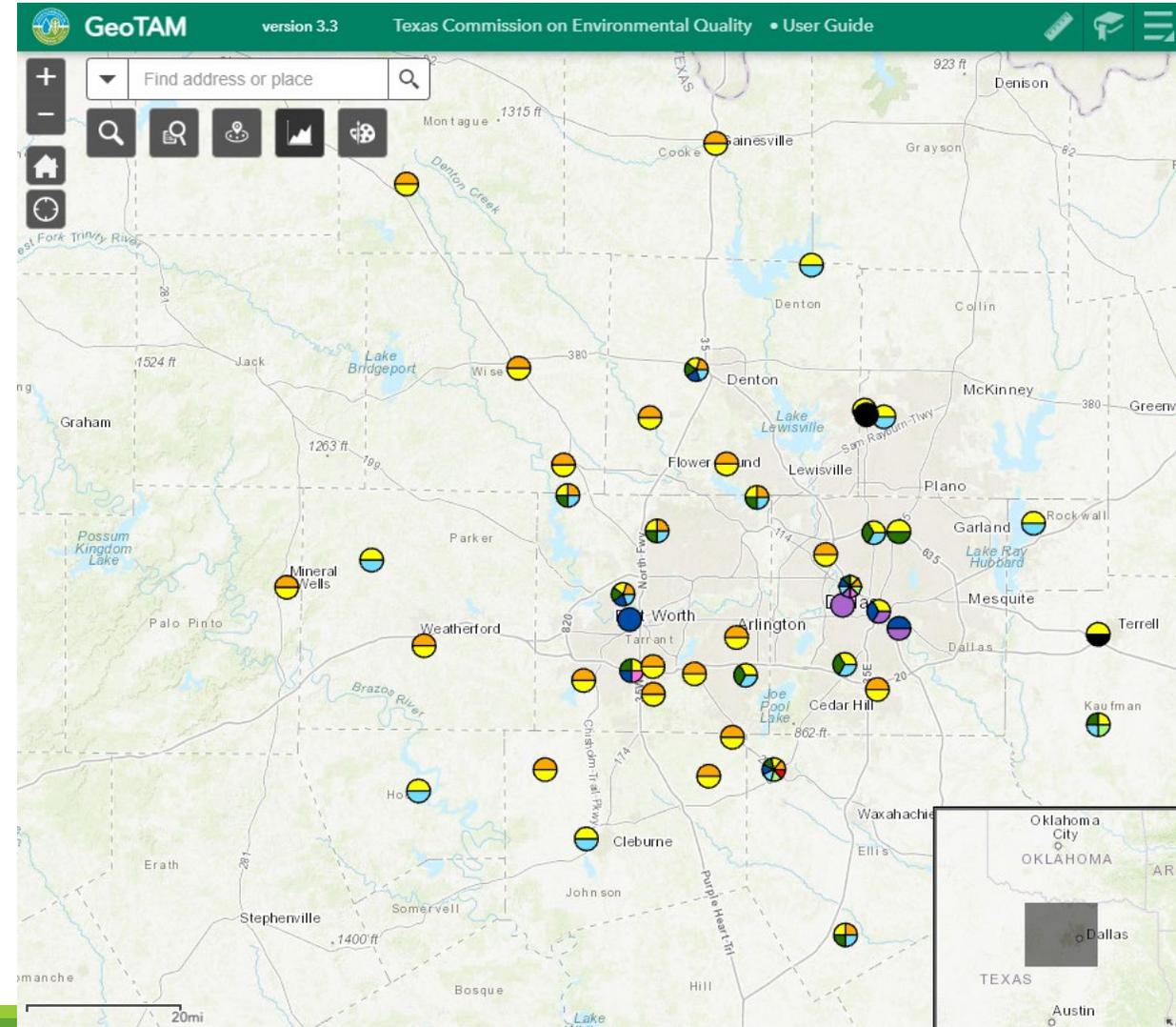


*Using current air monitoring comparison values (AMCVs)



