

## The Science of Shale Gas/Oil: The Latest Evidence on Leaky Wells, Methane Emissions, and Implications for Energy Policy



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Cornell University  
and  
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*North Carolina State University  
March 15, 2016*

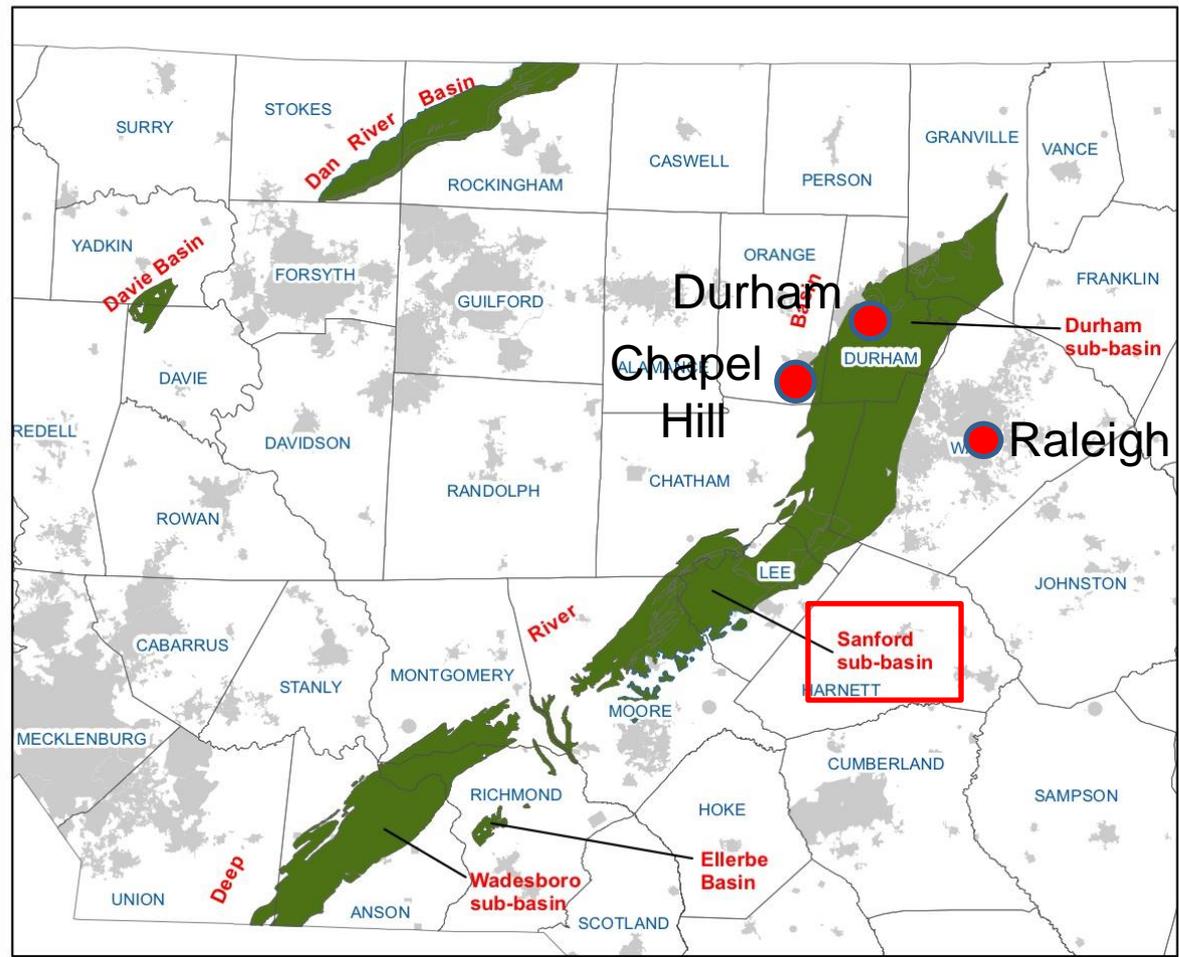
# OUTLINE

- **Shale gas development in North Carolina?**
- Because it is both a CO<sub>2</sub> and CH<sub>4</sub> source, shale gas development impedes national-scale efforts to combat climate change and to transition to the new energy economy
- Shale gas potential is a distraction from energy resources that are plentiful and economically viable today
- It's too late to hide behind ignorance

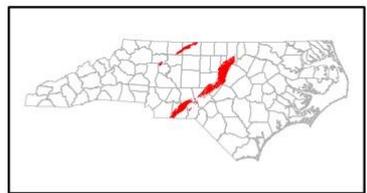
# Where Might the Shale Gas Be in North Carolina?



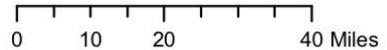
## Exposed North Carolina Triassic Rift Basins



- Municipalities (2006)
- County Outlines
- Triassic Basins



Location of North Carolina mapped Triassic basins.



Data source: NC Geologic Map of 1985, NC Center for Geographic Information and Analysis  
Map prepared September 21, 2011

# First Target: Sanford Sub-Basin

“This is just an opportunity for North Carolina to get into the game of energy development and to do it in a safe and responsible way,” said David McGowan, North Carolina Petroleum Council (NCPC) executive director.”

“We really won’t know the extent of the interest and potential development possibilities here until some of that exploratory work is conducted,” he said.

The sub-basin represents a small fraction of the total Triassic Basin formations in the state — **about 59,000 acres** out of a total of 785,000 acres.

***At 160-acre spacing, 368 wells could be drilling the Sanford, for a volume of technically recoverable gas of 309 billion cubic feet (Bcf) of gas, according to the DENR.***”

# How Much Natural Gas Resource Might There Be in North Carolina, the Sanford?

Total Petroleum System (TPS) and Assessment Unit (AU)	Field type	Total undiscovered resources											
		Oil (MMBO)				Gas (BCFG)				NGL (MMBNGL)			
		F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean
<b>Taylorsville Basin Composite TPS</b>													
Taylorsville Basin Continuous Gas AU	Gas					516	985	1,880	1,064	16	34	71	37
<b>Richmond Basin Composite TPS</b>													
Richmond Basin Continuous Gas AU	Gas					99	194	382	211	4	10	20	11
<b>Newark Basin Composite TPS</b>													
South Newark Basin Continuous Gas AU	Gas					363	785	1,698	876	1	4	10	4
<b>Deep River Basin Composite TPS</b>													
Deep River Basin Continuous Gas AU	Gas					779	1,527	2,990	1,660	35	75	158	83
<b>Dan River-Danville Basin Composite TPS</b>													
Dan River-Danville Basin Continuous Gas AU	Gas					17	42	106	49	0	0	1	0
<b>Total continuous resources</b>						<b>1,774</b>	<b>3,533</b>	<b>7,056</b>	<b>3,860</b>	<b>56</b>	<b>123</b>	<b>260</b>	<b>135</b>

Collectively, 50% probability of ~ 3.5 Tcf

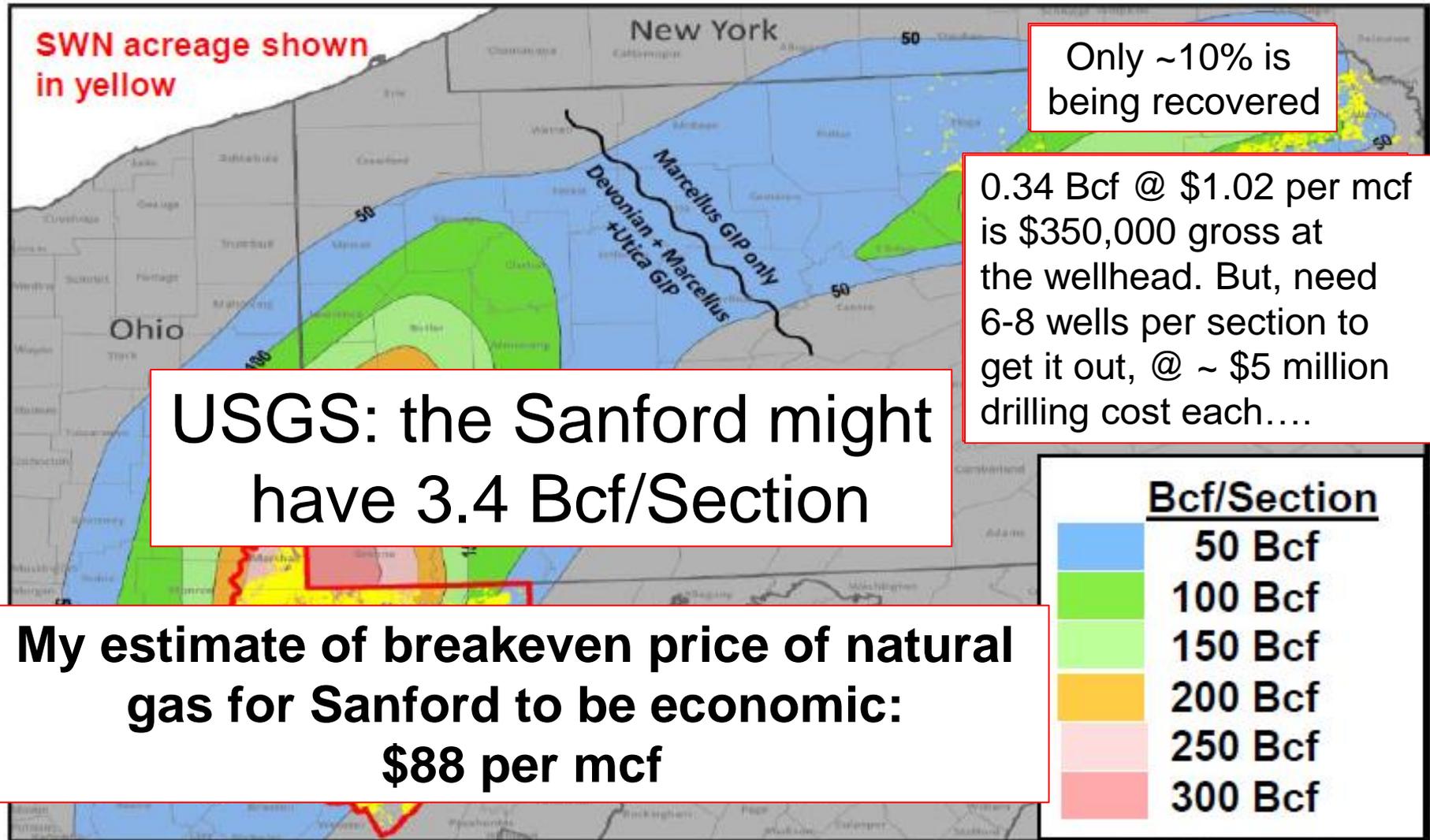
Deep River Basin, ~ 1.5 Tcf

**Sanford Sub-Basin, ~305 Bcf**

**In 2015, the U.S. consumed about 25 Tcf**

FS 2012-3075 (U.S. Geological Survey fact sheet, [June 2012](#))

