Unconventional Gas & Oil Drilling (UGOD) in the Marcellus Shale and Health Disparities

Center of Excellence in Environmental Toxicology:
Environmental Health Sciences Core Center
http://ceet.upenn.edu/

Director: Trevor M. Penning, Ph.D.

NIH National Institute of Environmental Health Sciences

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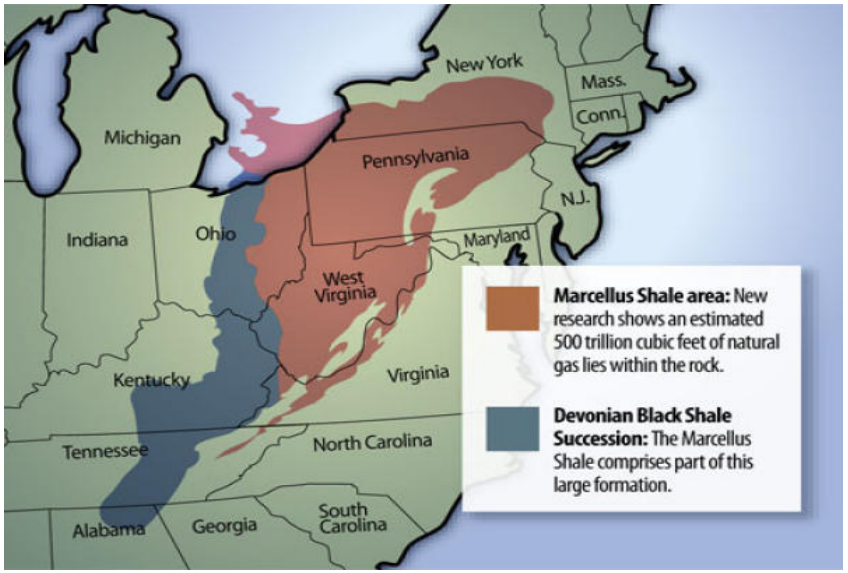
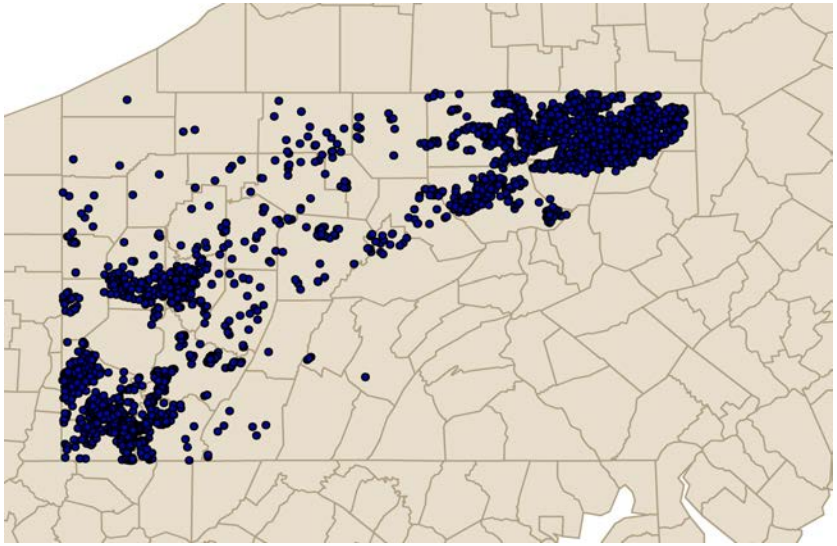
What is the Marcellus Shale?



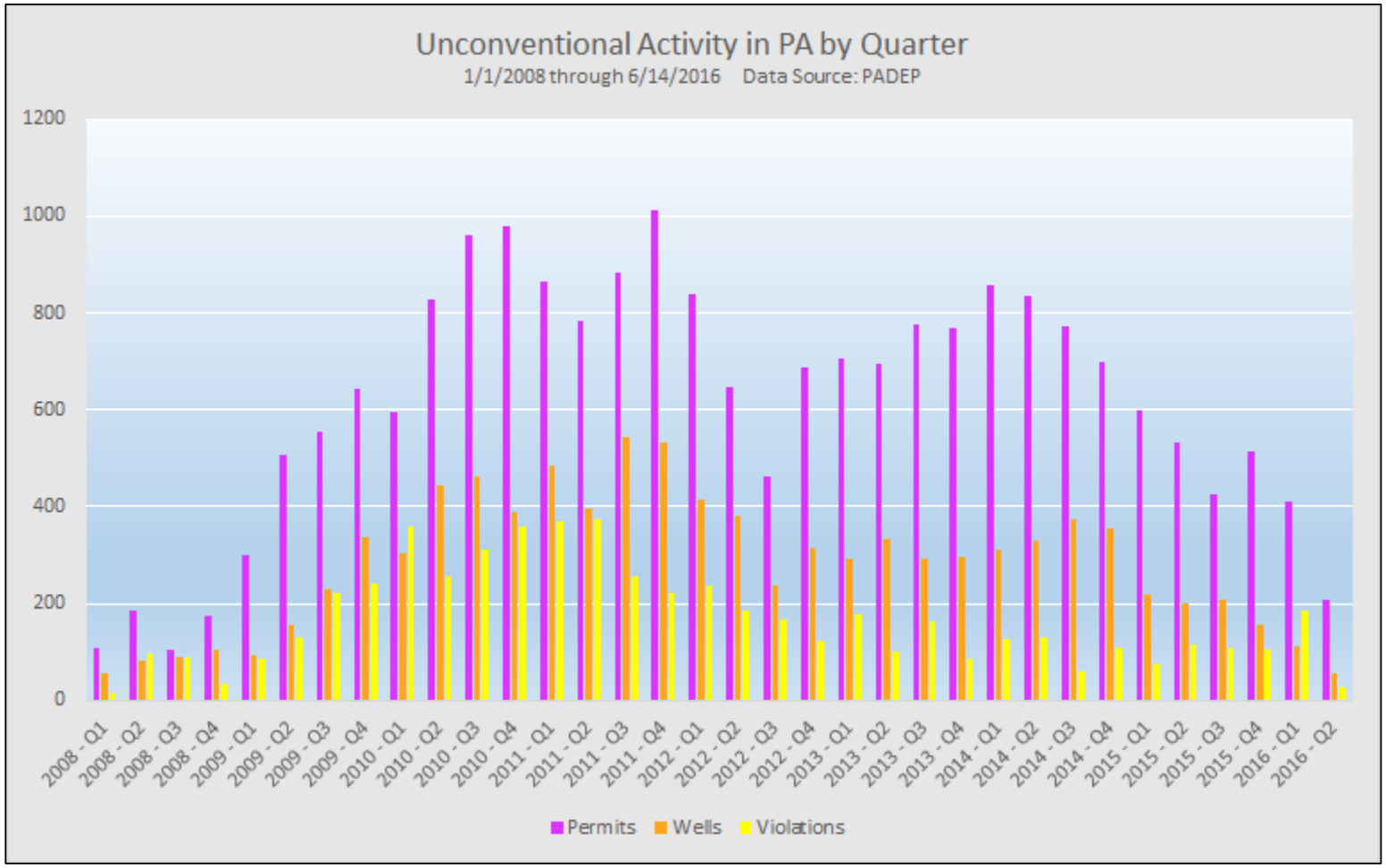
- Half the land mass of Pennsylvania
- 22,835 sq. miles
- 84 trillion cubic ft of natural gas
- Price is $8 - $16 per thousand cu. ft.
- Enough for the entire US population for 4 yrs
- Shale sedimentary rock
- Organic rich and porous
- Contains thermogenic methane