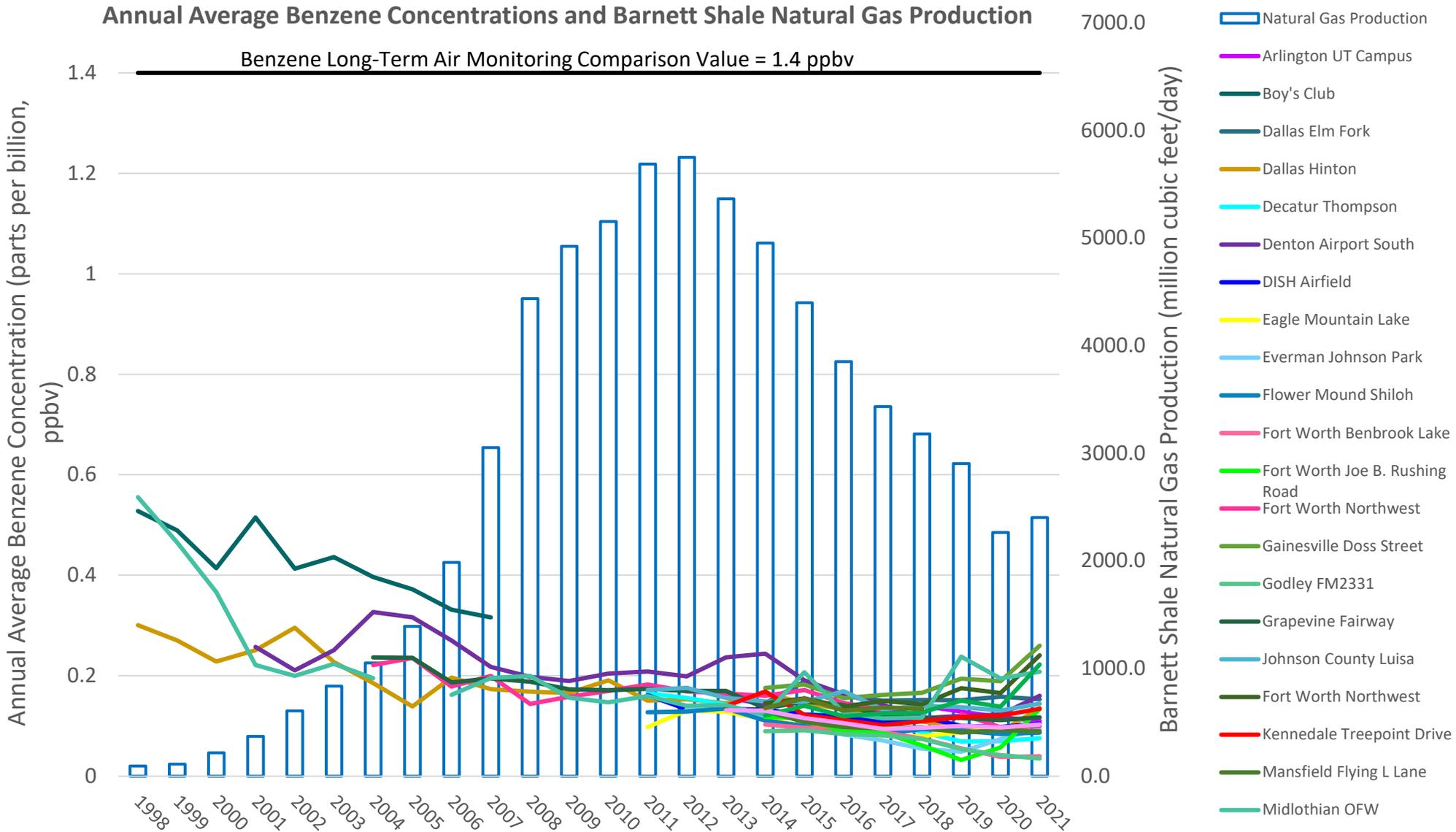
TCEQ substantially expanded ambient air toxics stationary monitoring in the Barnett Shale

- Fixed-site monitors in 2009 – 6 monitoring sites
 - 2 automated gas chromatographs (autoGCs)
 - 6 canister samplers (2 collocated with autoGCs)
 - 2 carbonyl samplers
- Fixed-site monitors by 2014 (and still present in 2023) – 26 monitoring sites
 - 15 autoGCs
 - 13 canister samplers (2 collocated with autoGCs)
 - 2 carbonyl samplers





NG Production had little effect on benzene concentrations





VOC levels from ambient monitors in the Barnett Shale are below levels of toxicological concern

- TCEQ Toxicology regularly reviews ambient air monitoring data to evaluate whether levels may impact human health or the environment
- The TCEQ evaluated the hourly, 24-hour, and annual average concentrations of monitored VOCs at the air toxics monitors in the Barnett Shale area
- From 2008 to 2021, no short- or long-term VOC concentrations in the Barnett Shale area exceeded their respective air monitoring comparison values at any of the monitors
- Annual monitoring evaluations can be found on the TCEQ Toxicology webpage: <https://www.tceq.texas.gov/toxicology/regmemo/AirMain.html> (the Barnett Shale air monitors are evaluated as part of TCEQ Region 4)

Research on the impact of NG production on air quality in the Barnett Shale



Research Question: Did NG development and production have any impact on air quality in the Barnett Shale?