# The Marcellus Gas In Place (GIP) Map => \$\$\$ ?



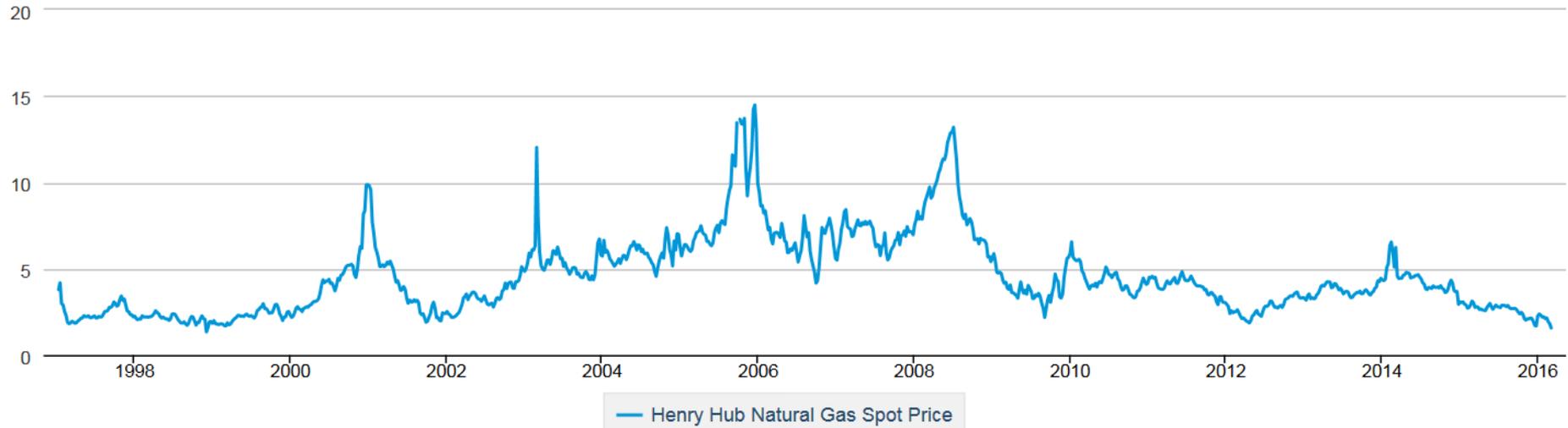
From Southwestern Energy (SWN) Investors Report, July 2015

<https://www.swn.com/investors/LIP/latestinvestorpresentation.pdf>

# \$88 per thousand cubic feet? Never.

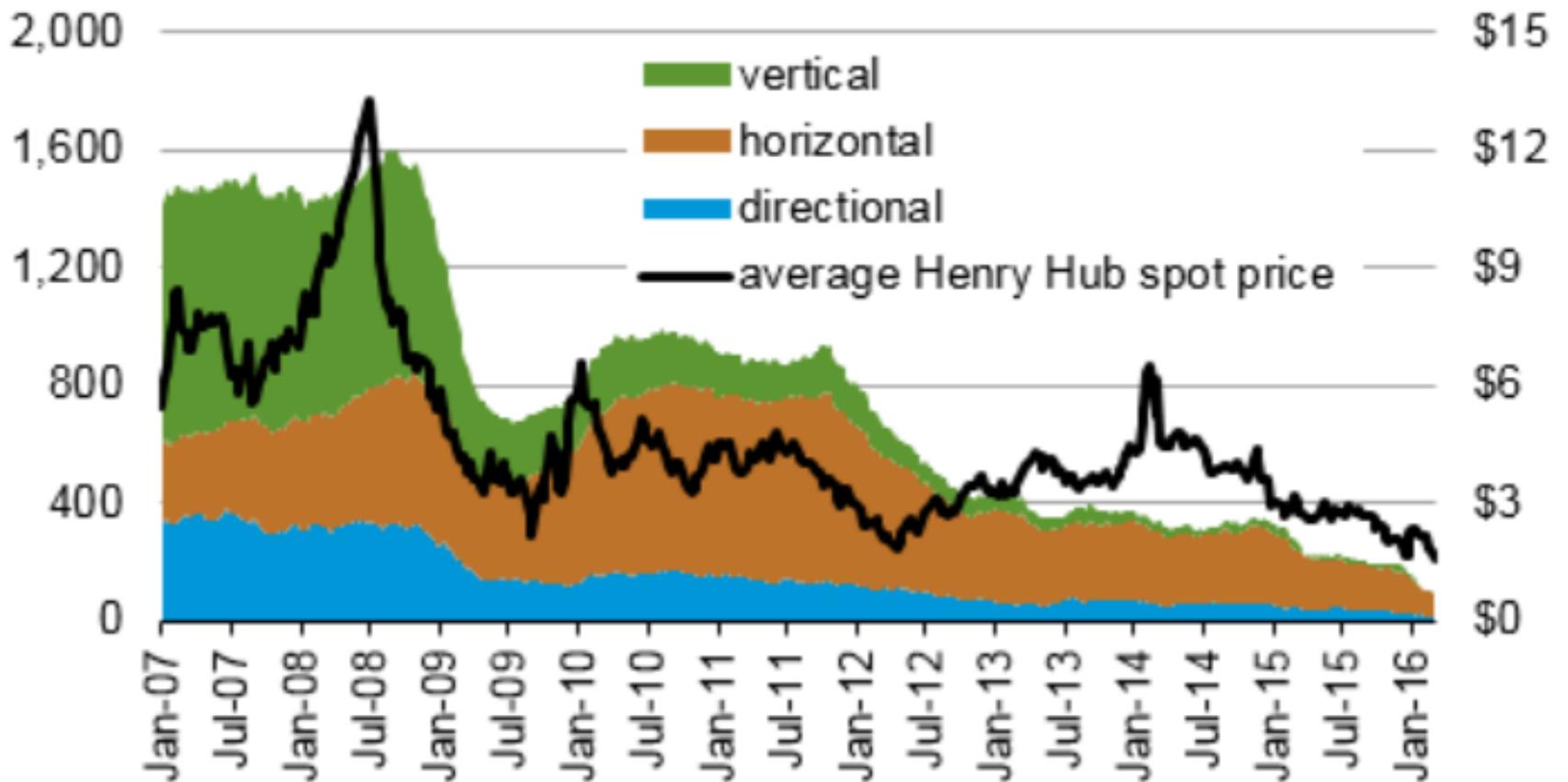
## Henry Hub Natural Gas Spot Price

Dollars per Million Btu



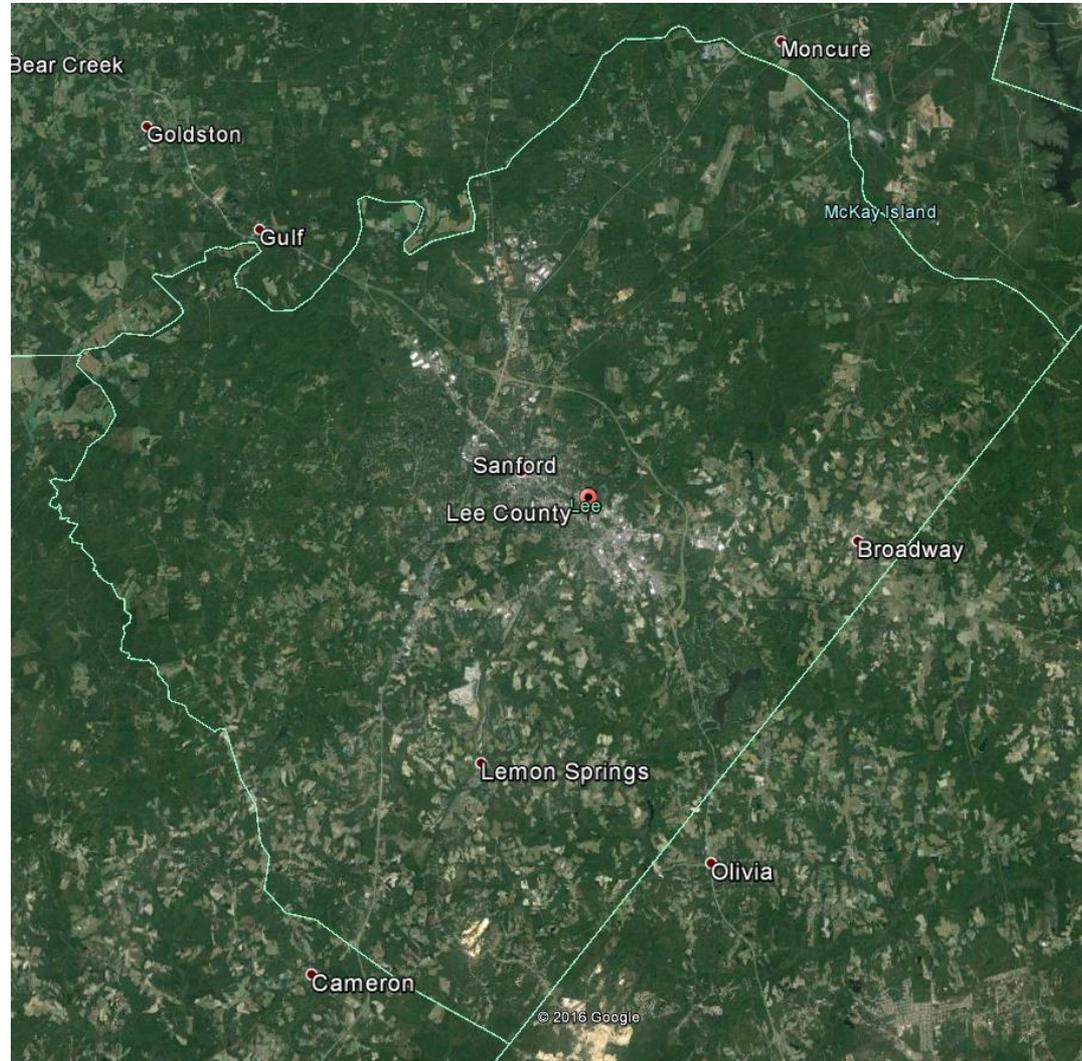
# The North Carolina Story: Too Little, Too Late?

Weekly natural gas rig count and average spot Henry Hub  
active rigs \$ per MMBtu