The Drill Rig

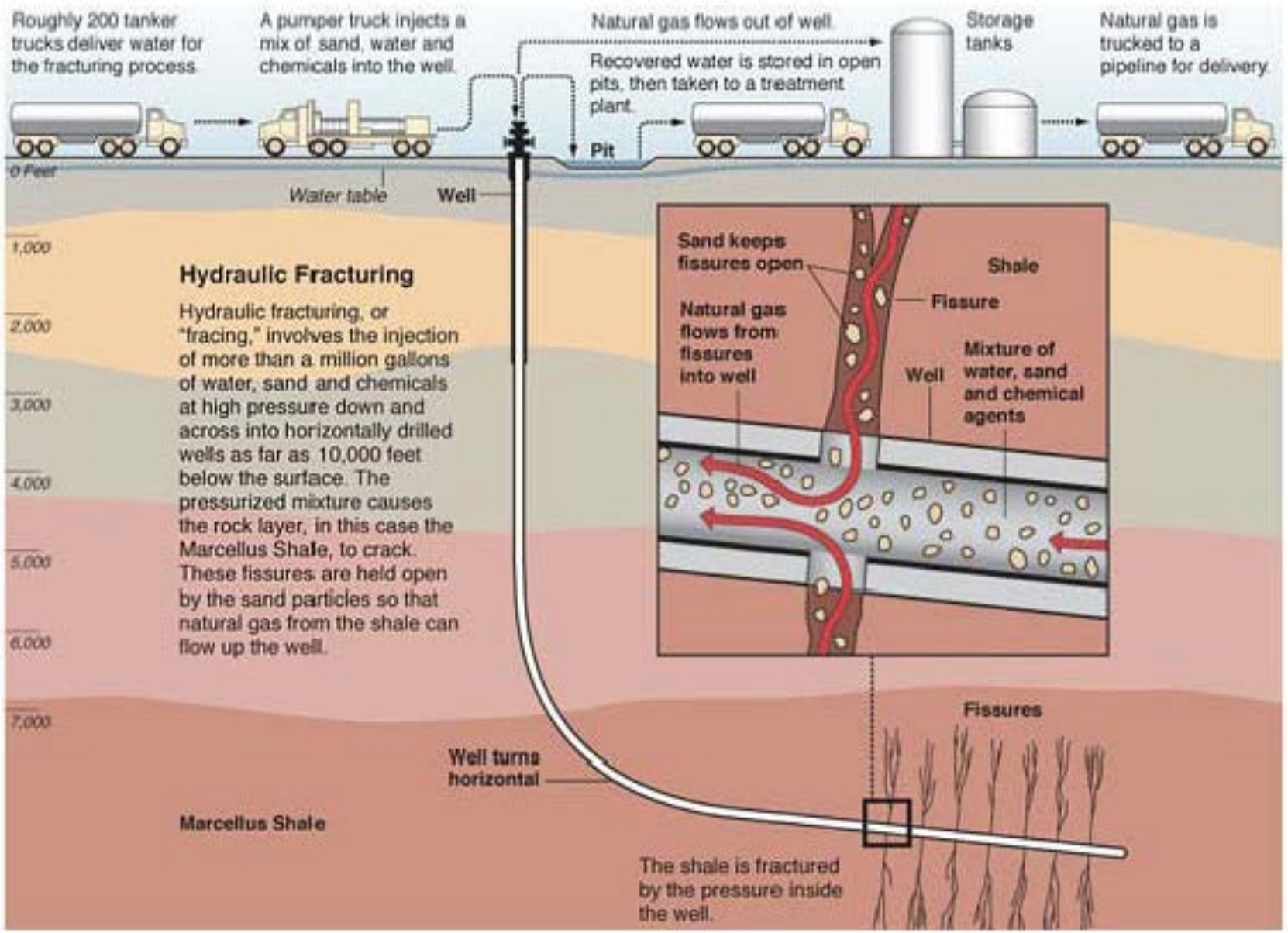


- Drill head and pad 5-10 acre plot
- Ideally one per sq mile
- Saturating drilling 8 per square mile
- High density drilling in Susquehanna Co, PA
- Pennsylvania would need 22,000 to 160,000 drill rigs
- Active wells 2008-2014 > 12,000

Unconventional Gas Drilling in PA



The "Fracking" Process



The Holding Ponds for Flow-Back Water

- Need 5M gallons water per well head
- Each truck carries 4,000 gallons water
- 1250 truck loads
- Proppant: 1.5 M pounds (silica/sand)
- Requires 750 truck loads
- X1 to x10 “frack” episodes per well
- <30% in the flow back water held in pits

Diesel Trucking

Diesel Trucks Deliver:

- Drill-Rigs
- Proppant
- Fracking chemicals
- Compressor parts
- Gas line piping

Diesel Trucks Remove:

- Natural gas
- Waste water

Night-Time Flaring

- Well is tested by flaring
- Release of methane: BETEX (benzene, ethylbenzene, toluene and xylene)
- Move towards marketing "wet-gas" a larger portion of methane is burned
- Release of hydrogen sulfide

2014-Emissions Inventory for UGOD Released in PA

Year	Well-sites reporting	Midstream Facilities reporting	Carbon Monoxide (CO)	Nitrogen Oxides (NOx)	PM_{10}	Sulfur Dioxide (SO_2)	VOC's	Methane
2011	9,037	150	6,852	16,542	577	122	2,820	NA
2012	8.996	453	7,350	16,361	600	101	4,024	123,684
2013	10,275	447	6,606	17,659	670	159	4,790	107.945
2014	10,009	508	8,230	21,663	864	263	6,389	109,555

Expressed as Tons per year

Released by PA-DEP: 08-19-16

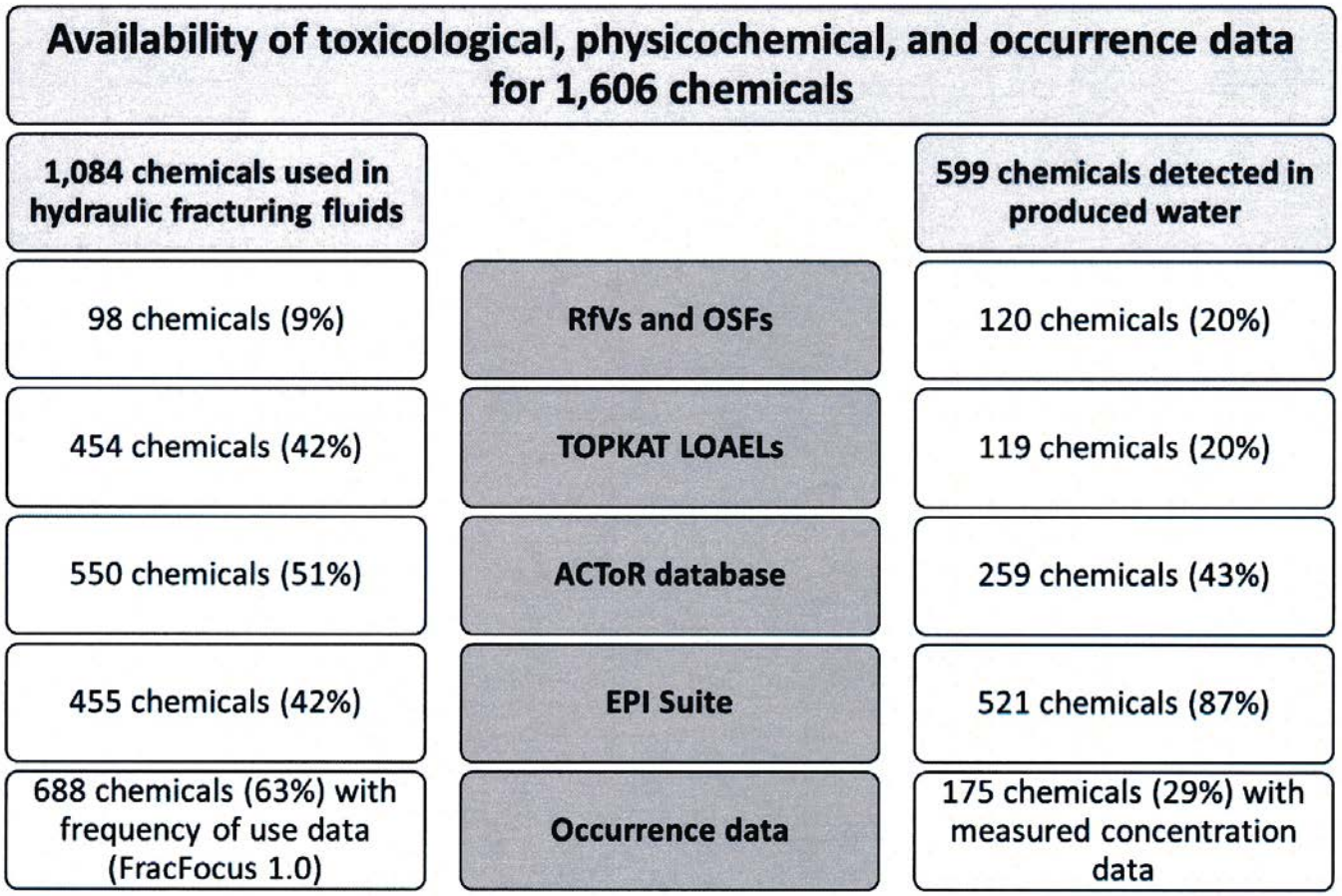
Potential for Air Pollution –VOCs and PM 2.5

- Photochemistry between VOCs and nitrogen oxides generate ground level ozone

- Ground level ozone exacerbates underlying asthma and COPD and causes lung injury

- Diesel Exhaust – Transportation and Compressor Stations
  - -VOCs
  - -Butadiene, acrolein, formaldehyde
  - -PM2.5: carbonaecous core adsorbs PAH, nitro-PAH and metals
  - -PM2.5: lodge in the deep lung (bronchioles and alveoli)
  - -PM2.5: invoke an inflammatory response exacerbate lung disease
  - -Diesel exhaust: Group 1: carcinogenic in humans (IARC)