Citation: Sabine S Lange, Lalita Shrestha, Nnamdi Nnoli, Stanley Aniagu, Swati Rawat, Darrell McCant. 2023. **Do shale oil and gas production activities impact ambient air quality? A comprehensive study of 12 years of chemical concentrations and well production data from the Barnett Shale region of Texas.** *Environ Int.* 175:107930. doi: 10.1016/j.envint.2023.107930.
<https://www.sciencedirect.com/science/article/pii/S0160412023002039?via%3Dihub>



Does NG activity impact air concentrations of chemicals?

- Emissions from NG production don't seem to be causing air concentrations of toxicological concern. But have the concentrations of chemicals in the air changed at all because of these operations?
- The current study involved evaluation of air concentrations of targeted analytes near active natural gas wells to study patterns of chemical profiles in the area.
- The goal of this study was to determine if oil and NG activity has an impact on the types and concentrations of chemicals in ambient air in the Barnett Shale area.



Data used to study research question

➤ Ambient air monitoring data:

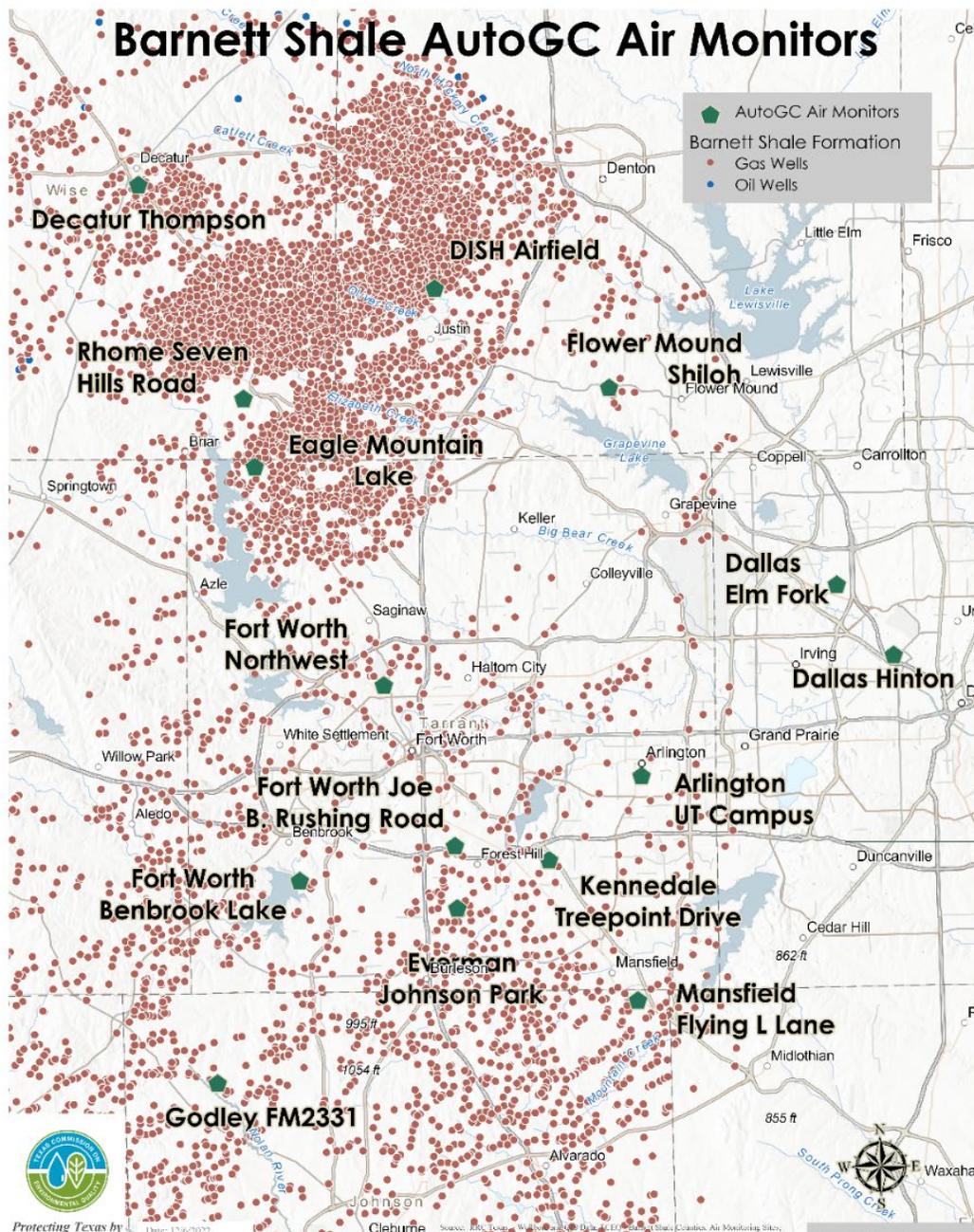
- 15 automated gas chromatograph (autoGC) monitors
- Years 2008 – 2019
- Total of 122 monitor-years of data
- From <https://www17.tceq.texas.gov/tamis/index.cfm?fuseaction=home.welcome>