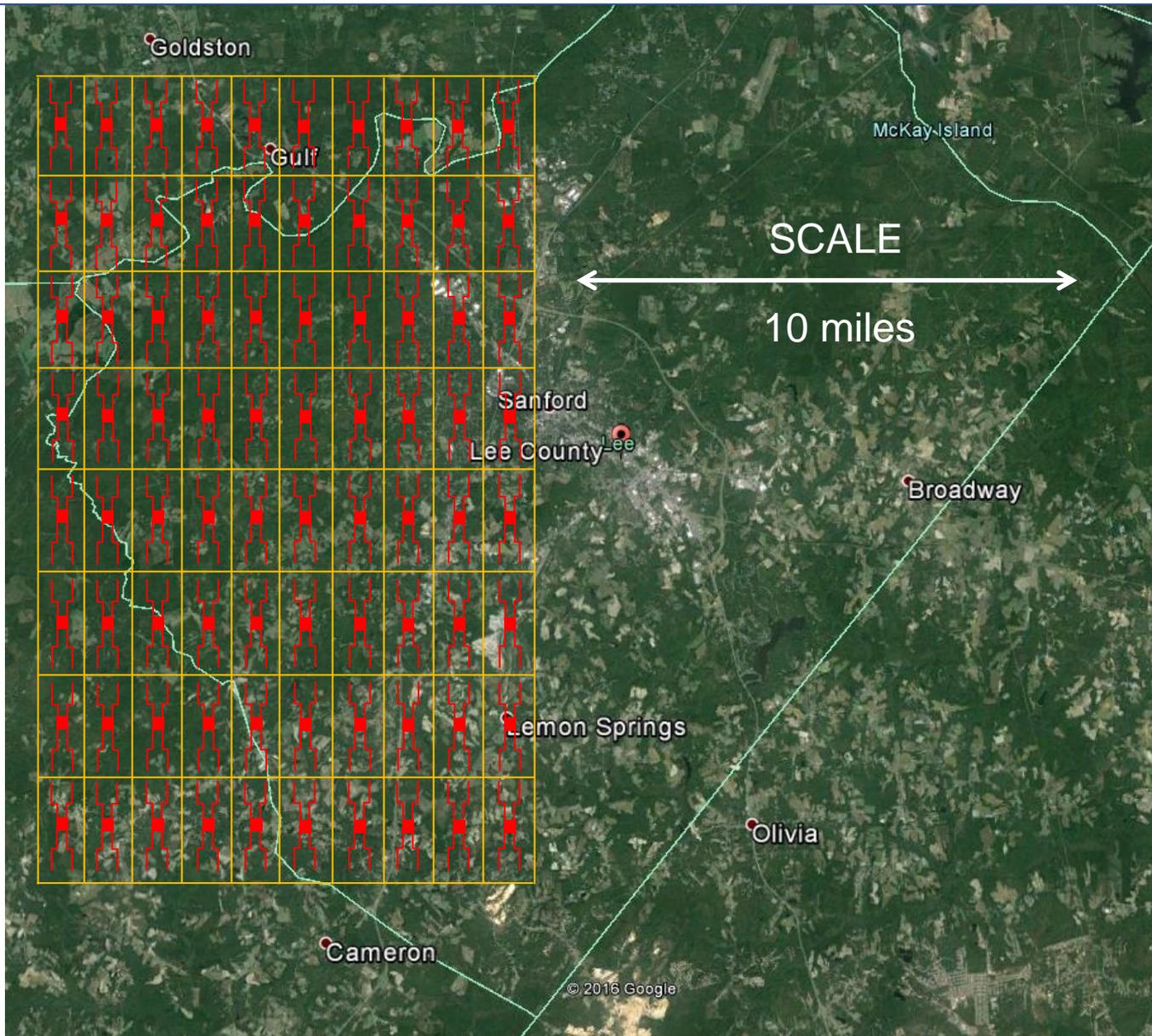


Source: Baker Hughes

# But, Someday, Some Wildcatter Might Come to Try and Prove the USGS Wrong...

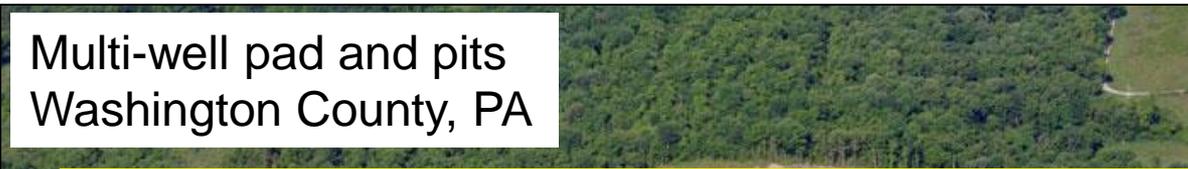


# Ideal Spacing-Unit and Pad Layout for the Sanford





Multi-well pad and pits  
Washington County, PA



Yeager Pit, Washington County, PA



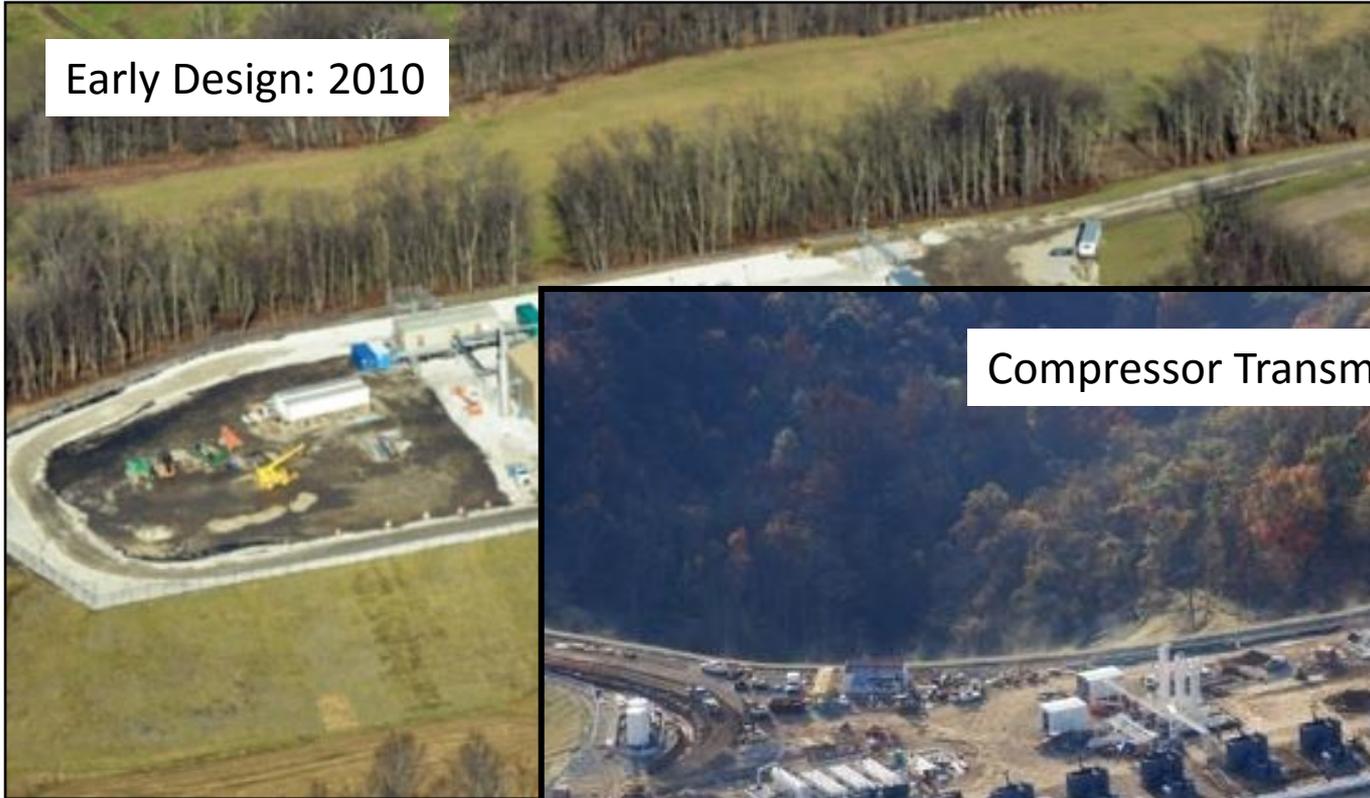
Flaring during flowback  
Washington County, PA



# Clearing Right-of-Way for A Marcellus Pipeline in WVa



# Marcellus Compressor Stations In PA

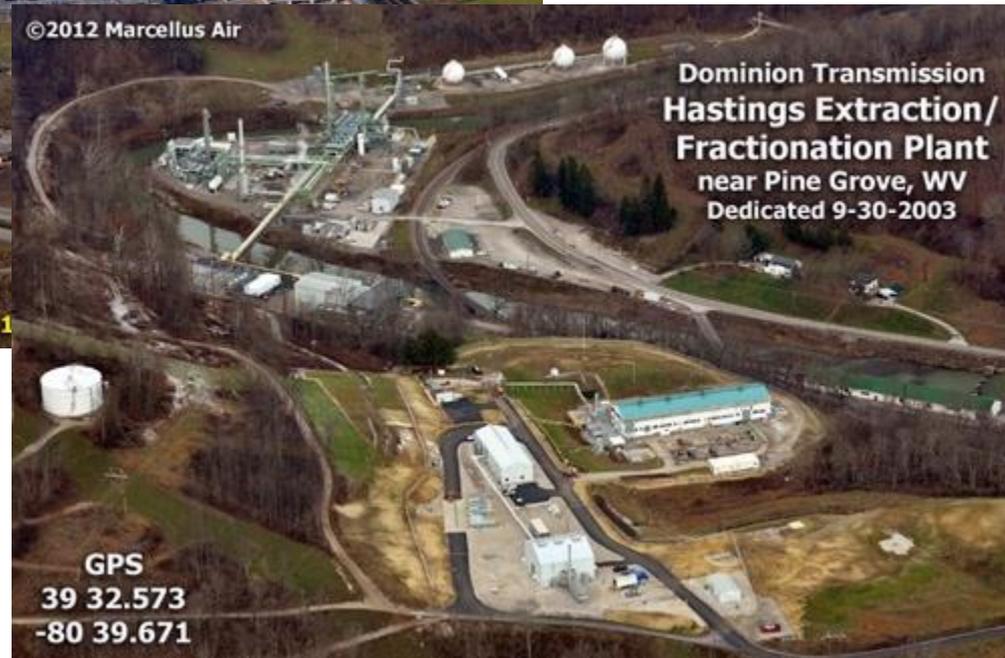


Early Design: 2010



Compressor Transmission Station : 2013

# Processing Plants for Natural Gas Liquids

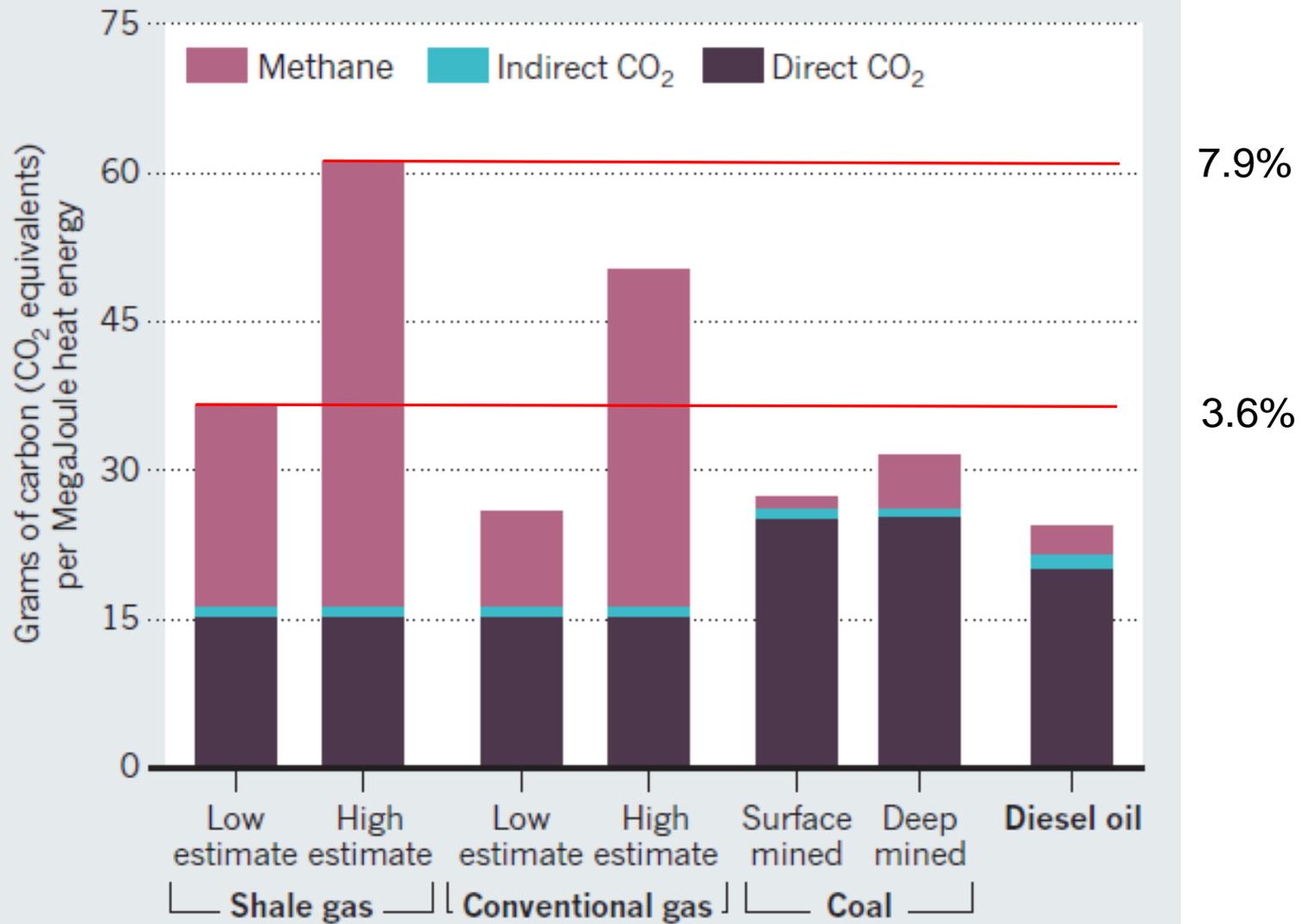


# OUTLINE

- Shale gas development in North Carolina?
- **Because it is both a CO<sub>2</sub> and CH<sub>4</sub> source, shale gas development impedes national-scale efforts to combat climate change and to transition to the new energy economy**
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# A DAUNTING CLIMATE FOOTPRINT

Over 20 years, shale gas is likely to have a greater greenhouse effect than conventional gas or other fossil fuels.