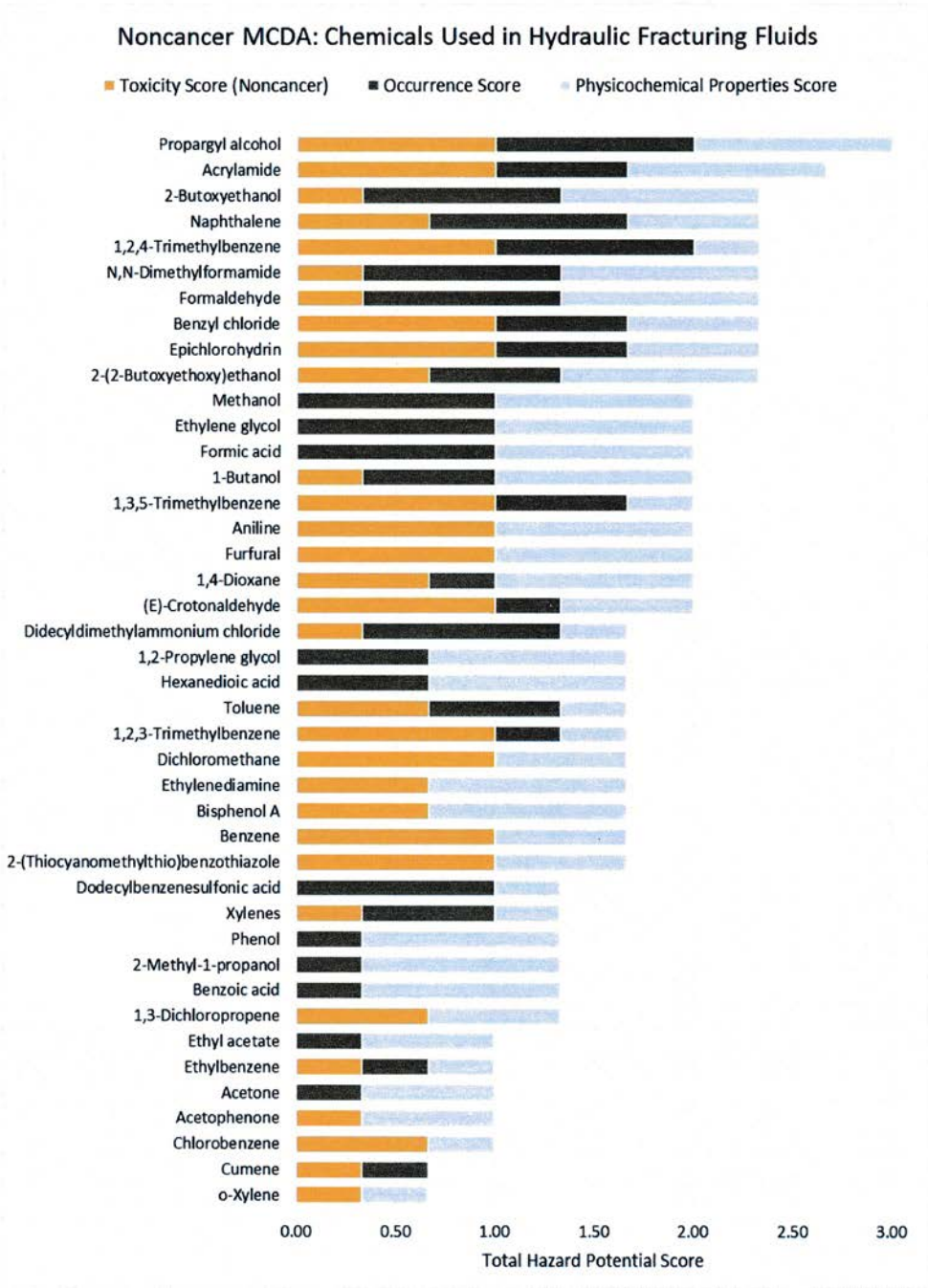
Additives in Fracking Fluid



FracFocus.org Chemical Disclosure Registry- 35,957 disclosures; 1,084 different chemicals used; only 9% have RfVs and OSFs - Source US EPA 2016

Common Additives in Fracking Fluid

Table 2: Fracturing Fluid Additives, Main Compounds and Common Uses.		
Additive Type	**Main Compound**	**Common Use of Main Compound**
Acid	Hydrochloric acid or muriatic acid	Swimming pool chemical and cleaner
Biocide	Glutaraldehyde	Cold sterilant in health care industry
Breaker	Sodium Chloride	Food preservative
Corrosion inhibitor	N,n-dimethyl formamide	Used as a crystallization medium in Pharmaceutical Industry
Friction Reducer	Petroleum distillate	Cosmetics including hair, make-up, nail and skin products
Gel	Guar gum or hydroxyethyl cellulose	Thickener used in cosmetics, sauces and salad dressings.
Iron Control	2-hydroxy-1,2,3-propanetricaboxylic acid	Citric Acid it is used to remove lime deposits Lemon Juice ~7% Citric Acid
Oxygen scavenger	Ammonium bisulfite	Used in cosmetics
Proppant	Silica, quartz sand	Play Sand
Scale inhibitor	Ethylene glycol	Automotive antifreeze and de-icing agent



Fracking Fluid

- 0.49% of fracking fluid contains a mixture of chemicals
- 95 tons of chemicals are used per well base
- Composition is a trade-secret
- Some chemicals listed by class and not by CAS registry number
- Multi-Criteria Decision Analysis (MCDA) Framework
  -Toxicity Score (Rfv, TTC, LOC)
  -Occurrence Score (frequency of use)
  -Physiochemical properties (mobility, volatility, persistence)

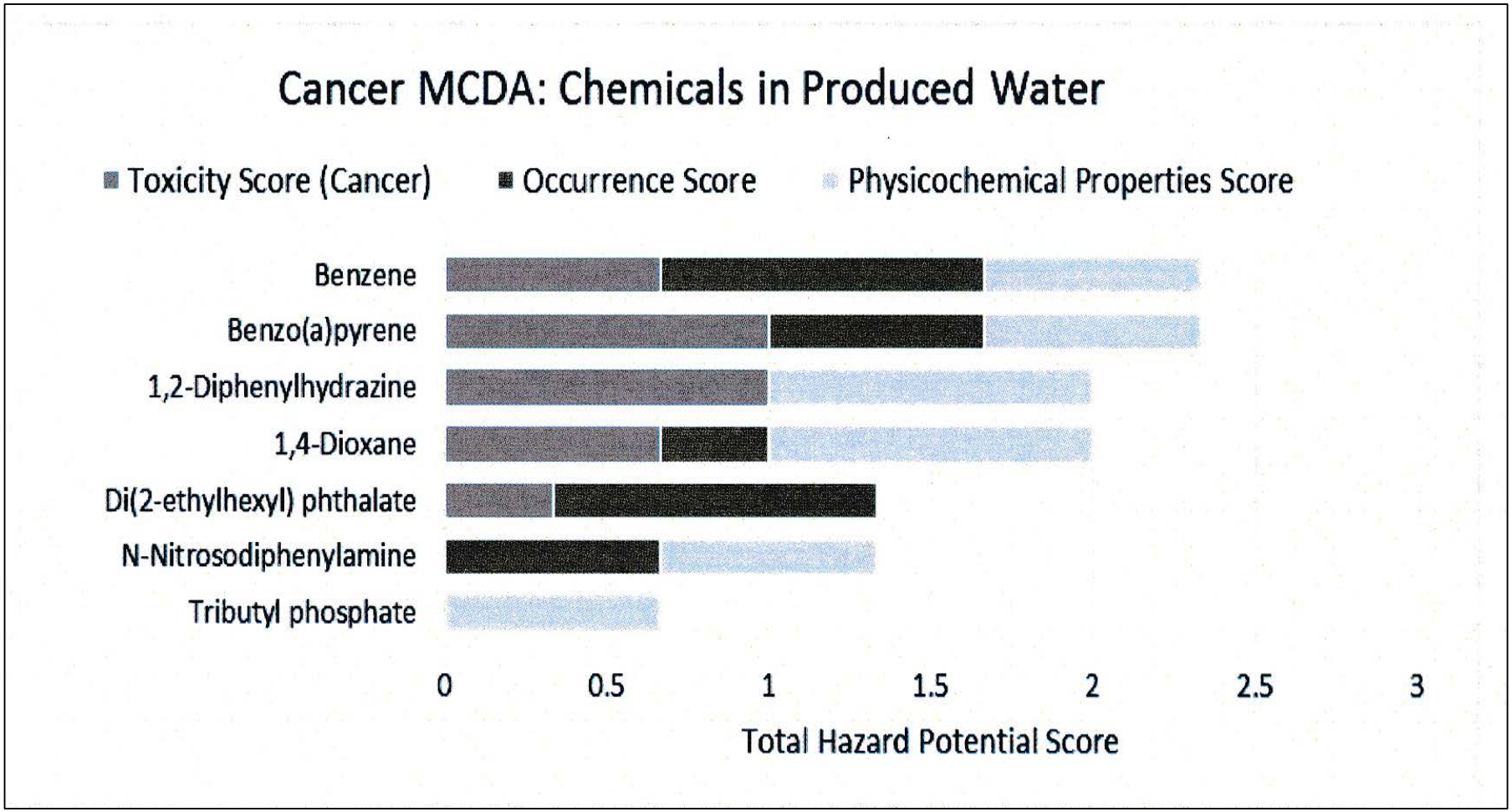
(Source US-EPA)

Frequency of HF Chemical Use and Critical Oral Effects

Chemical Name	% Disclosures	Rfv (mg/Kg)	Critical Effect	Organ System
Methanol	73%	2	Extra cervical ribs	Skeletal
Ethylene glycol	47%	2	Kidney toxicity	Kidney
Propargyl alcohol	33%	0,002	Renal and heaptotoxicity	Kidney & Liver
2-Butoxyethanol	23%	0.1	Hemosiderin deposition in liver	Liver
Naphthalene	19%	0.02	Decreased terminal body wt	Whole body
1,2,4-trimethylbenzene	13%	0.01	Decreased pain sensitivity	Nervous system
Quaternary ammonium salts	12%	0.44	Decreased body wt	Whole Body
Formic Acid	11%	0.9	Reproductive toxicity	Reproductive
Sodium chlorite	11%	0.03	Neurodevelopmental	CNS

Only 9/31 top used chemicals have established critical oral health effects-US EPA (2016)

Cancer MCDA in Produce Water



Source-US-EPA 2016

Potential for Water Pollution- Flow-Back Fluid

Typical Concentrations of "Flow Back" Constituents in Gas Well Water in Marcellus Shale based on Limited Samples from PA and WV Wells [14]

Chemical	Min	Median	Max	Units	MCL[15]	Max Excess
Arsenic	0.09	0.1065	0.123	mg/L	.010	12.3 x
Barium	0.553	661.5	15700	mg/L	2	7,850 x
Benzene	15.7	479.5	1950	ug/L	5	390 x
Cadmium	0.009	0.032	1.2	mg/L	.005	340 x
Chromium	0.122	5.0	5.9	mg/L	0.1	59 x
Ethyl benzene	3.3	53.6	164	ug/L	0.7	234 x
Fluoride	5.23	392.615	780	mg/L	4	195 x
Lead	0.02	0.24	0.46	mg/L	0.015	31 x
Toluene	2.3	833	3190	ug/L	1	3,190 x
Xylene	16	487	2670	ug/L	10	267 x

MCL = maximum contaminant level ppm

Potential for Water Pollution- Flow-Back Fluid

Concentrations of NORM Constituents Based on Limited Samples from Pennsylvania and West Virginia Marcellus Shale[17]

Radioisotope	Minimum	Maximum	Units	USEPA PRG [18,19] (health risk)	Max Excess
Gross alpha	22.41	18.950	pCi/L	15	1,263 x
Total alpha radium	3.8	7.445	pCi/L	5	362 x
Radium-226	2.58	33	pCi/L	0.000833	40,097 x
Radium-228	1.15	18.41	pCi/L	0.0458	402 x

(NORM = Naturally Occurring Radioactive Material)
(PRG = Preliminary Remediation Goals)

EHSCC Hydraulic Fracturing ICWG

- Driven by an emerging environmental public health threat
- Community-driven concern
- Required spectrum of expertise: mechanistic toxicology; epidemiology; exposure science; social science; environmental law; regulatory science; and public health
- Galvanized 16/20 EHSCC to work together
- Resourced with inter-Center Pilot Projects & P30 Supplements