➤ NG well data:

- Number of active wells within 2 miles of each monitor
- NG production data for wells within 2 miles of each monitor
- Condensate production data for wells within 2 miles of each monitor
- From <http://webapps.rrc.texas.gov/PDQ/home.do>

➤ Urbanicity classification:

- Urban, suburban, and rural
- Provides information about urban sources such as vehicular emissions



Ambient air monitors had varying amounts of nearby NG activity



Barnett Shale AutoGC Monitors by Active Well Number

	Monitor	Years of Data	Urbanicity Classification	# Active Wells within 2 Miles	NG Production within 2 Miles (MMcf)
1	DISH Airfield	2010-2019	Rural	176	14,154
2	Eagle Mountain Lake	2010-2019	Rural	168	17,198
3	Decatur Thompson	2011-2019	Suburban	105	5,038
4	Mansfield Flying L Lane	2013-2019	Rural	97	5,860
5	Everman Johnson Park	2012-2019	Suburban	91	10,154
6	Kennedale Treepoint Drive	2013-2019	Suburban	82	20,353
7	Fort Worth Northwest	2008-2019	Urban	58	11,215
8	Fort Worth Joe B. Rushing Road	2014-2019	Suburban	50	4,903
9	Flower Mound Shiloh	2011-2019	Suburban	40	4,716
10	Rhome Seven Hills Road	2013-2019	Rural	38	2,909
11	Arlington UT Campus	2013-2019	Urban	35	6,804
12	Fort Worth Benbrook Lake	2014-2019	Suburban	31	4,513
13	Godley FM2331	2014-2019	Rural	30	1,673
14	Dallas Elm Fork	2014-2019	Urban	0	0
15	Dallas Hinton	2008-2019	Urban	0	0

Control monitors (no nearby NG sources)



Barnett Shale AutoGC Monitors by NG Production

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Control monitors (no nearby NG sources)



Some monitors with more nearby NG production had fewer nearby wells

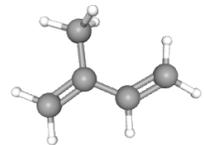
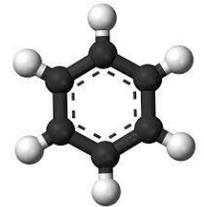
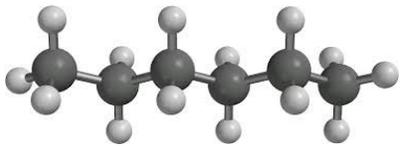
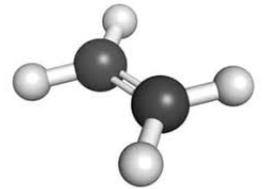
- Wells can produce varying amounts of NG
- Having some monitors that are higher on the list of NG production, and lower on the list of active wells (and vice versa) helps to determine whether chemical concentrations are better predicted by the presence of an active well, or by how much NG is produced

Monitor	Rank for # Active Wells	Rank for NG Production
DISH Airfield	1	3
Eagle Mountain Lake	2	2
Decatur Thompson	3	8
Mansfield Flying L Lane	4	7
Everman Johnson Park	5	5
Kennedale Treepoint Drive	6	1
Fort Worth Northwest	7	4
Fort Worth Joe B. Rushing Road	8	9
Flower Mound Shiloh	9	10
Rhome Seven Hills Road	10	12
Arlington UT Campus	11	6
Fort Worth Benbrook Lake	12	11
Godley FM2331	13	13

Analysis focused on 17 Chemicals

➤ Evaluated concentrations of 15 most abundant chemicals, plus two more (m/p-xylene and 2,2,4-trimethylpentane) added as markers of vehicular traffic emissions.