Howarth and Ingraffea said:

- “The large GHG footprint of shale gas undercuts the logic of its use as a bridging fuel over coming decades, if the goal is to reduce global warming.”
- “Given the importance of methane in global warming, these emissions deserve far greater study than has occurred in the past. We urge both more direct measurements and refined accounting to better quantify lost and unaccounted for gas.”

# Large-Scale Shale Gas Production Creates 3 Major Climate Problems

- Produces CO<sub>2</sub> when it is burned
- Methane, CH<sub>4</sub>, leaks or is purposefully vented:
  - During drilling
  - During initial frac fluid flow-back period
  - **Continuously at the pad site via leaking wells**
  - During liquid unloading
  - During gas processing
  - **During transmission, storage, and distribution**
  - From abandoned, orphaned, lost wells
- Produces black carbon (BC, soot) during flaring and processing

# Gas Is Supposed to Rise Only Inside the Production Casing, Not Outside to the Atmosphere



Methane Bubbling At Well Head

# Methane Is a Much More Potent Greenhouse Gas Than Carbon Dioxide

Global Warming Potential Values for Methane

	<b>20 years</b>	<b>100 years</b>
	<hr/>	
<b>IPCC 1996</b>	<b>56</b>	<b>21</b>
<b>IPCC 2007</b>	<b>72</b>	<b>25</b>
<b>Shindell et al. 2009</b>	<b>105</b>	<b>33</b>
<b>IPCC 2013</b>	<b>86</b>	<b>34</b>

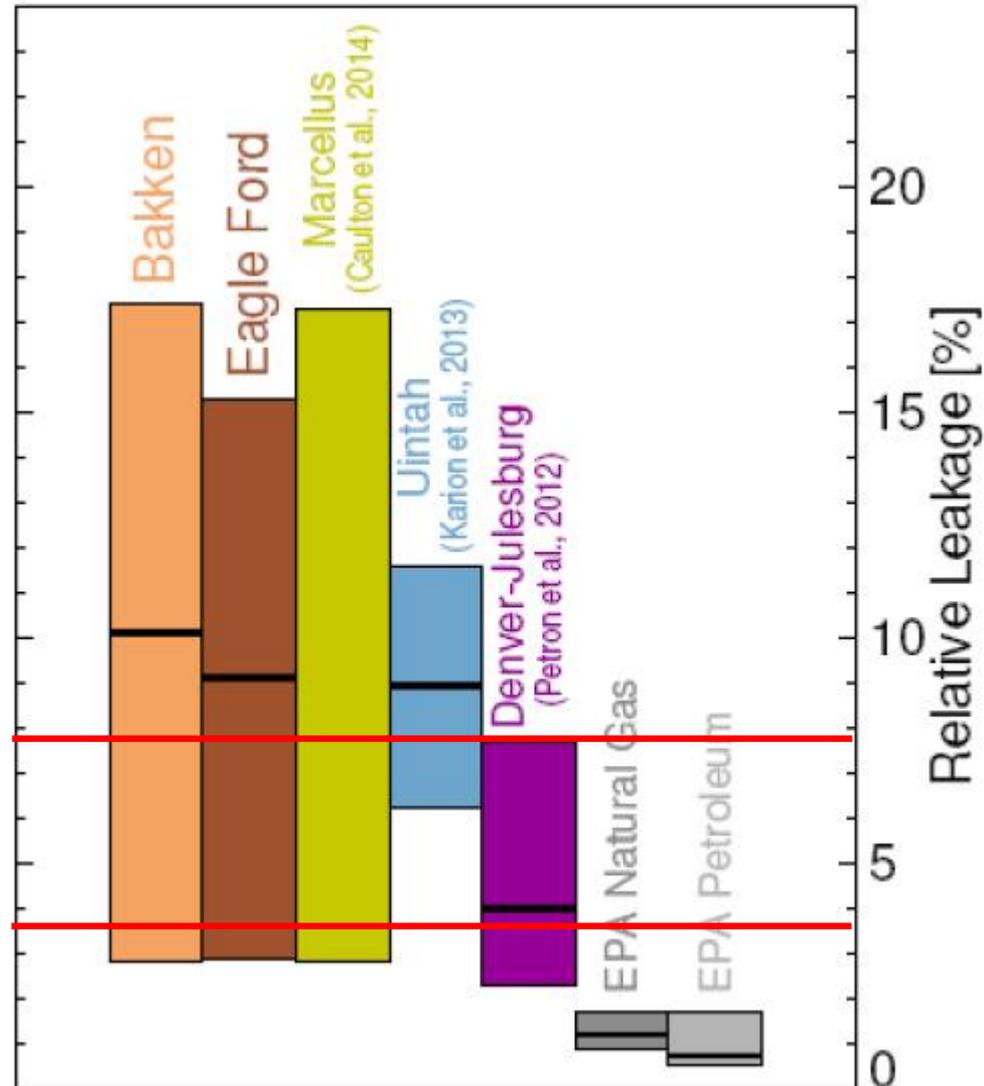
# Initially, the White House Judged Our Work Not “Credible”

“There were numerous studies on fugitive emissions of methane. There was a **very famous Cornell report** which we looked at and decided was not as credible as...**well we didn't think it was credible**, I'll just put it that way and it was over estimating fugitive emissions.”

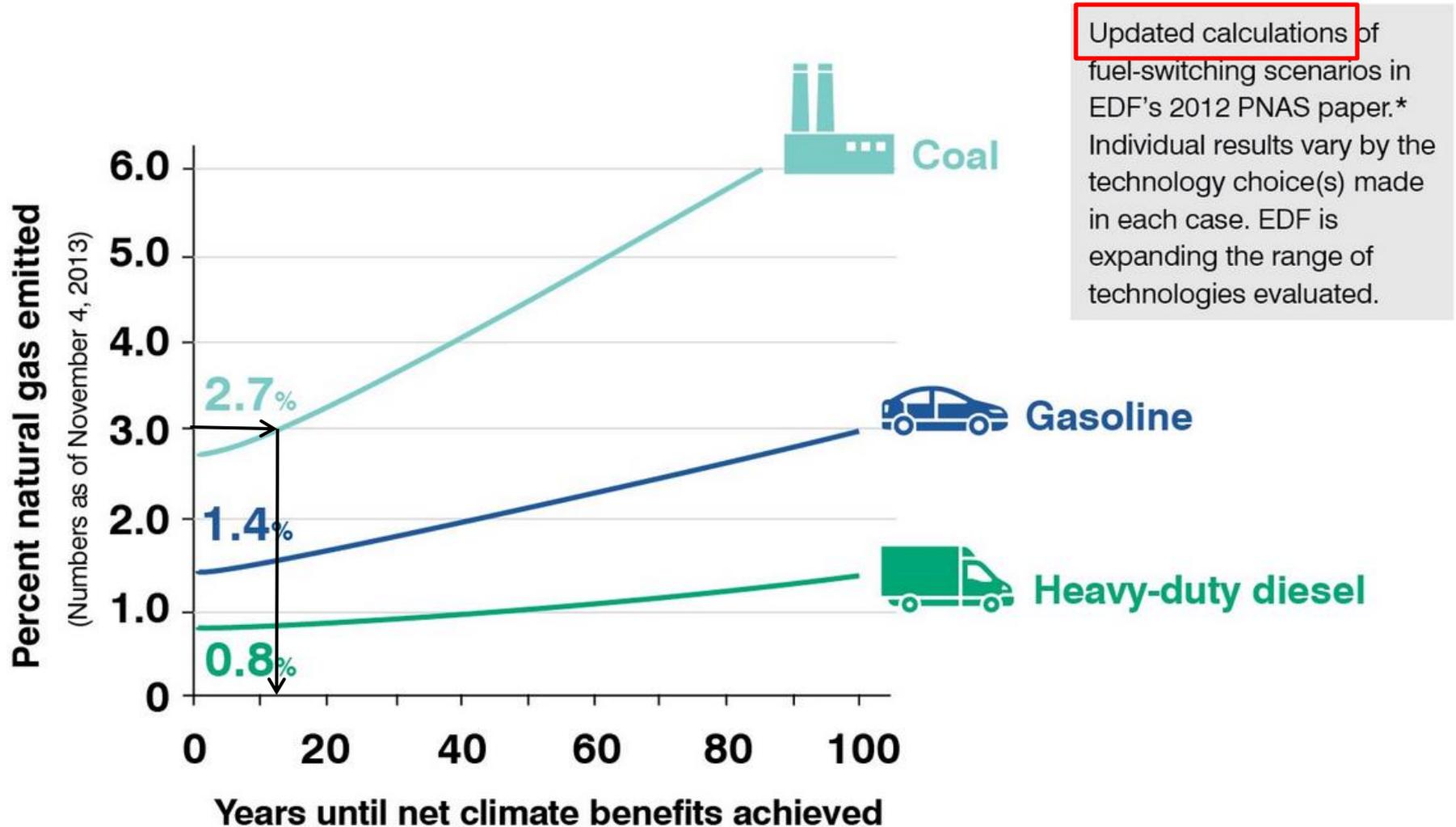
Former U.S. Energy Secretary and Nobel Prize Winner Steven Chu while giving a speech at America's Natural Gas Alliance “Think About Energy Summit”, Columbus, Ohio