Deliverables

- High profile papers in EHP and PLoS One: Health Care Utilization Study >22,000 downloads
- Consortium of Health and Energy Research (CHER)-Judy Zelikoff-NYU
- Written and oral comments on “EPA Assessment on the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources”- EPA SAB

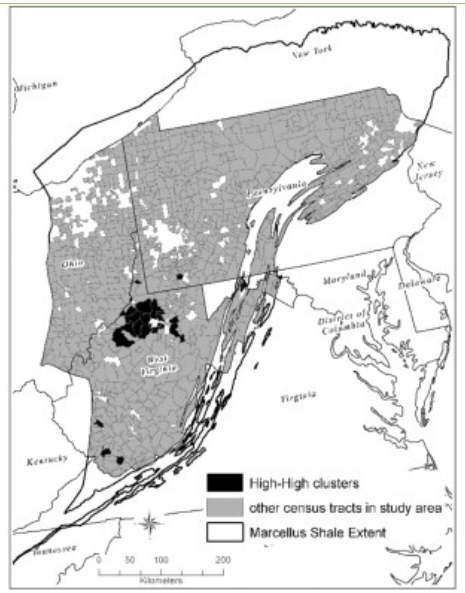
Health Disparity

Disparities exist when differences in health outcomes or health determinants are observed between populations

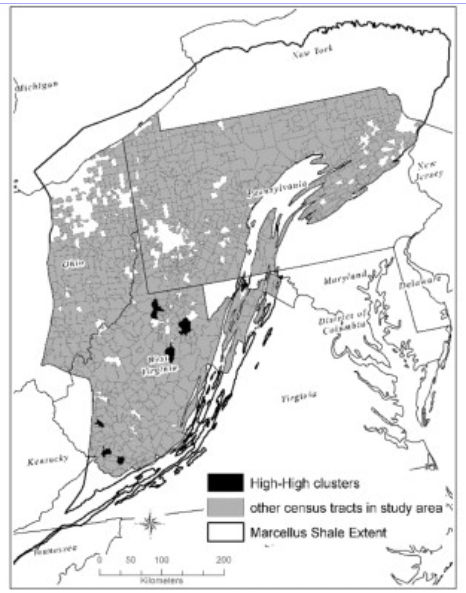
- **-race and ethnicity**
- **-sexual orientation**
- **-age and disability**
- **-socioeconomic status**
- **-geographic location**
- **-exposures**

(CDC-Health Disparity and Inequalities Reports)

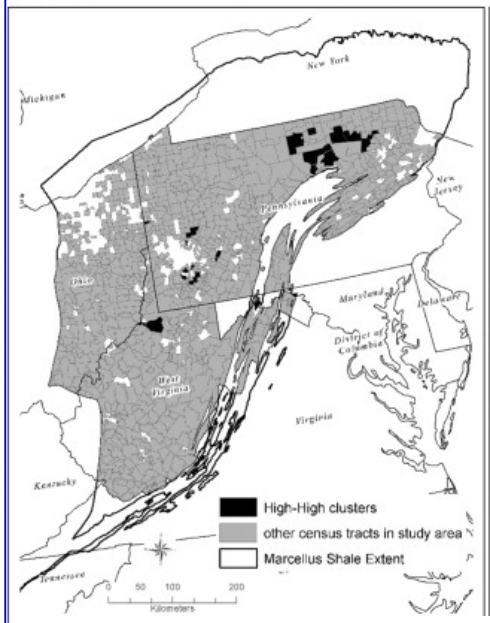
Health determinants in Marcellus Shale



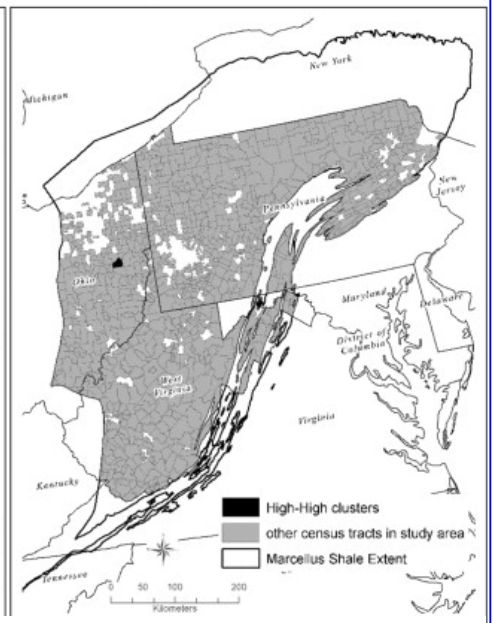
% below poverty level



% without HS diploma



% above 65 yrs of age



% below 15 yrs of age

- Examined residential census tracks In rural areas
- Conducted spatial autocorrelation for health determinants with well density

Yelena Ogneva-Himmelberger, Liyao Huang-

Applied Geography, 60, 2015, 165–174

RESEARCH ARTICLE

Unconventional Gas and Oil Drilling Is Associated with Increased Hospital Utilization Rates

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PLoS ONE 10, e0131093. Downloaded > 22,000 times

Hypotheses

Increases in health care utilization are associated with number of wells and well-density in Pennsylvania counties and zip codes.

Objectives

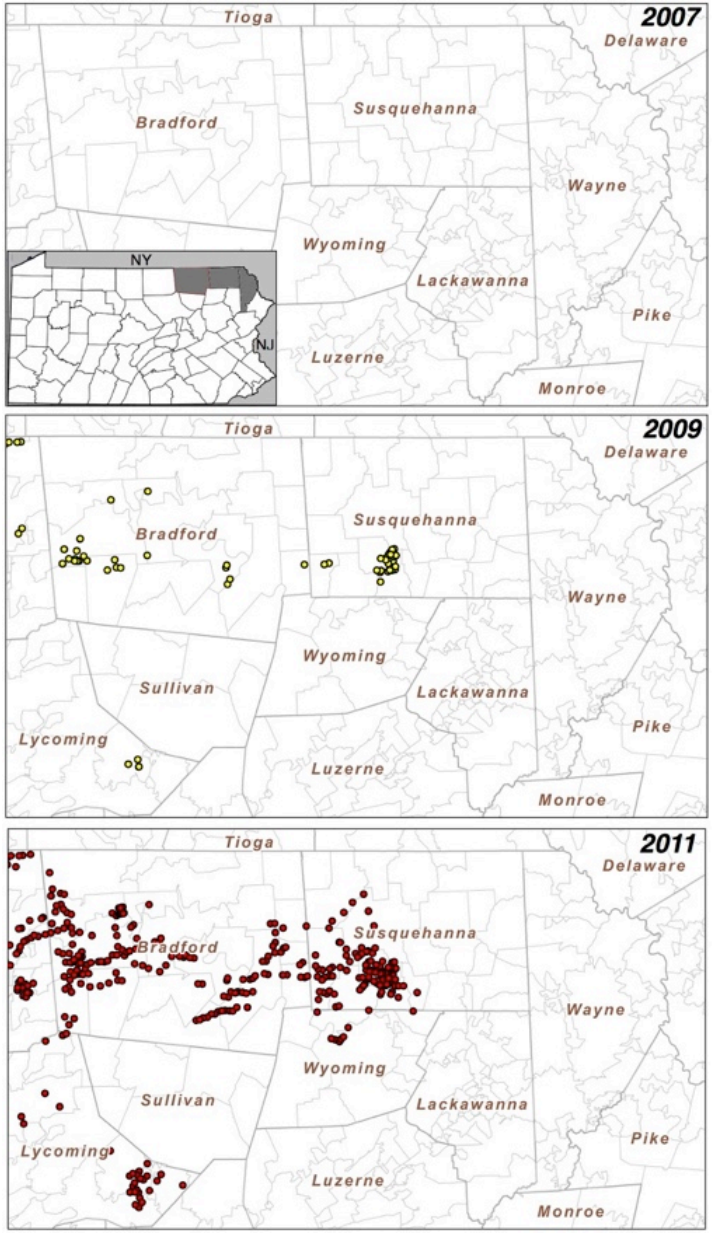
1. Determine increase in UGOD activity in 3 PA counties matched in demographics for the period 2007-2011 where one county serves as a control

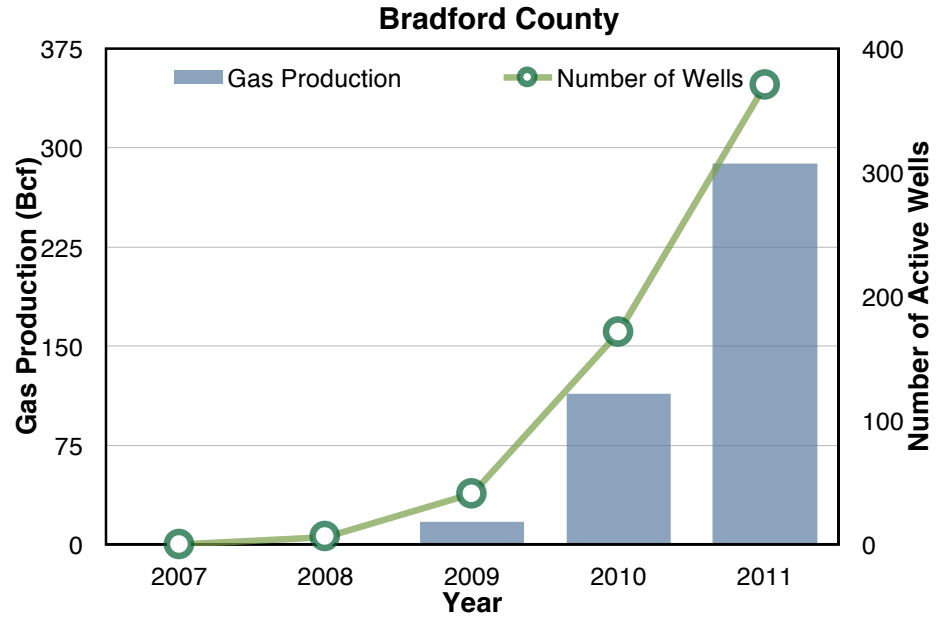
2. Examine all inpatient billable insurance records for the 3 counties and group by medical category over 5 years (n= 92,850) obtained from Truven Health Analytics