Chemical	Type		Chemical	Type
Ethane	C2 alkane		Acetylene	C2 alkyne
Propane	C3 alkane		Ethylene	C2 alkene
Isobutane	C4 alkane		Propylene	C3 alkene
n-Butane	C4 alkane			
Isopentane	C5 alkane		Benzene	C6 aromatic
n-Pentane	C5 alkane		Toluene	C7 aromatic
n-Hexane	C6 alkane		m/p-Xylene	C8 aromatic
Methylcyclohexane	C6 alkane			
n-Heptane	C7 alkane		Isoprene	Terpene
2,2,4-Trimethyl pentane	C8 alkane			





Evaluated correlations between chemical concentrations and well activity

Correlation Analysis

- Mean and peak (95th percentile) annual chemical concentrations compared to NG production, condensate production, or number of active wells within 2 miles

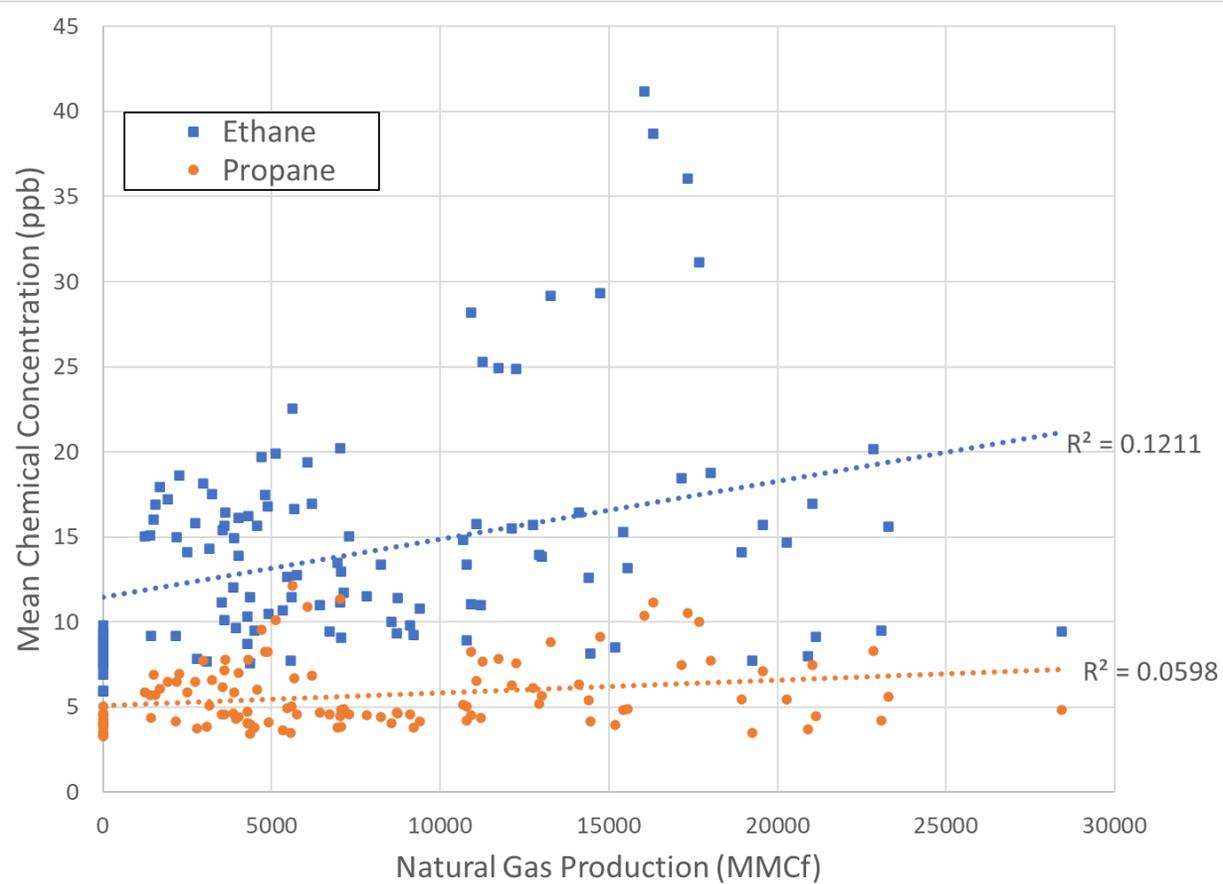
No significant correlations between NG production and mean or peak chemical concentrations