# But Then MEASURED Methane Leakage Rate Data Began to Be Published

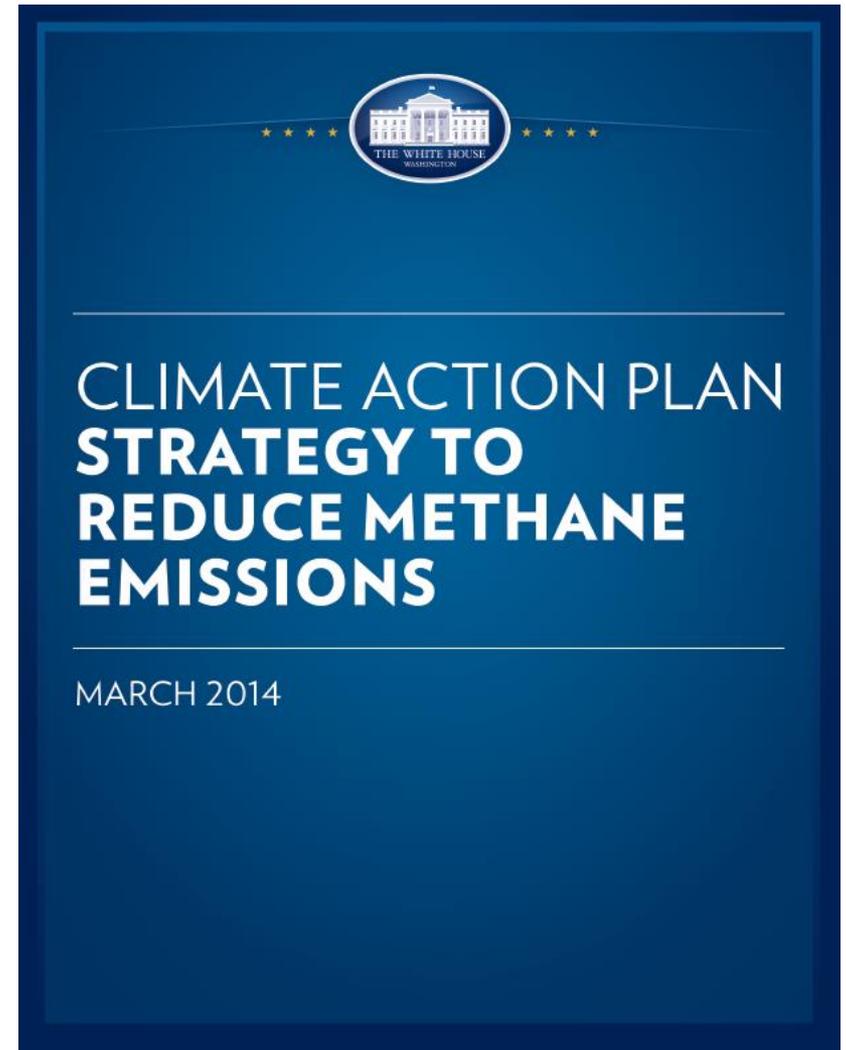
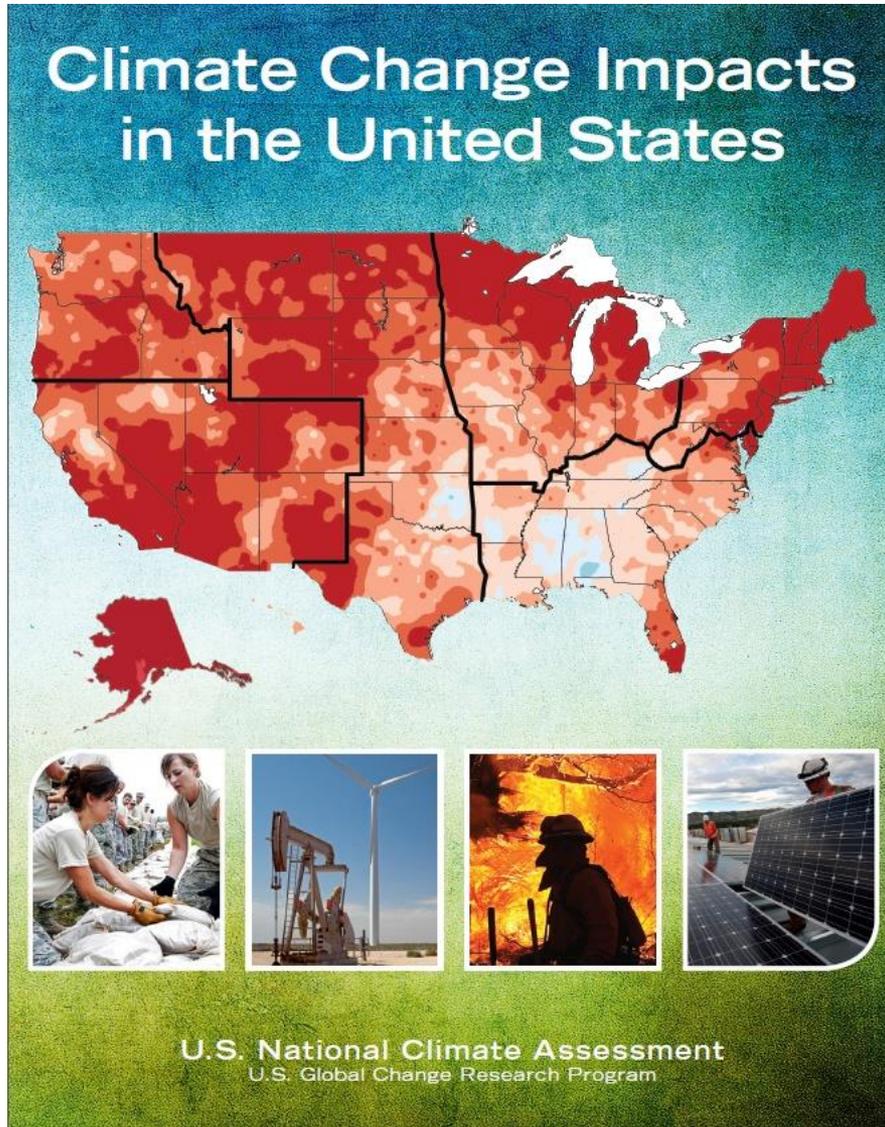
Range Predicted by Howarth et al., 2011



# Can Natural Gas Deliver Sustained Climate Benefits?



# Fast Forward: Two Key White House Reports in Early 2014



# More Anti-Methane White House Actions in Early 2016: They Finally Got It!

**OBAMA ADMINISTRATION EXPANDS CLIMATE FIGHT—The Washington Post’s Joby Warrick:** “The Obama administration took a step Friday toward **plugging thousands of small methane leaks from oil and gas operations around the country, saying the escaping gas is contributing to climate change.** The Interior Department announced proposed regulations that would require energy companies to reduce methane leaks in order to drill anywhere on land owned by the government or Native American tribes. The proposals would affect more than 100,000 oil wells that supply about 10 percent of the nation’s natural gas.”

<http://wapo.st/1NtPG8x>

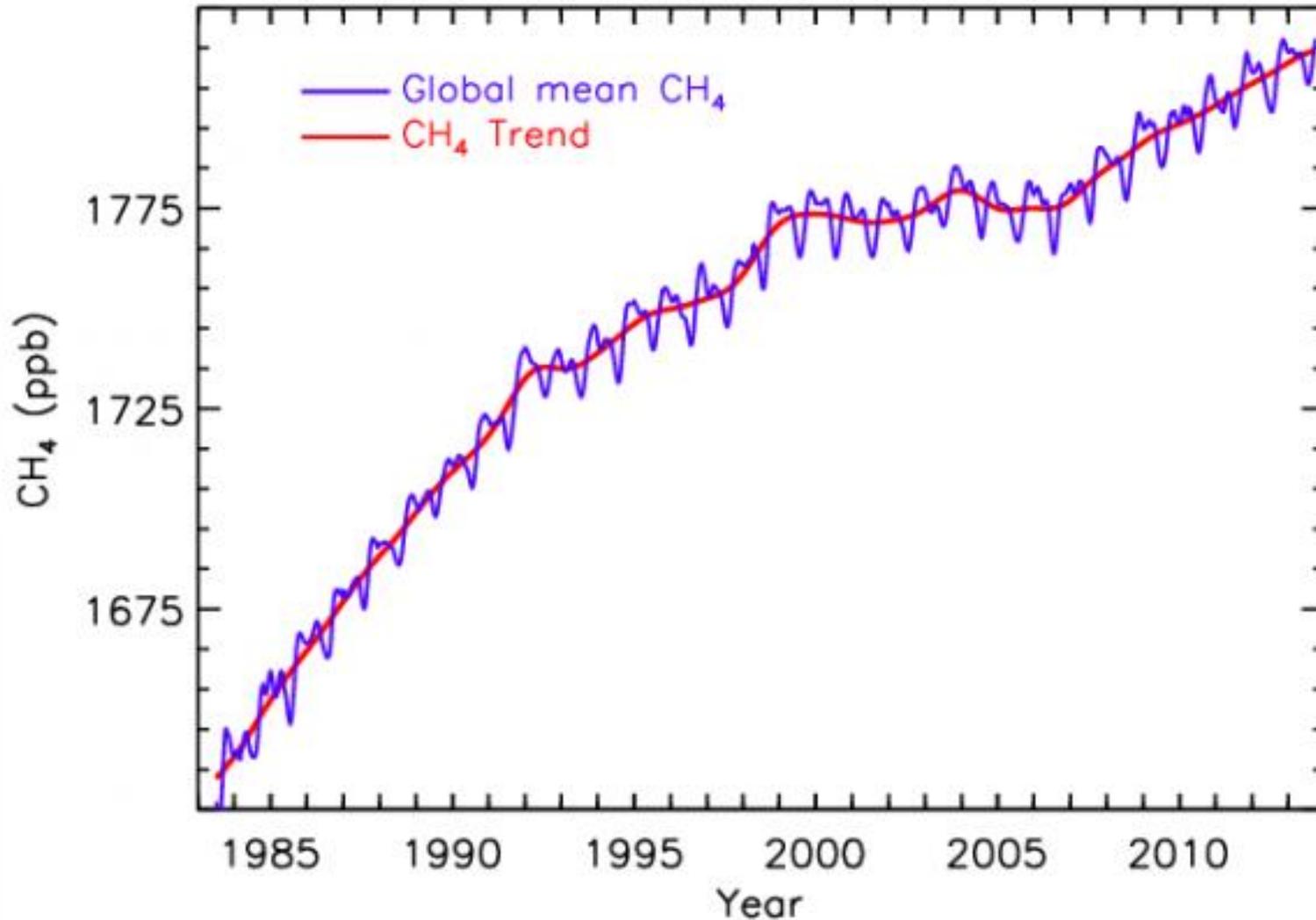
# EPA Underestimates Methane Emissions

**A large increase in US methane emissions over the past decade inferred from satellite data and surface observations**

Turner et al., 2016, AGU, doi: 10.1002/2016GL067987

“Here we use satellite retrievals and surface observations of atmospheric methane to suggest that US methane emissions have increased by more than 30% over the 2002-2014 period. This large increase in US methane emissions could account for 30-60% of the global growth of atmospheric methane seen in the past decade.”