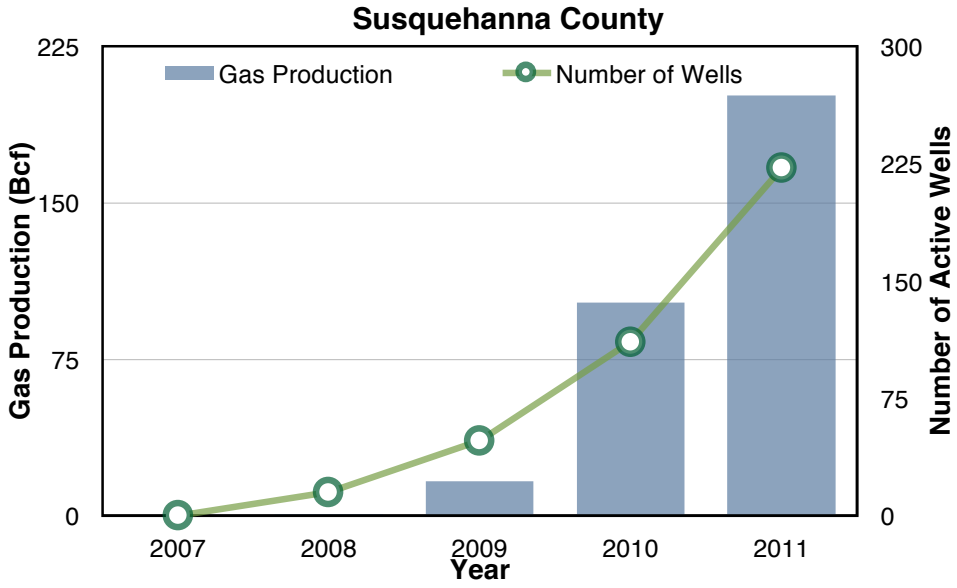
3. Determine whether well number or well density by zip-code is associated with changes in health care utilization

4. Can the changes in utilization be associated with suspected air or water pollution

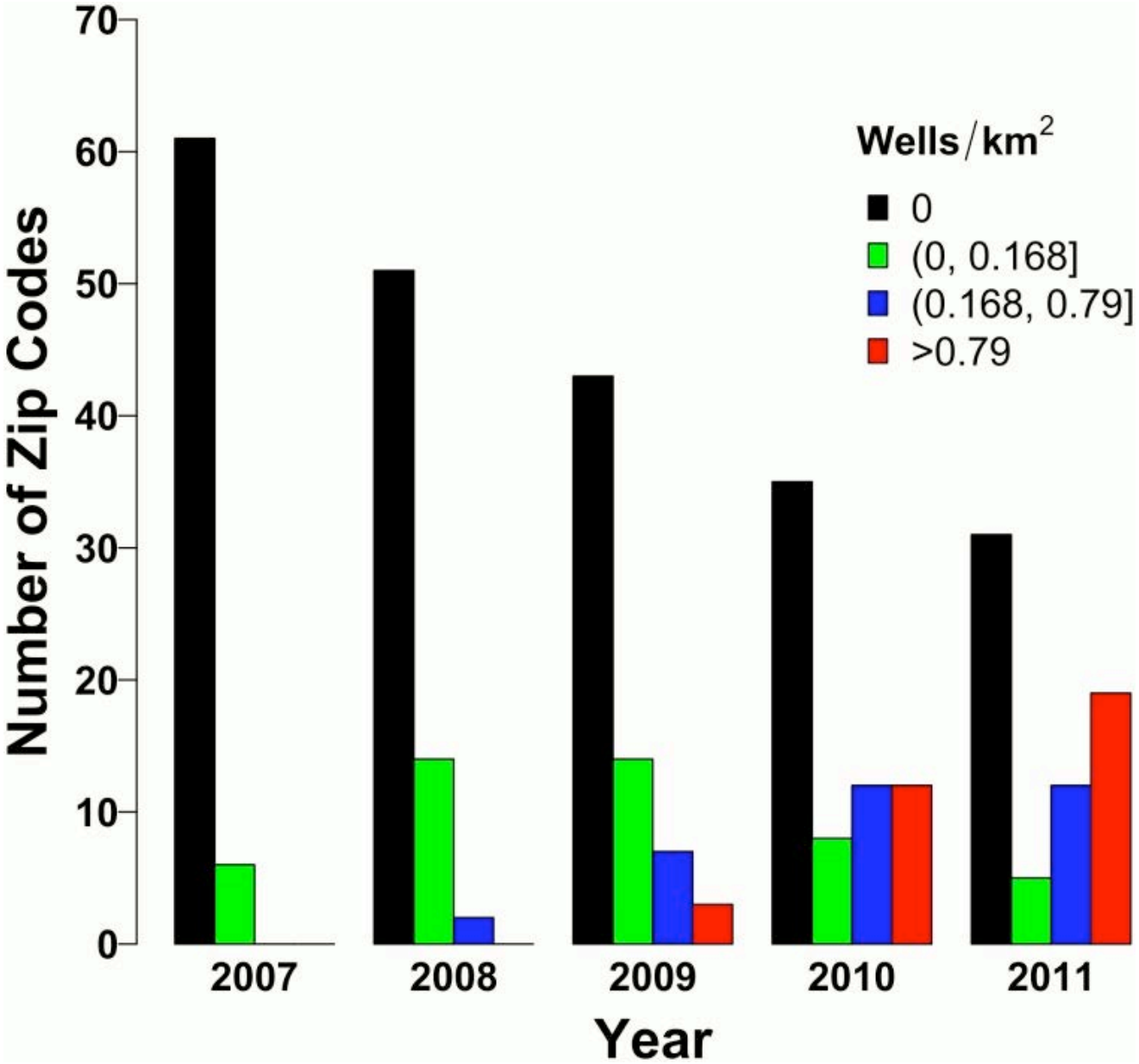
Drilling Activity and Gas Production in PA Counties 2007-2011







Increase in well-density by zip-code in Bradford and Susquehanna Counties

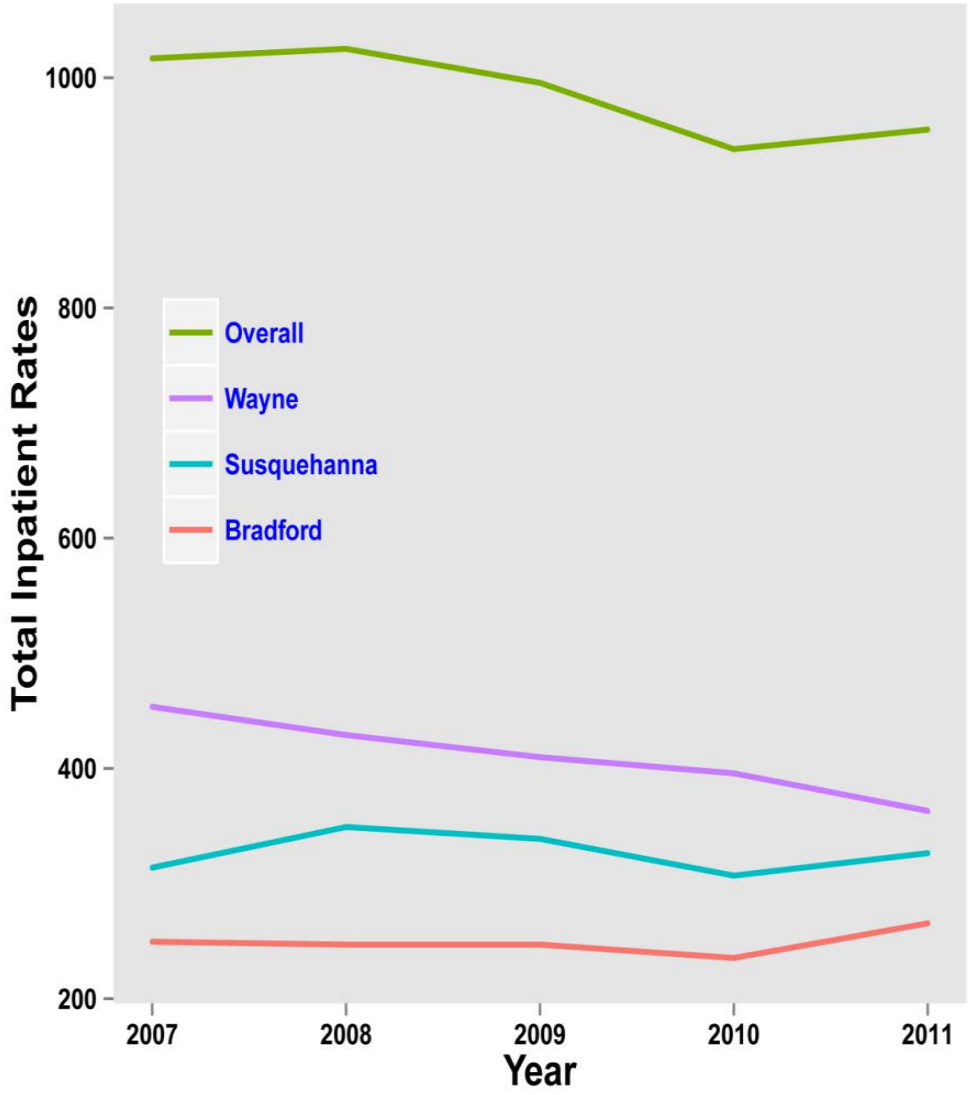


Demographics of Populations are Similar

		Bradford	Susquehanna	Wayne
Population		62,622	43,356	51,548
Overall Hospitalizations 2007–2011		39,821	22,559	30,425
Age (median)		43.4	45.1	45.9
Male %		49.5	50.4	52.8
High School Graduate, percent of person age 25+ %		86.6	88.1	87.4
Bachelor Degree or Higher, percent of person age 25+ %		16.4	16.1	18.4
Median Income (2008–2012) $		44,650	46,815	50,153
Race %	White	97.4	98.0	94.7
	Black	0.6	0.4	3.5
	Asian	0.6	0.3	0.5
	Other	1.4	1.3	1.3
Median Number of Wells	2007	0	0	0
	2008	1	0	0
	2009	13	0	0
	2010	81	1	0
	2011	149	6	0
Number of Zip Codes with >0 Wells (%)	2007	4 (19)	2 (9)	0 (0)
	2008	12 (57)	4 (17)	0 (0)
	2009	16 (76)	8 (35)	0 (0)
	2010	20 (95)	12 (52)	0 (0)
	2011	20 (95)	16 (70)	0 (0)

doi:10.1371/journal.pone.0131093.t002

Total Inpatient Rates and Health Economic Impact



- n = 92,805 hospitalizations
- increase at 3% per year
- 3,000 x 30K per hospitalization
- 10 M per year increase in health care costs

Poisson Fixed Effects Models: Number of Wells per Zip Code per Year.