Some alkane hydrocarbon concentrations were correlated with active well number

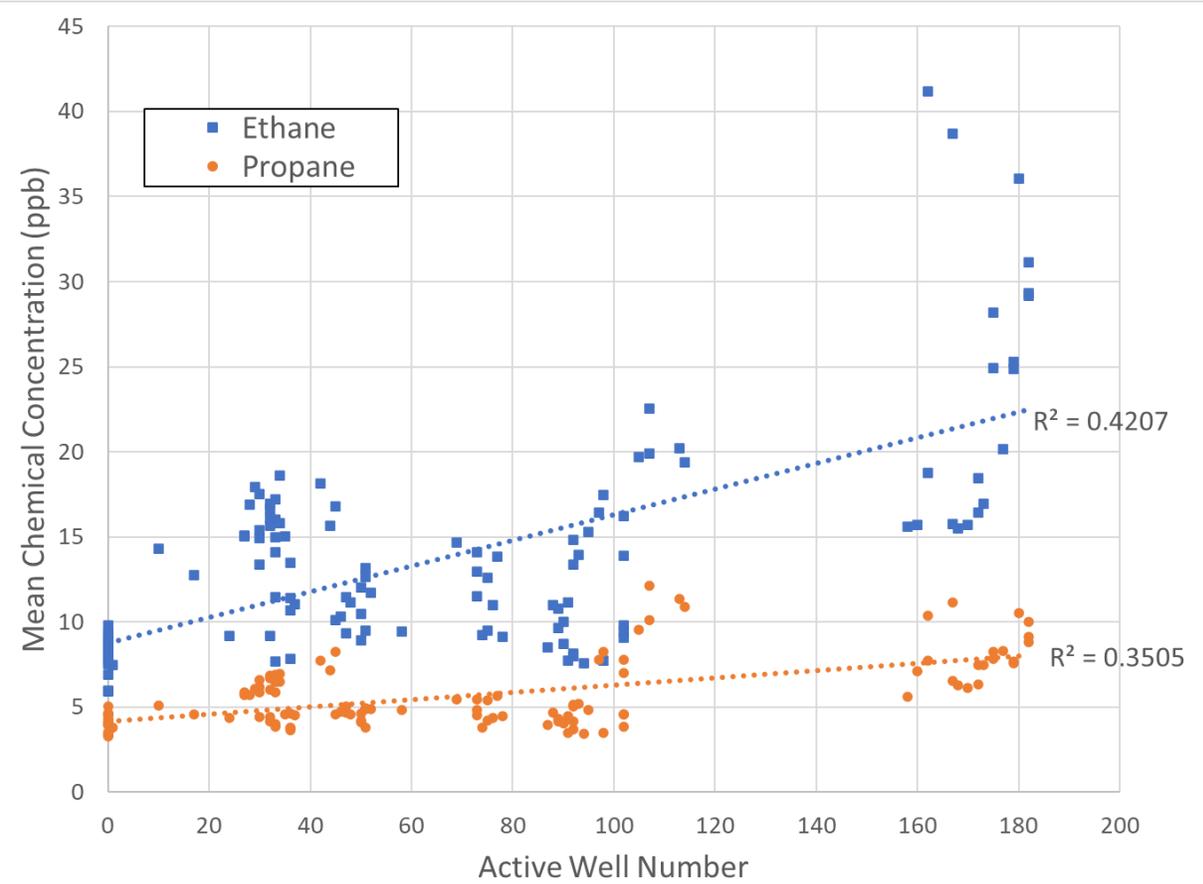


Mean concentrations of alkanes were correlated with active well number but not NG production

Correlation with NG Production



Correlation with Active Well Number





Higher correlations between active wells and lighter (more abundant) alkanes

- Active well number was positively correlated with mean & peak *ethane, isobutane, methylcyclohexane, propane, n-hexane*; peak only *n-butane, n-heptane, n-pentane*

Light Chain Alkane	Abundance in NG (%)	Correlation between Mean Conc & Active Well Number (R ²)	Correlation between Peak Conc & Active Well Number (R ²)	Correlation between Mean Conc & NG Production (R ²)
Ethane	5.03	0.421*	0.394*	0.121
Propane	2.13	0.351*	0.392*	0.06
Isobutane	0.38	0.214*	0.294*	0.05

* correlation coefficients statistically significant

- Altogether, the data suggests that active wells are predominantly markers of NG emissions.



Which well and urbanicity variables together predict average chemical concentrations?