# Measured Methane Concentration in the Atmosphere: Recent Record



courtesy of Ed Dlugokencky, NOAA



MAR 10, 2016

## EPA Taking Steps to Cut Methane Emissions from Existing Oil and Gas Sources

[0 Comments](#)

[Gina McCarthy](#)

March 10, 2016

By Gina McCarthy, EPA Administrator

9:13 am EDT

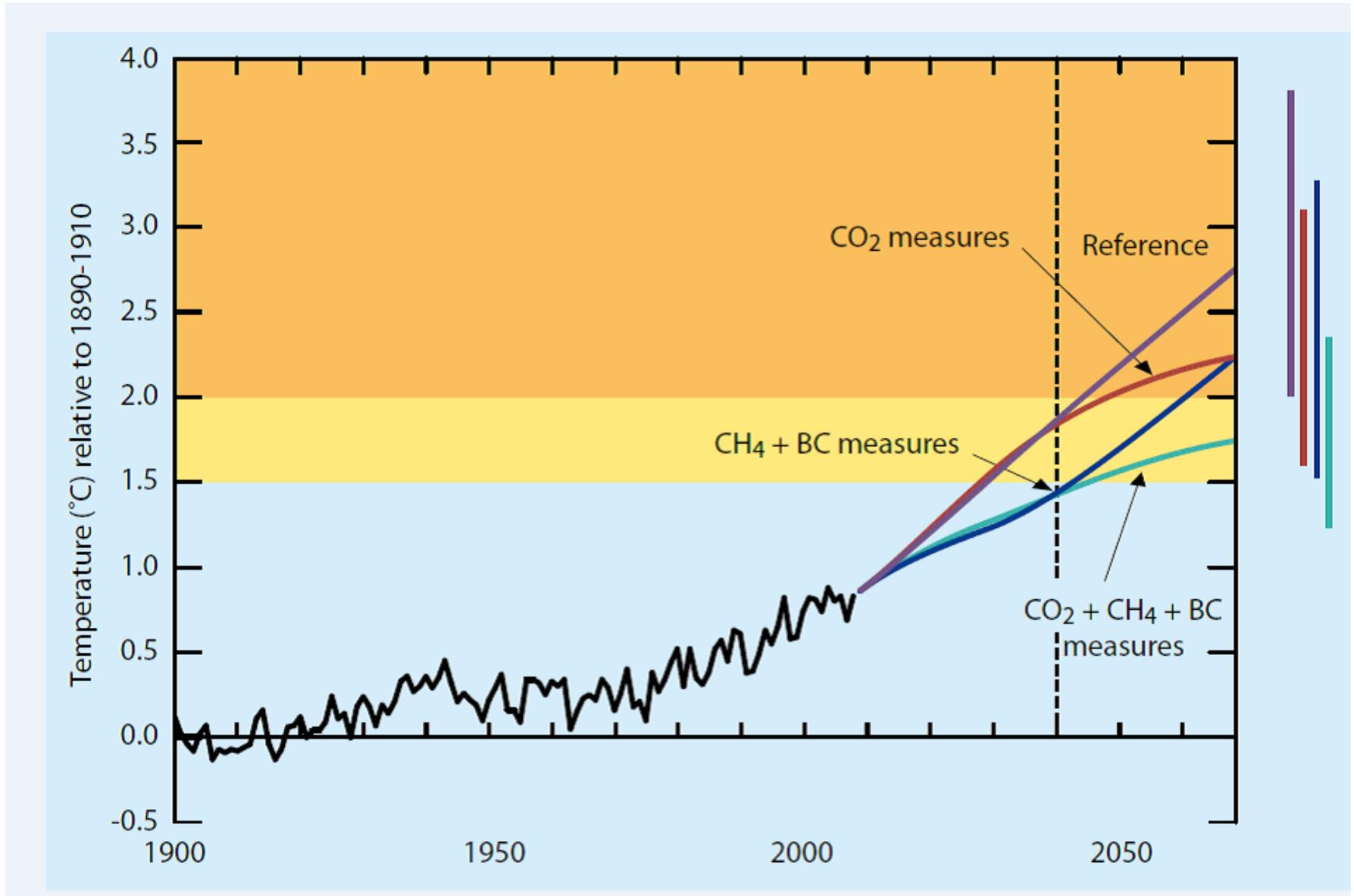
“Today, as part of the Obama Administration’s ongoing commitment to act on climate, President Barack Obama and Canadian Prime Minister Justin Trudeau committed to new actions to reduce methane pollution from the oil and natural gas sector, the world’s largest industrial source of methane. These actions build on the historic agreement that nearly 200 nations made in Paris last December to combat climate change and ensure a more stable environment for future generations.”

WASHINGTON (AP) — The leaders of the United States and Canada committed on Thursday to **curbing methane emissions** by undertaking regulations that would **target oil and gas production**.



Associated Press March 10, **2016**  
By KEVIN FREKING, Associated Press

# Why Is Controlling Methane (CH<sub>4</sub>) Emission So Important?

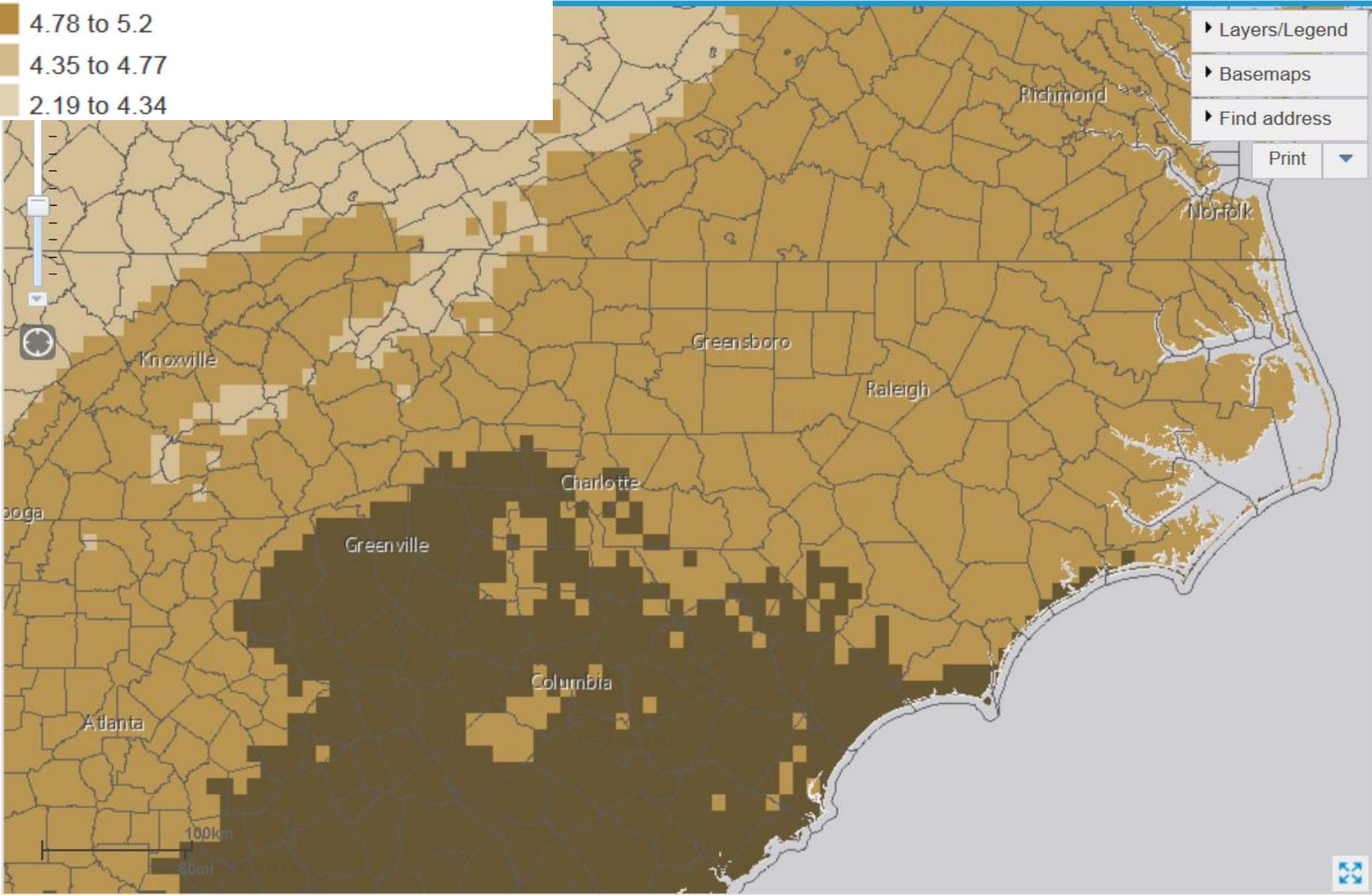


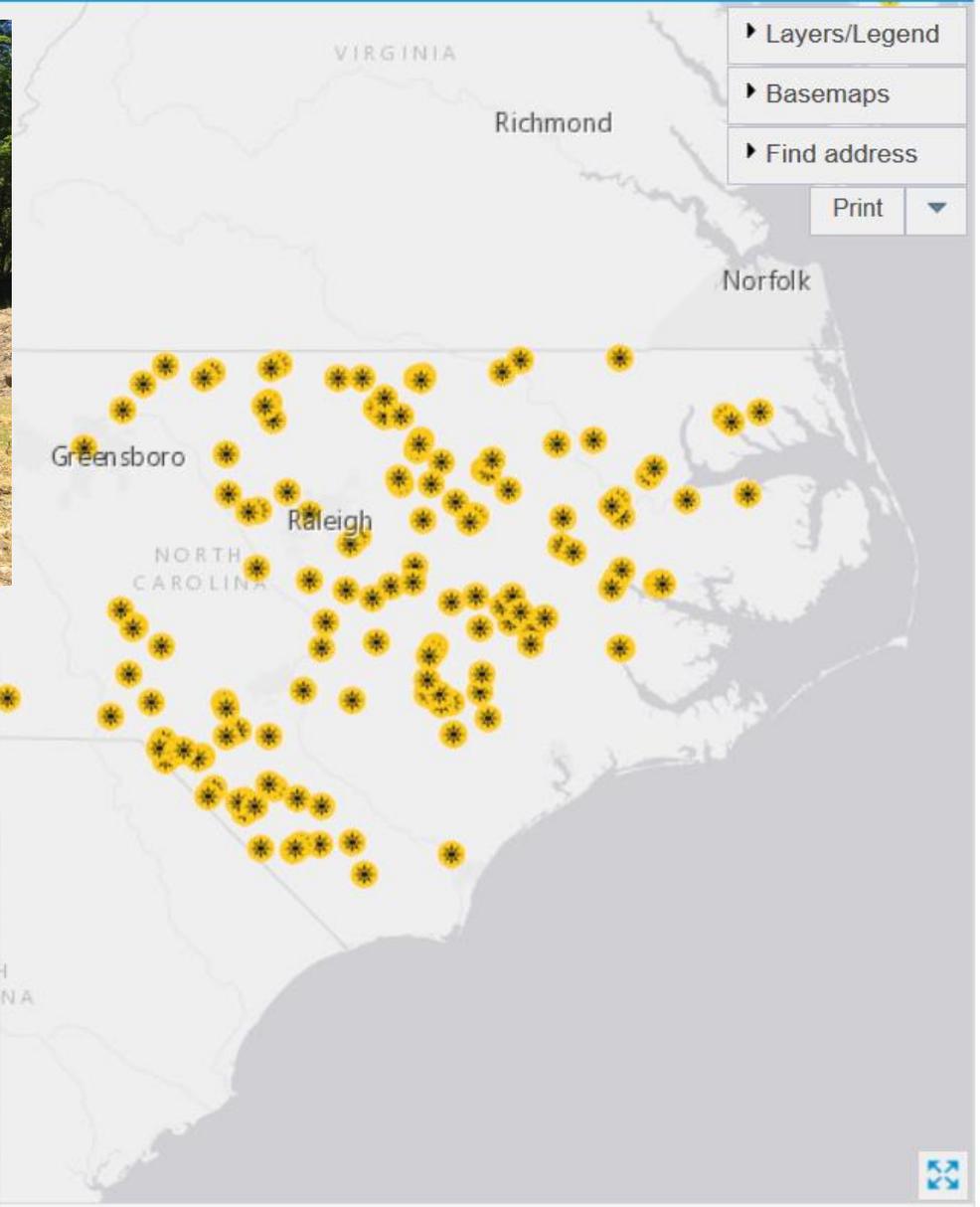
Shindell, *et al. Science* **335**, 183 (2012);