	Wells RR (p-value)	Year RR (p-value)
Inpatient total	1.0003 (0.076)	0.984 (0.128)
Cardiology	**1.0007 (0.0007)**	**0.966 (0.029)**
Dermatology	1.0010 (0.039)	0.977 (0.345)
Endocrine	1.0008 (0.086)	0.963 (0.316)
Gastroenterology	1.0003 (0.338)	0.992 (0.749)
General medicine	1.0002 (0.574)	1.037 (0.022)
Generals surgery	1.0000 (0.849)	1.104 (0.213)
Gynecology	1.0002 (0.708)	0.860 (<0.0001)
Hematology	0.9997 (0.657)	1.023 (0.616)
Neonatology	1.0014 (0.018)	0.959 (0.125)
Nephrology	0.9998 (0.461)	1.025 (0.250)
Neurology	1.0006 (0.037)	1.001 (0.948)
Normal newborns	1.0000 (0.969)	0.963 (0.030)
Ob/delivery	1.0002 (0.411)	0.968 (0.411)
Oncology	1.0015 (0.004)	0.956 (0.081)
Ophthalmology	1.0010 (0.593)	1.084 (0.255)
Orthopedics	0.9993 (0.011)	0.970 (<0.0001)
Other/ob	1.0003 (0.727)	0.899 (0.007)
Otolaryngology	1.0000 (0.982)	0.978 (0.614)
Psych/drug abuse	1.0004 (0.073)	1.035 (0.006)
Pulmonary	1.0000 (0.850)	0.989 (0.482)
Rheumatology	1.0014 (0.043)	0.961 (0.227)
thoracic surgery	1.0011 (0.100)	0.989 (0.708)
Trauma	1.0008 (0.174)	1.021 (0.505)
Urology	1.0010 (0.012)	0.983 (0.464)
Vascular surgery	0.9997 (0.539)	0.948 (0.024)

Note: RR = Risk ratio

doi:10.1371/journal.pone.0131093.t004

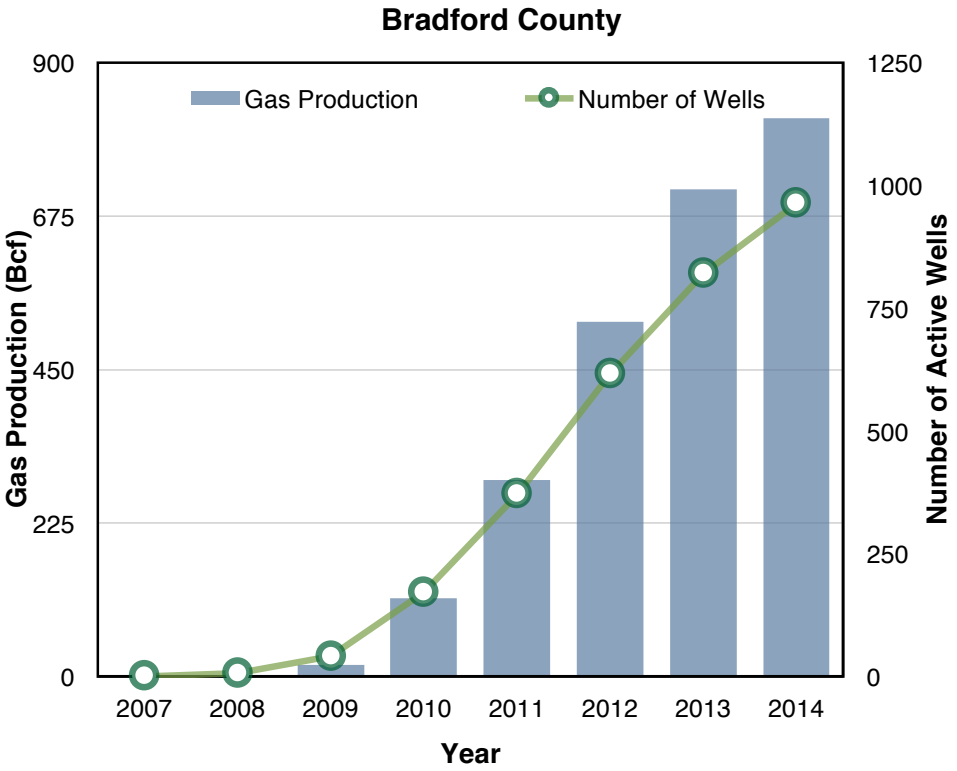
Poisson Fixed Effects Models: Quantile Analysis of Wells/km^2

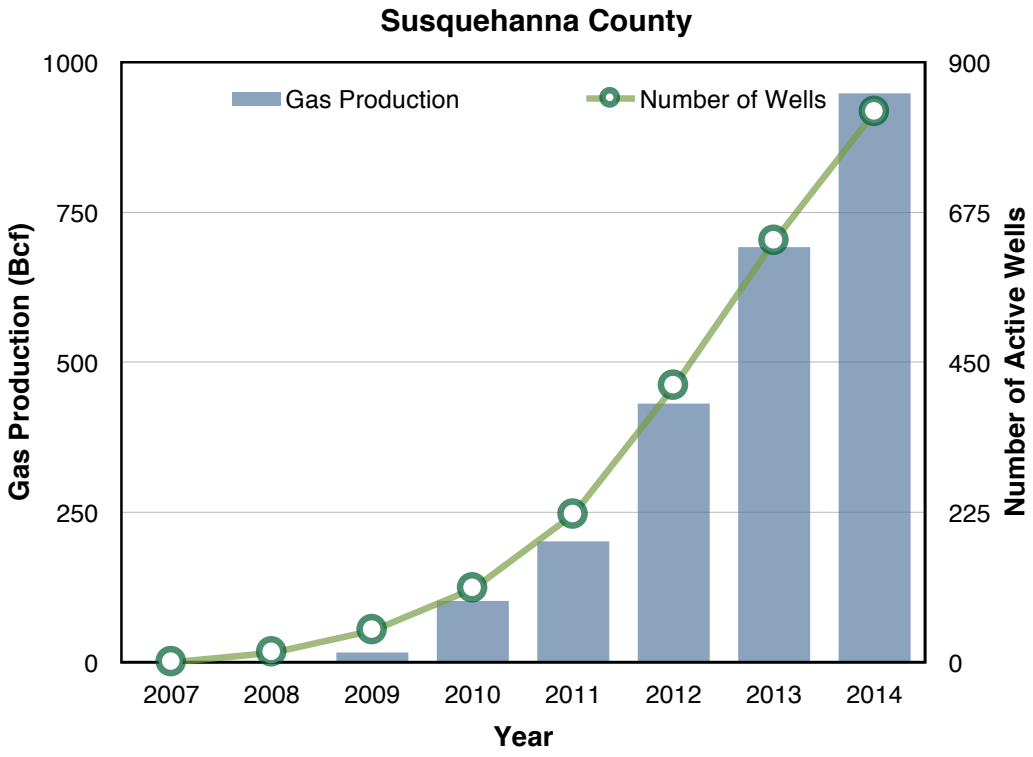
	Q1 Wells RR (p-value)	Q2 Wells RR (p-value)	Q3 Wells RR (p-value)	Wald Test of all Q Wells = 0	Year RR (p-value)
Inpatient total	0.979 (0.475)	1.069 (0.044)	1.108 (0.041)	P = 0.0058	0.977 (0.013)
Cardiology	**1.021 (0.667)**	**1.142 (0.018)**	**1.27 (0.001)**	**P = 0.0008**	**0.957 (0.004)**
Dermatology	1.051 (0.572)	1.108 (0.429)	1.454 (0.013)	P = 0.0329	0.972 (0.329)
Endocrine	0.975 (0.862)	1.228 (0.045)	1.391 (0.029)	P = 0.0068	0.942 (0.039)
Gastroenterology	0.943 (0.369)	1.12 (0.168)	1.105 (0.364)	P = 0.1101	0.98 (0.406)
General medicine	0.911 (0.234)	0.993 (0.931)	0.985 (0.872)	P = 0.6373	1.037 (0.006)
Generals surgery	0.875 (0.011)	0.921 (0.228)	0.944 (0.424)	P = 0.0669	1.015 (0.157)
Gynecology	0.887 (0.300)	0.938 (0.606)	0.967 (0.849)	P = 0.7549	0.865 (<0.0001)
Hematology	1.202 (0.365)	1.21 (0.320)	1.221 (0.429)	P = 0.7145	0.993 (0.868)
Neonatology	0.994 (0.975)	1.301 (0.152)	1.527 (0.100)	P = 0.0745	0.95 (0.052)
Nephrology	1.115 (0.203)	1.143 (0.227)	1.151 (0.211)	P = 0.5566	1.004 (0.871)
Neurology	**0.922 (0.344)**	**1.157 (0.048)**	**1.188 (0.062)**	**P = 0.0003**	**0.99 (0.542)**
Normal newborns	0.949 (0.481)	0.978 (0.764)	0.964 (0.731)	P = 0.8980	0.965 (0.064)
Ob/delivery	0.958 (0.524)	1.028 (0.670)	1.029 (0.749)	P = 0.4219	0.956 (0.002)
Oncology	1.217 (0.144)	1.415 (0.028)	1.815 (0.002)	P = 0.0166	0.938 (0.022)
Ophthalmology	0.717 (0.381)	1.014 (0.976)	1.116 (0.836)	P = 0.5215	1.099 (0.263)
Orthopedics	0.996 (0.940)	0.981 (0.740)	0.875 (0.130)	P = 0.3591	0.963 (<0.0001)
Other/ob	0.966 (0.885)	1.176 (0.451)	1.264 (0.502)	P = 0.7209	0.879 (0.001)
Otolaryngology	1.052 (0.744)	1.194 (0.412)	1.004 (0.988)	P = 0.5564	0.966 (0.527)
Psych/drug abuse	0.944 (0.307)	0.927 (0.293)	1.13 (0.145)	P = 0.0535	1.039 (0.008)
Pulmonary	1.05 (0.267)	1.097 (0.202)	1.067 (0.572)	P = 0.3050	0.981 (0.306)
Rheumatology	1.091 (0.601)	1.432 (0.159)	1.866 (0.034)	P = 0.0774	0.94 (0.067)
Thoracic surgery	0.872 (0.391)	1.151 (0.470)	1.13 (0.654)	P = 0.0903	0.987 (0.751)
Trauma	0.997 (0.987)	1.057 (0.761)	1.265 (0.222)	P = 0.4373	1.02 (0.562)
Urology	0.827 (0.117)	1.105 (0.462)	1.24 (0.215)	P = 0.0334	0.977 (0.339)
Vascular surgery	1.103 (0.488)	1.052 (0.788)	0.966 (0.857)	P = 0.8116	0.946 (0.030)