- Multiple linear regression using urbanicity and well activity (explanatory variables) to predict changes in chemical concentrations (dependent variables)

Independent (Explanatory) Variables

Active Well Number within 2 Miles
NG Production within 2 Miles
Condensate Production within 2 Miles
Urban Area
Suburban Area
Rural Area



Dependent Variables: Mean or Peak Chemical Concentrations

Ethane	Acetylene
Propane	Ethylene
Isobutane	Propylene
n-Butane	
Isopentane	Benzene
n-Pentane	Toluene
n-Hexane	m/p-Xylene
Methylcyclohexane	
n-Heptane	Isoprene
2,2,4-Trimethyl pentane	Acetylene



Light chain alkane concentrations mostly impacted by well activity

- Higher mean concentrations of C2 to C4 alkanes were predicted ($R^2 \approx 0.45$ to 0.6) by increased well activity, and somewhat by rural locations

Increasing Amounts of:

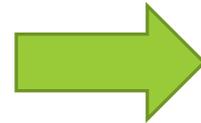
Active Well Numbers or NG Production

Condensate Production



Monitor Locations in:

Rural Areas



Correlated with higher mean concentrations of:

Chemical	Type
Ethane	C2 alkane
Propane	C3 alkane
Isobutane	C4 alkane





Heavier chain alkane concentrations impacted by well activity and urban areas

- Higher mean concentrations of C4 to C7 alkanes were predicted ($R^2 \approx 0.48$ to 0.55) by increased well activity, and somewhat by urban locations (likely influenced by vehicular exhaust)

Increasing Amounts of:

Active Well Numbers

Condensate Production

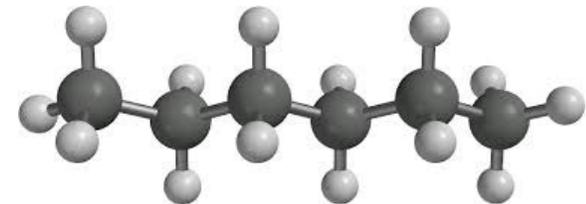


Monitor Locations in:

Urban Areas

Correlated with higher mean concentrations of:

Chemical	Type
n-Butane	C4 alkane
n-Pentane	C5 alkane
n-Hexane	C6 alkane
Methylcyclohexane	C6 alkane
n-Heptane	C7 alkane





Alkene and alkyne concentrations impacted by urban areas, not well activity

- Higher mean concentrations of alkynes and alkenes were predicted ($R^2 \approx 0.54$ to 0.76) by monitor presence in urban locations (vehicular exhaust is a known source of these chemicals)

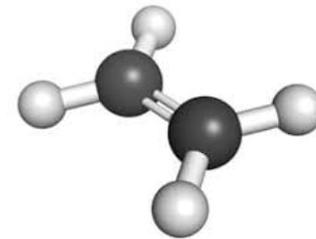
Monitor Locations in:

Urban Areas



Correlated with higher mean concentrations of:

Chemical	Type
Acetylene	C2 alkyne
Ethylene	C2 alkene
Propylene	C3 alkene

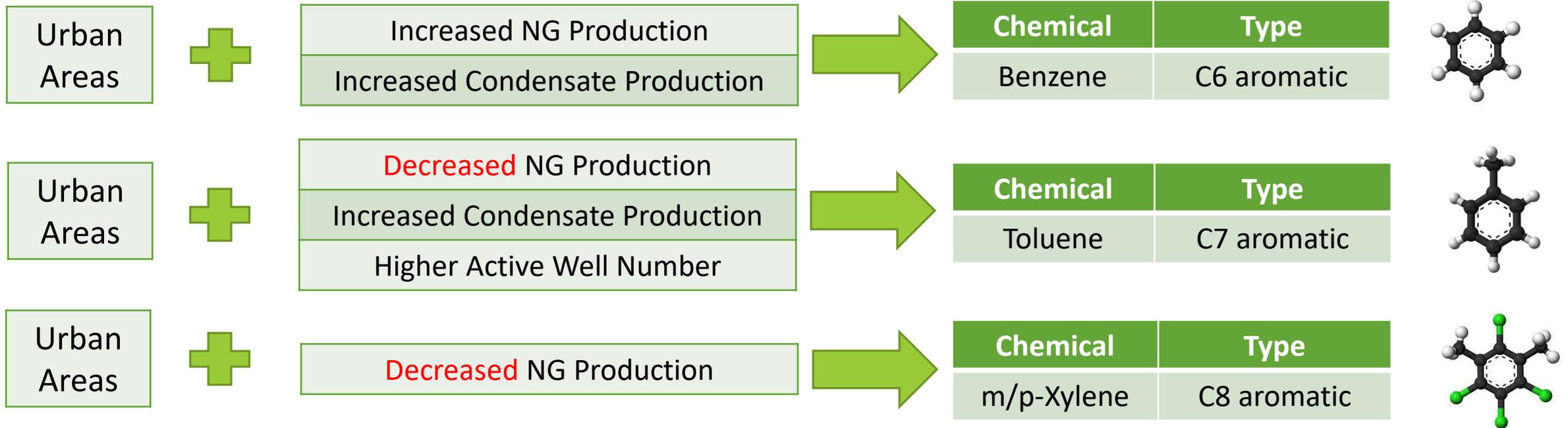




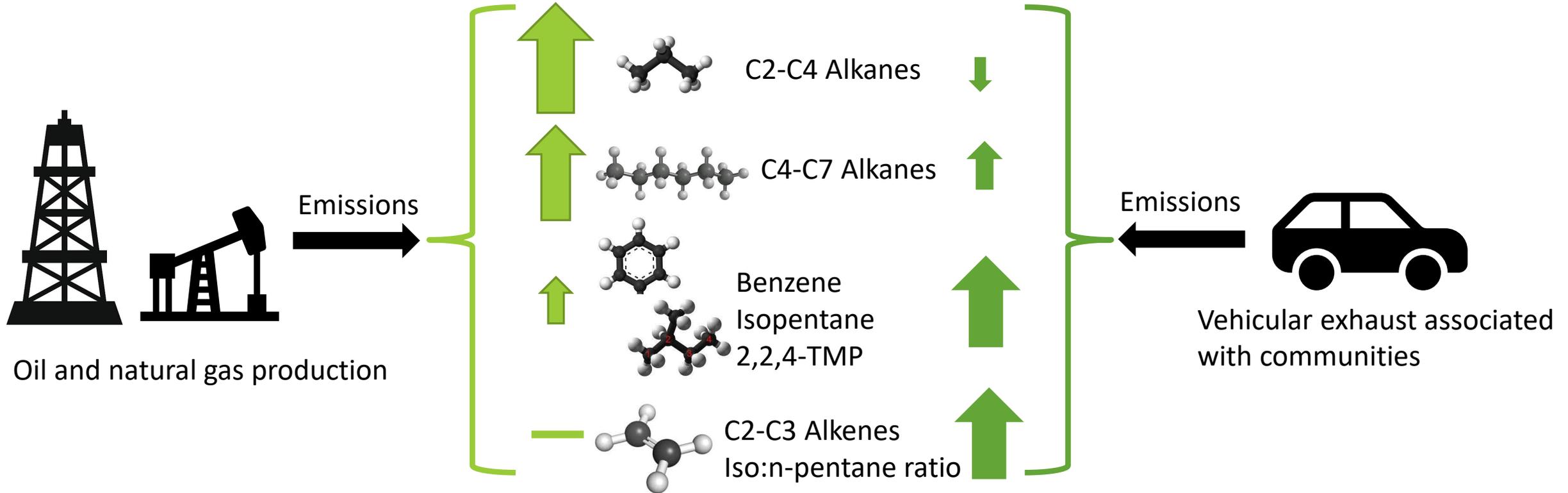
No clear pattern of association with concentrations of aromatics as a group and well activity or urbanicity

- Aromatic compounds are often a source of concern for their potential to cause health effects
- Benzene, toluene, and xylenes all had different patterns of impact by well variables, although all were increased in urban areas (they are emitted by vehicles)

Correlated with higher mean concentrations of:



Overall pattern of well activity and urbanicity impacts on chemical concentrations





Summary

- Natural gas production in the Barnett Shale increased substantially from the mid-2000s, moving into populated areas
- Because of concerns about effects on air quality that could impact human health, TCEQ conducted extensive monitoring in the area
- TCEQ's monitoring showed that the majority of measured chemical concentrations were below levels of toxicological concern
- TCEQ Toxicology conducted a research study on whether nearby well activity impacted measured chemical concentrations
- The research showed that alkanes (most abundant in NG) increase with nearby active wells, but alkynes/alkenes are impacted only by urban status
- Aromatics (of concern because of their toxicity) as a group do not show consistent patterns of impacts by well activity but were higher in urban areas



Acknowledgements

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 - Stanley Aniagu, PhD
 - Darrell McCant, MPH
 - Lalita Shrestha, PhD
 - Swati Rawat, PhD



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Questions?