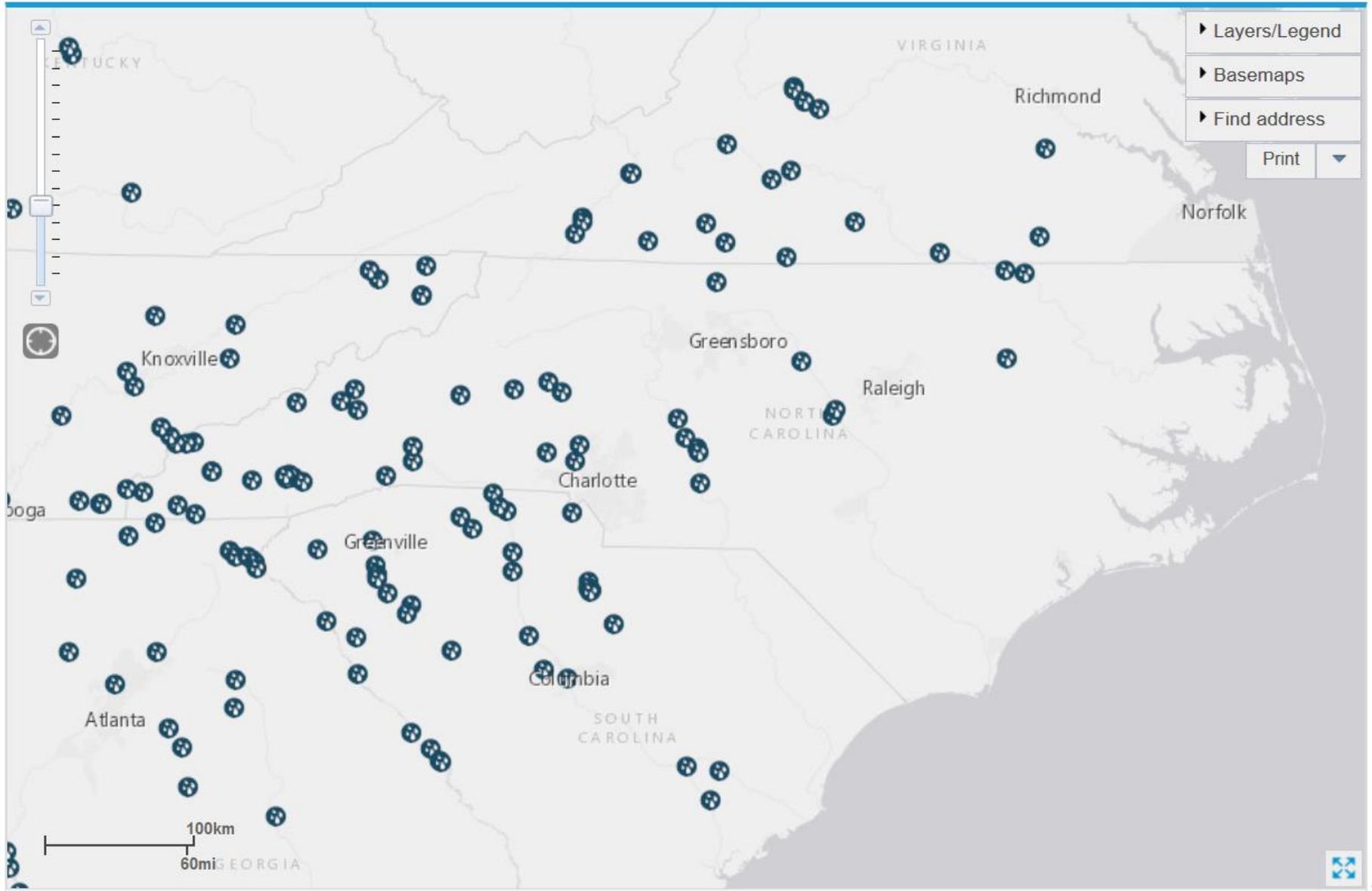
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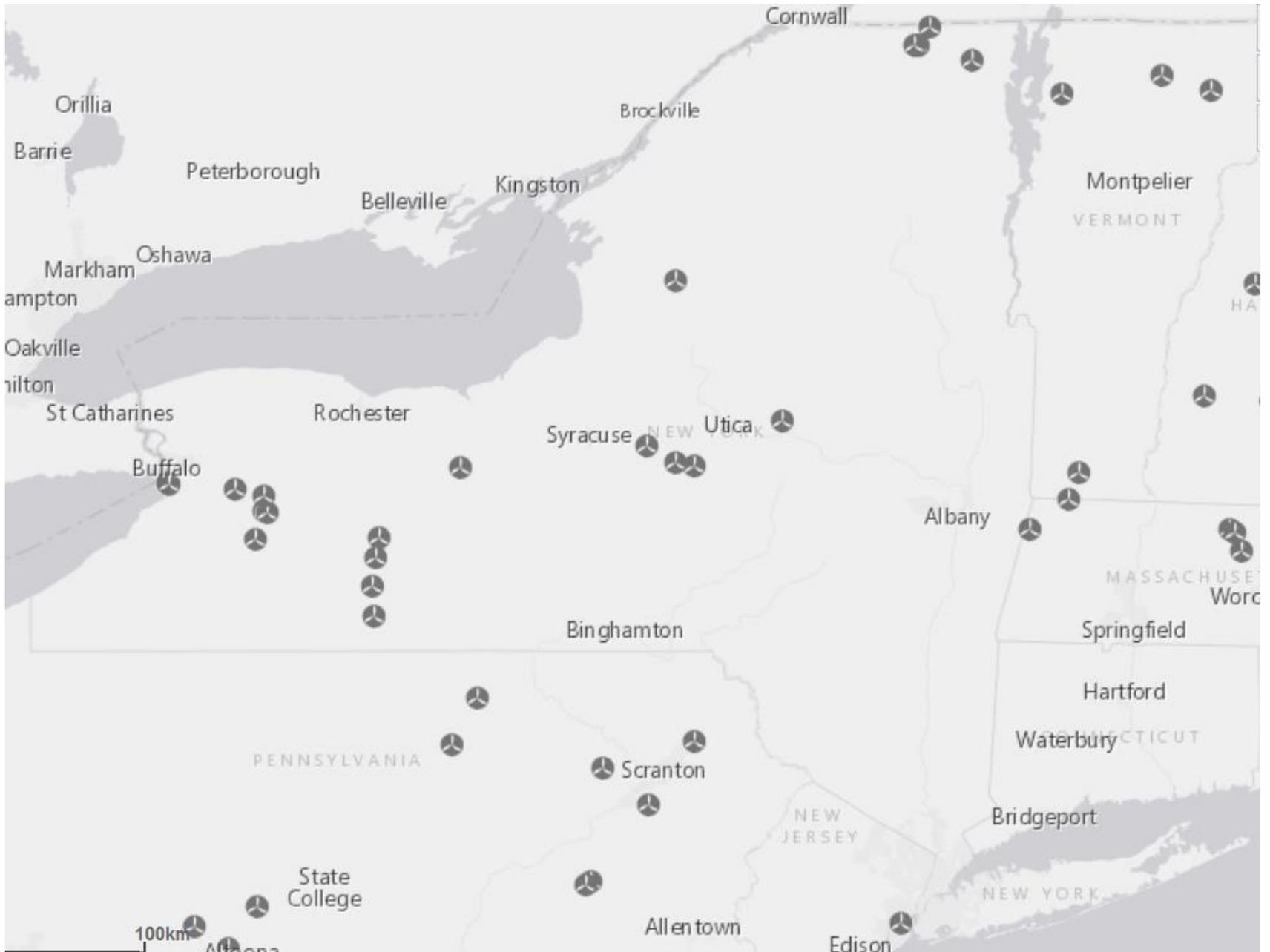
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# Photovoltaic Solar Potential