Note: RR = Risk ratio

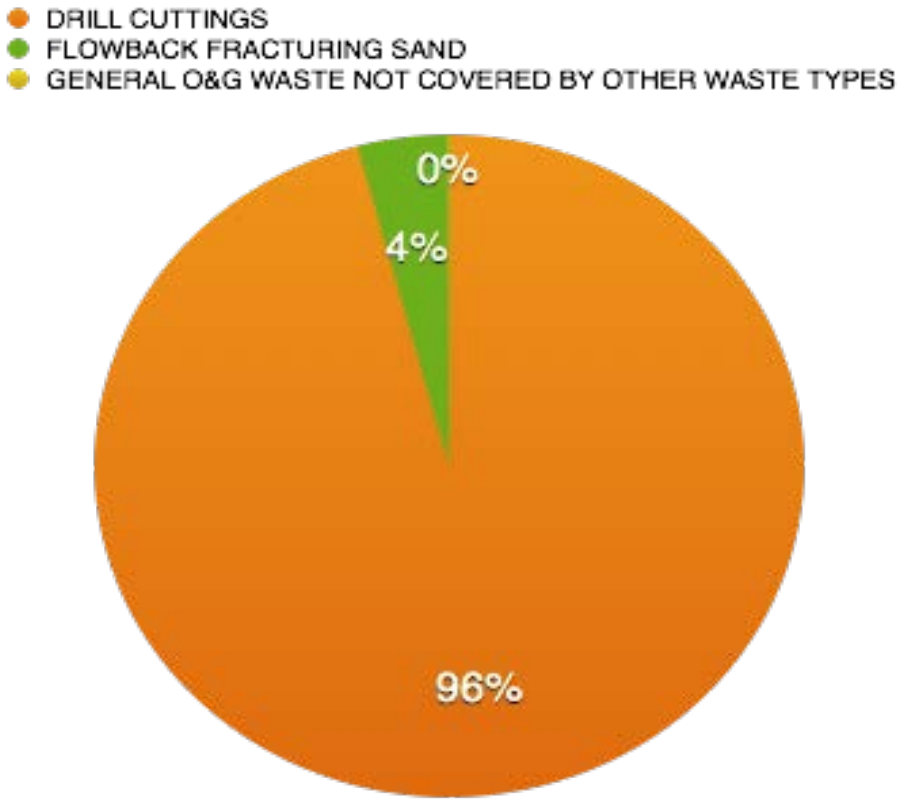
doi:10.1371/journal.pone.0131093.t005

Gas Production Since 2011



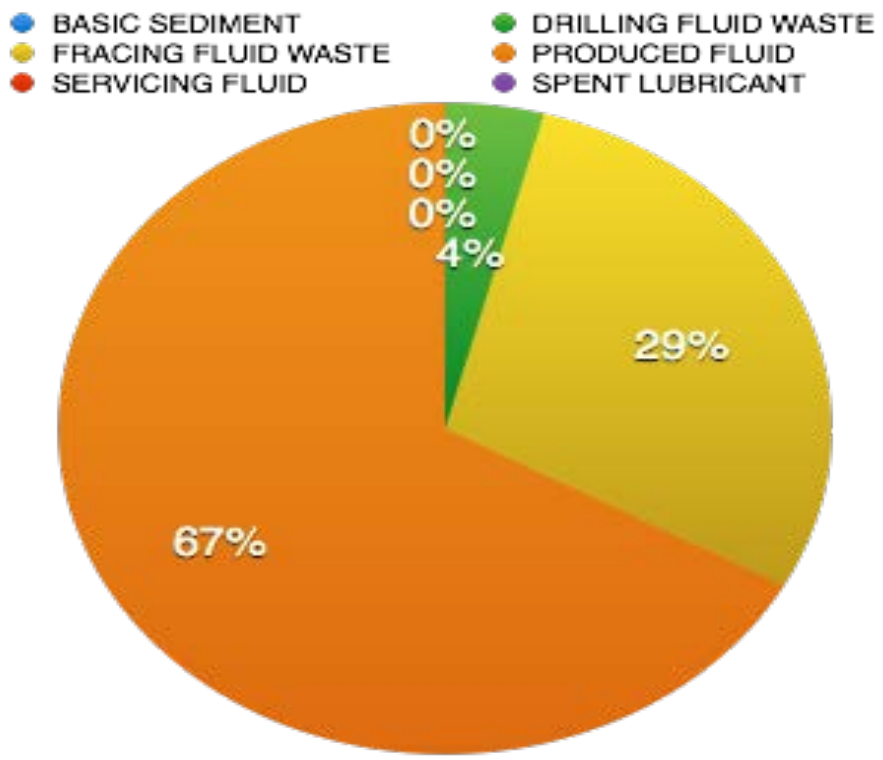


Solid and Liquid Waste Produced in PA 2014



Solid Waste

1,586,547 Tons



Liquid Waste

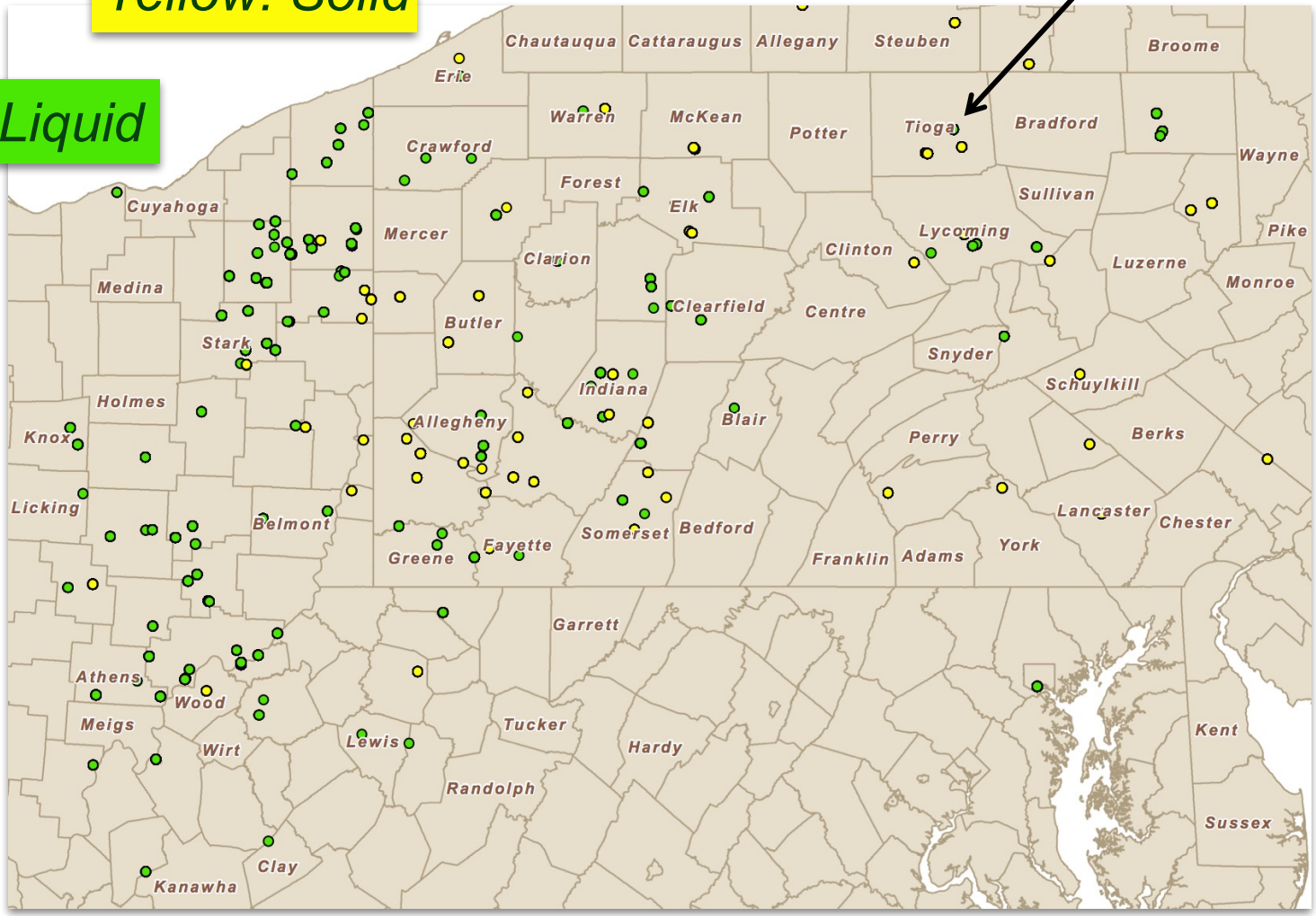
43,367,268 Bbls

Source:https://www.paoilandgasreporting.state.pa.us/publicreports/Modules/DataExports/DataExports.aspx

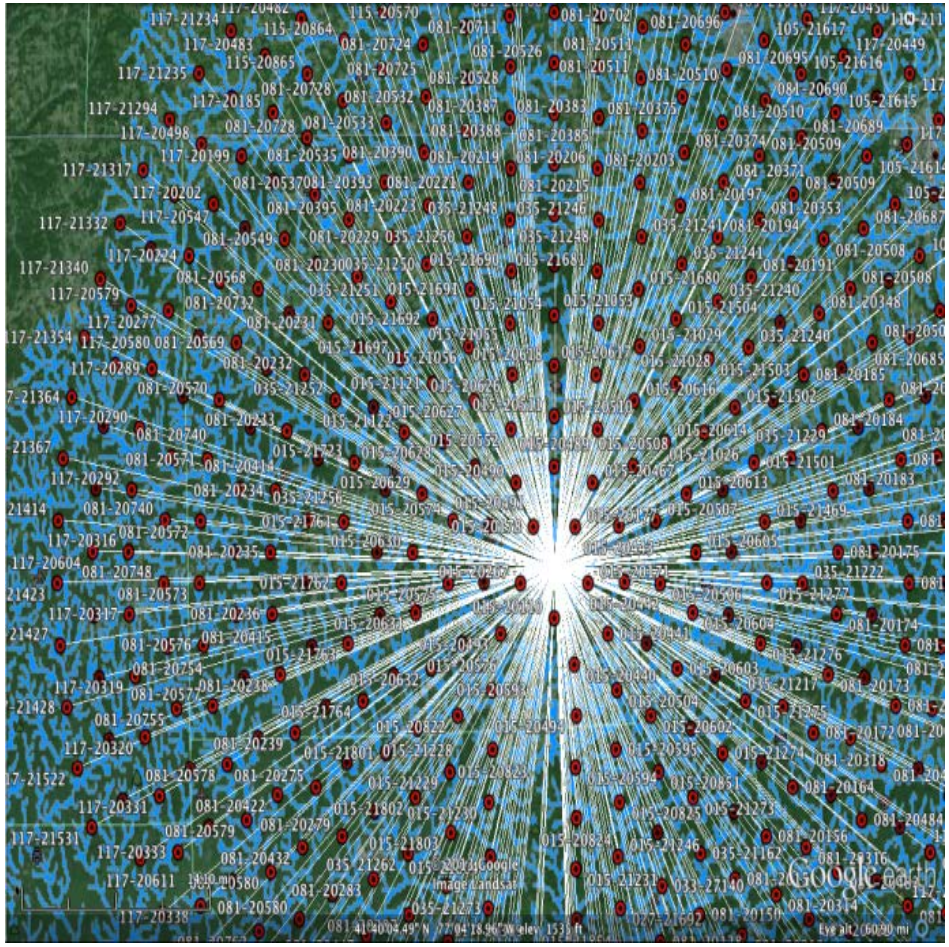
Where does the waste go?

Yellow: Solid

Green: Liquid



Tioga County: Waste-water Treatment



Each red dot identifies an active well which Sends waste water to a centralized waste water treatment (CWT) plant

- In PA 6 deepwater injection wells exist
- 2013-PA reuses 65% of its HF water waste
- 2013-20% goes to CWT facilities
- 39 CWT facilities in PA
- 30 zero-discharge and 9 are discharge
- 90% goes to zero-discharge
- TDS waste goes to 51 landfills
- 34 have radium-226 and radium-228 leachates that exceed the PRG by 65,000 and 52-fold respectively

Summary

- UGOD pose a public health threat
- UGOD occurs in communities that have subpockets of vulnerable populations
- Association between increases in inpatient hospitalization rates with number of wells and well density shows that health disparity exists between exposed and non-exposed groups
- Cardiology inpatient rates were significantly associated with wells per zip-code and and wells per km^2
- Dermatology, neurology, oncology and urology inpatient rates supported an association with wells per km^2
- Cardiology inpatient rates might be associated with exposure to PM2.5
- Dermatology inpatient rates night be associated with exposure to water pollutants
- Large number of uncertainties exist

  -lack of base line water monitoring

  -lack of real time air monitoring

  -lack of human exposure data (biosensors or biomarkers)

  -lack of complete toxicology data on 90% of the chemicals used

  -need for alternative approaches

EPA-Risk Assessment on Nation Water Resources

- **Preliminary Report July 2015:**
  "The effect of HF on the nation's drinking water resources was neither widespread or systemic"

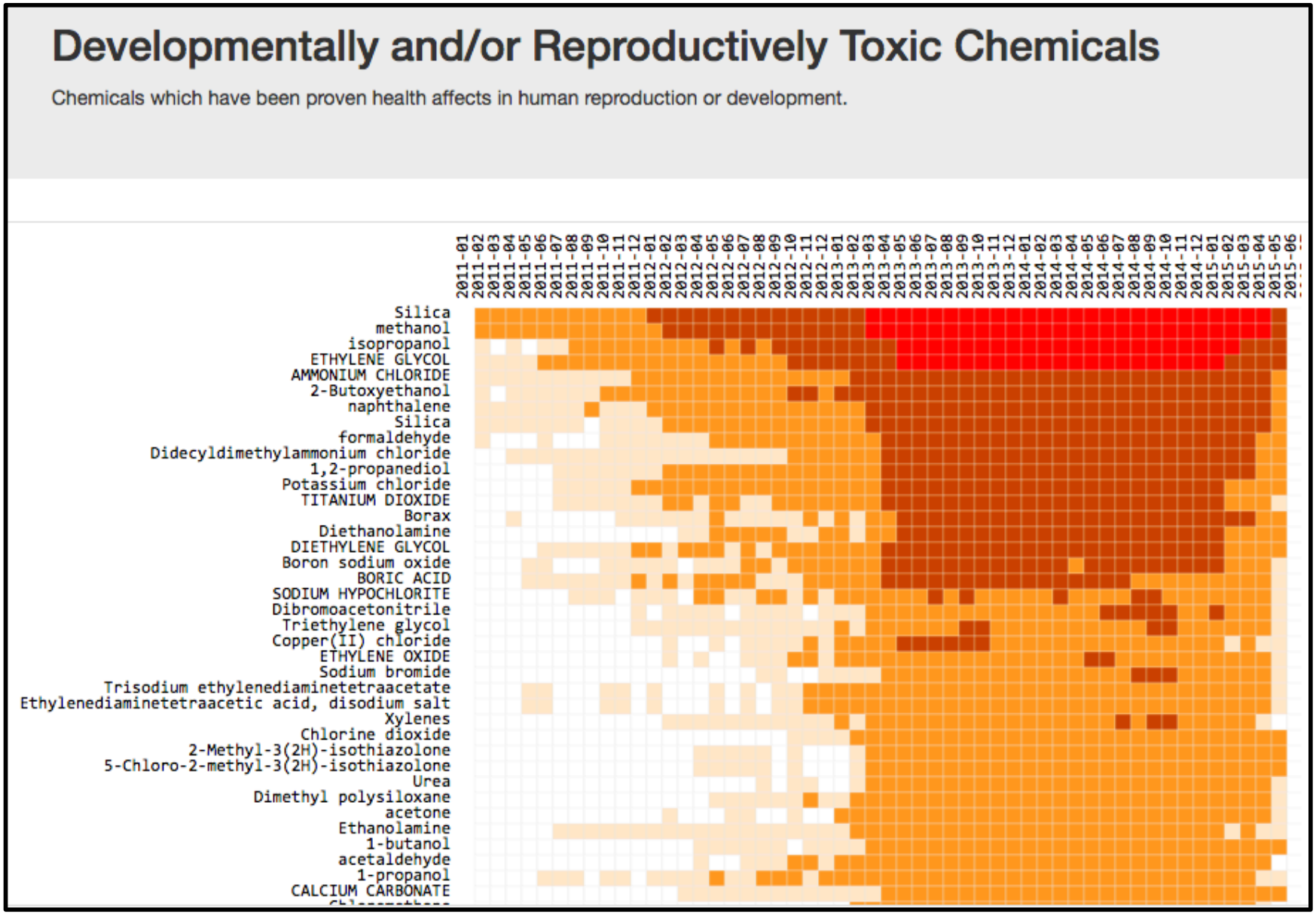
- **Final Report December 2016:**
  "HF can impact drinking water resources under some circumstances. Impacts can range in frequency and severity.."

Chemoinformatics

- FracFocus has >35,957 HF disclosures matched to well location
- 1,173 different chemicals used
- Cluster analysis of chemical use with toxic-endpoint e.g. REPROTOX Data base (Elliot et al., J. Exposure Sci and Eng. 2016 1-10)
- Provide health end-points for epidemiological studies

- https://bioinf.ceet.upenn.edu/fracking/

Matching Use to Toxic End-Points



Acknowledgements

Reynold Panettieri, M.D.
Thomas Jemielita
Kathleen Propert, Ph.D.
Nicholas Fausti
George Gerton, Ph.D.
Poune Saberi, M.D.
Marilyn Howarth, M.D.
Steve Vitale, B.S.

- Beizhan Yan, Ph.D.
- Steven Chillrud, Ph.D
- Martin Stute, Ph.D.

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NIH National Institute of Environmental Health Sciences

- Truven Inc.
- NIEHS
- INTER-ESHCC Pilot Project
- P30-ES013508 (Penn)
- P30-ES009089 (COLUMBIA)