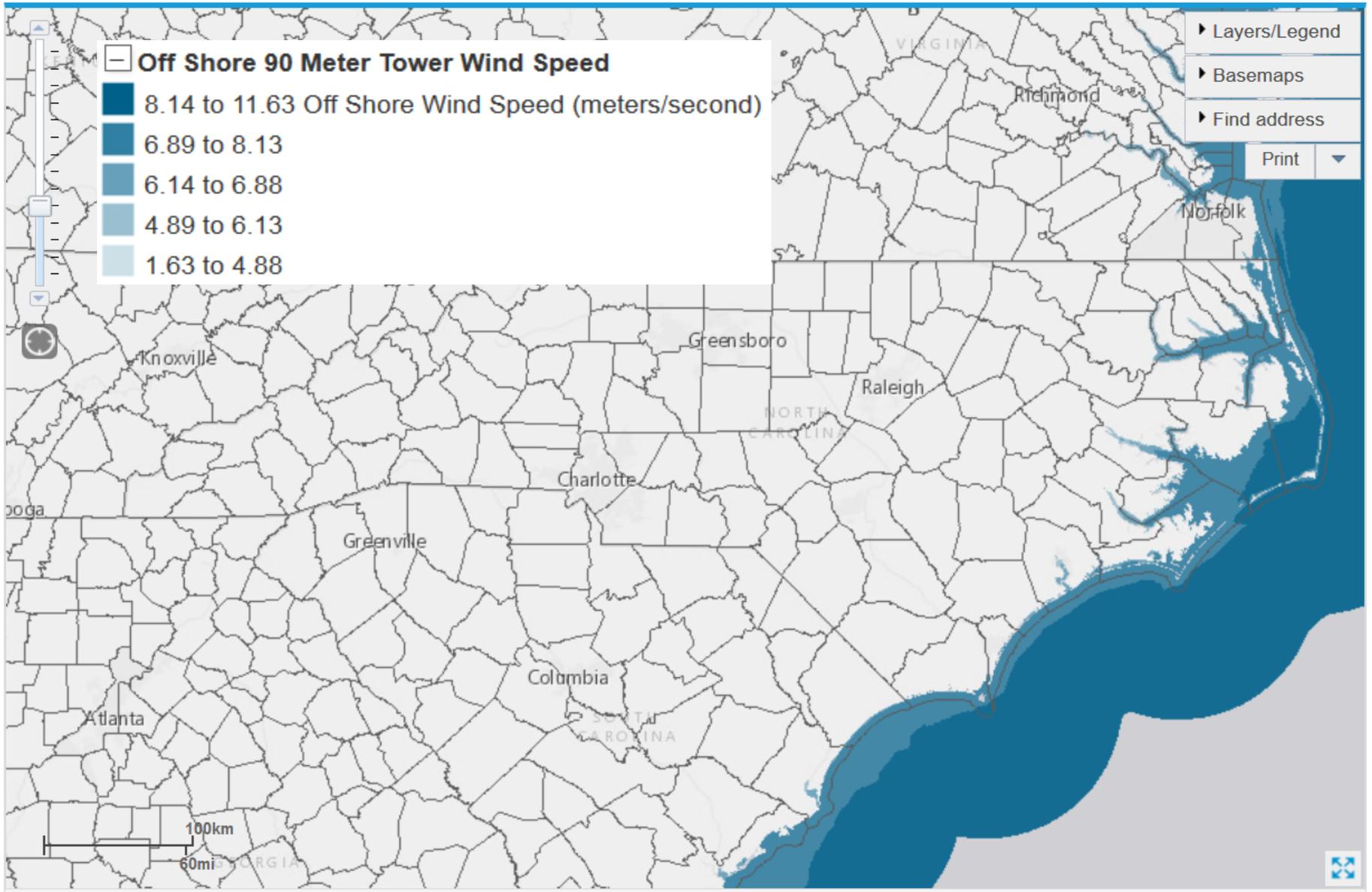






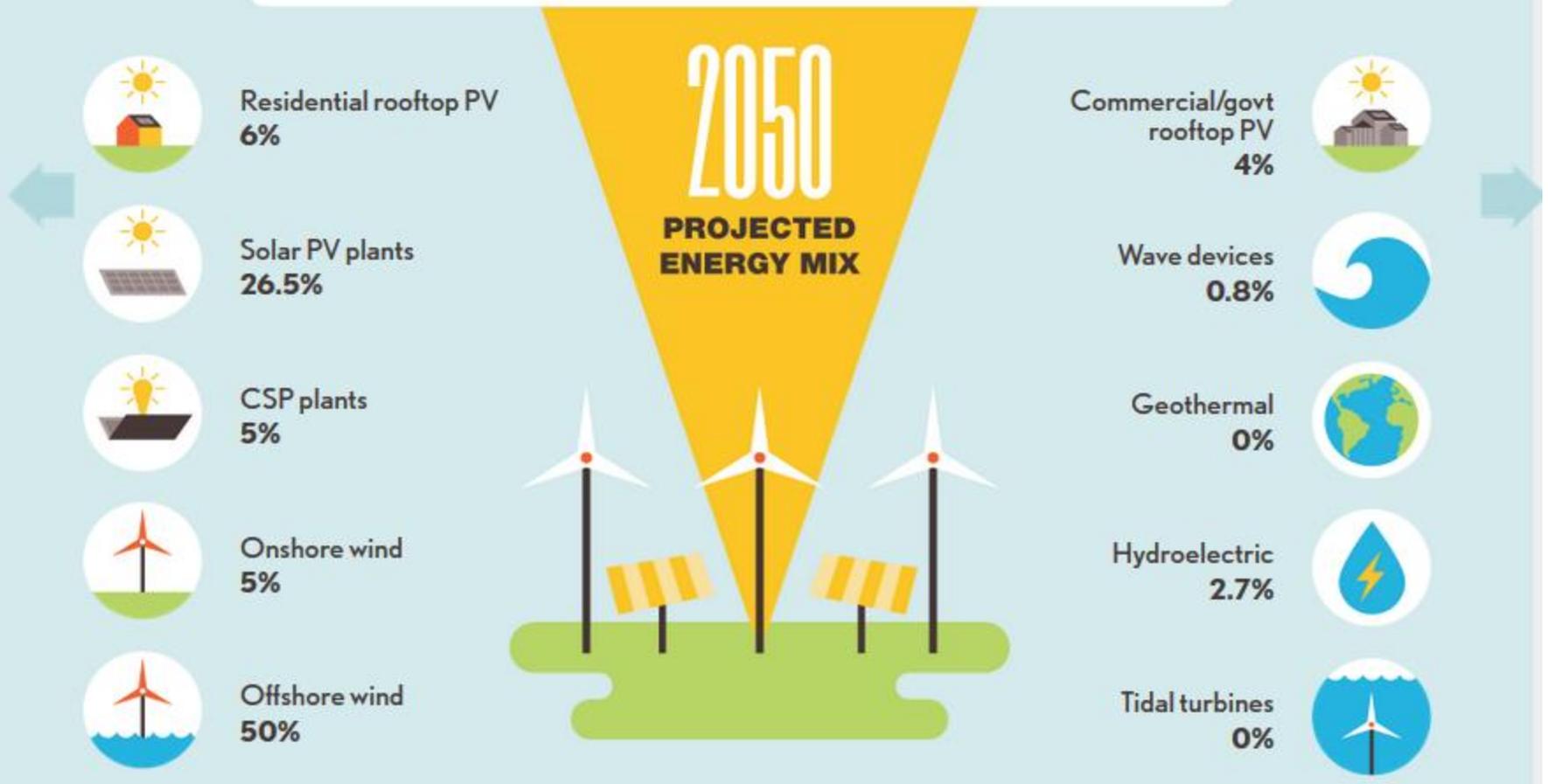


# U.S. Energy Mapping System



# 100% NORTH CAROLINA

Transition to 100% wind, water, and solar (WWS) for all purposes  
(electricity, transportation, heating/cooling, industry)



## Avoided Mortality and Illness Costs

Avoided health costs per year:



2% of state GDP

Air pollution deaths avoided every year: **1,672**



Plan pays for itself in as little as **3 years** from air pollution and climate cost savings alone

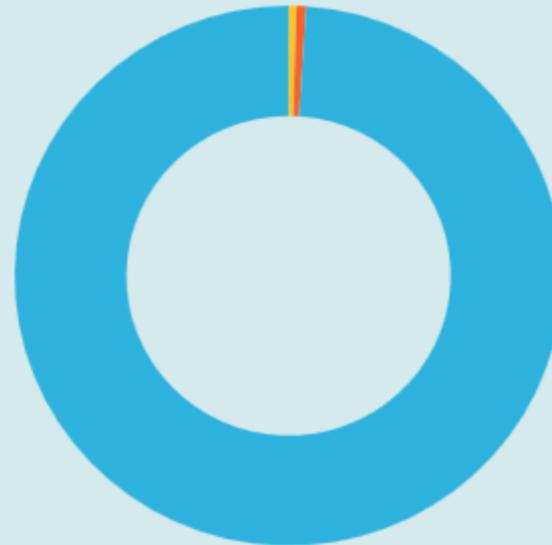
## Percentage of North Carolina Land Needed for All New WWS Generators

0.47%

Footprint area

0.56%

Spacing Area



## 40-Year Jobs Created

Number of jobs where a person is employed for 40 consecutive years

Construction jobs:



99,676

Operation jobs:



63,199

**Using WWS electricity for everything, instead of burning fuel, and improving energy efficiency means you need much less energy**

Current demand

Wind, water, solar

-40.0%



# Future Energy Costs 2050

 **BAU (Business as usual)**       **WWS (Wind, water, solar)**

 State average fossil fuel plus nuclear energy costs\*  **10.5¢/kWh**

\*Health and climate externality costs of fossil fuels are another 5.7¢/kWh

 State average WWS electricity costs  **11.1¢/kWh**

## Money in Your Pocket

 = **\$1,000**

Annual energy, health, and climate cost savings per person in 2050: **\$6,623**

Annual energy cost savings per person in 2050: **\$131**



**VISIT [THE SOLUTIONS PROJECT.ORG](http://THE SOLUTIONS PROJECT.ORG)  
TO LEARN MORE AND [100.ORG](http://100.ORG) TO JOIN THE MOVEMENT**

# Summary

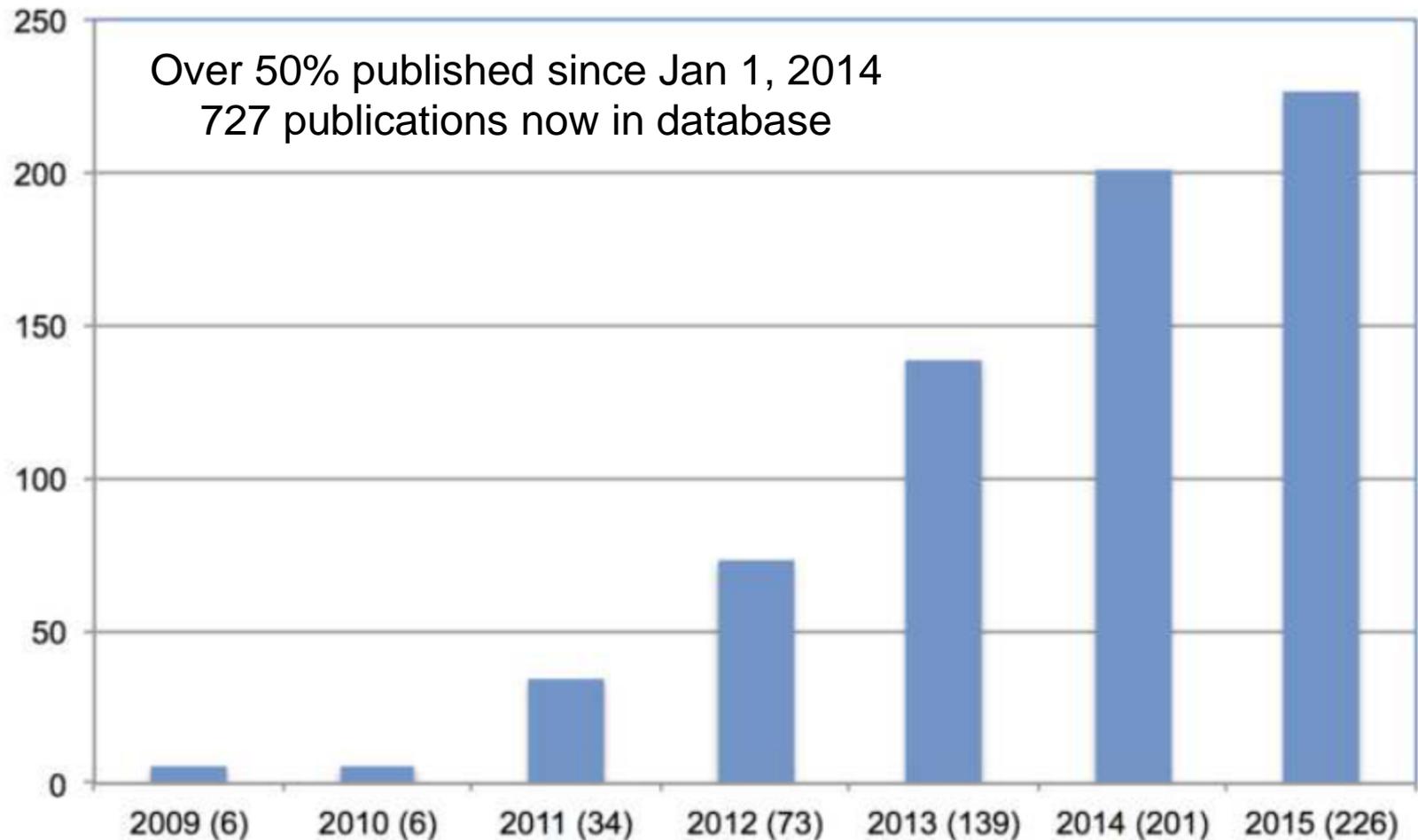
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# Results from the 2012 DENR Study

*“To our knowledge, no comprehensive studies are currently available on the long-term impacts to health from hydraulic fracturing for natural gas, and DENR is not qualified to conduct such a study. DENR recognizes that questions remain about health impacts....”*

**That was then, this is now.....**

# Number of publications that assess the impacts of shale or tight gas development per year, 2009-2015



# PSE STUDY CITATION DATABASE on Shale & Tight Gas Development

This citation database provides bibliographic information, abstracts, and links to many of the vetted scientific papers housed in the *PSE Healthy Energy Library*, as well as other peer-reviewed journal articles. This database is a near exhaustive and evolving list of the peer-reviewed literature that directly pertains to shale and tight gas development. This literature is organized into twelve different categories, including air quality, water quality, climate, public health, and regulations. PSE Healthy Energy does not necessarily support the methods and the findings of the studies included in this database.



Once accessed, users have the ability to sort, search, and select from the database. We recommend sorting the list by author name. This can be done by clicking the "creator" heading on the right side of the screen. Library settings can also be changed by clicking the button above "date modified" (here we recommend including "year" in the library view). Additionally, the Zotero library search bar (top right) is useful and can be used to search journal articles by topic, author, title, etc.

[https://www.zotero.org/groups/pse\\_study\\_citation\\_database/items](https://www.zotero.org/groups/pse_study_citation_database/items)

# PSE STUDY CITATION DATABASE on Shale & Tight Gas Development

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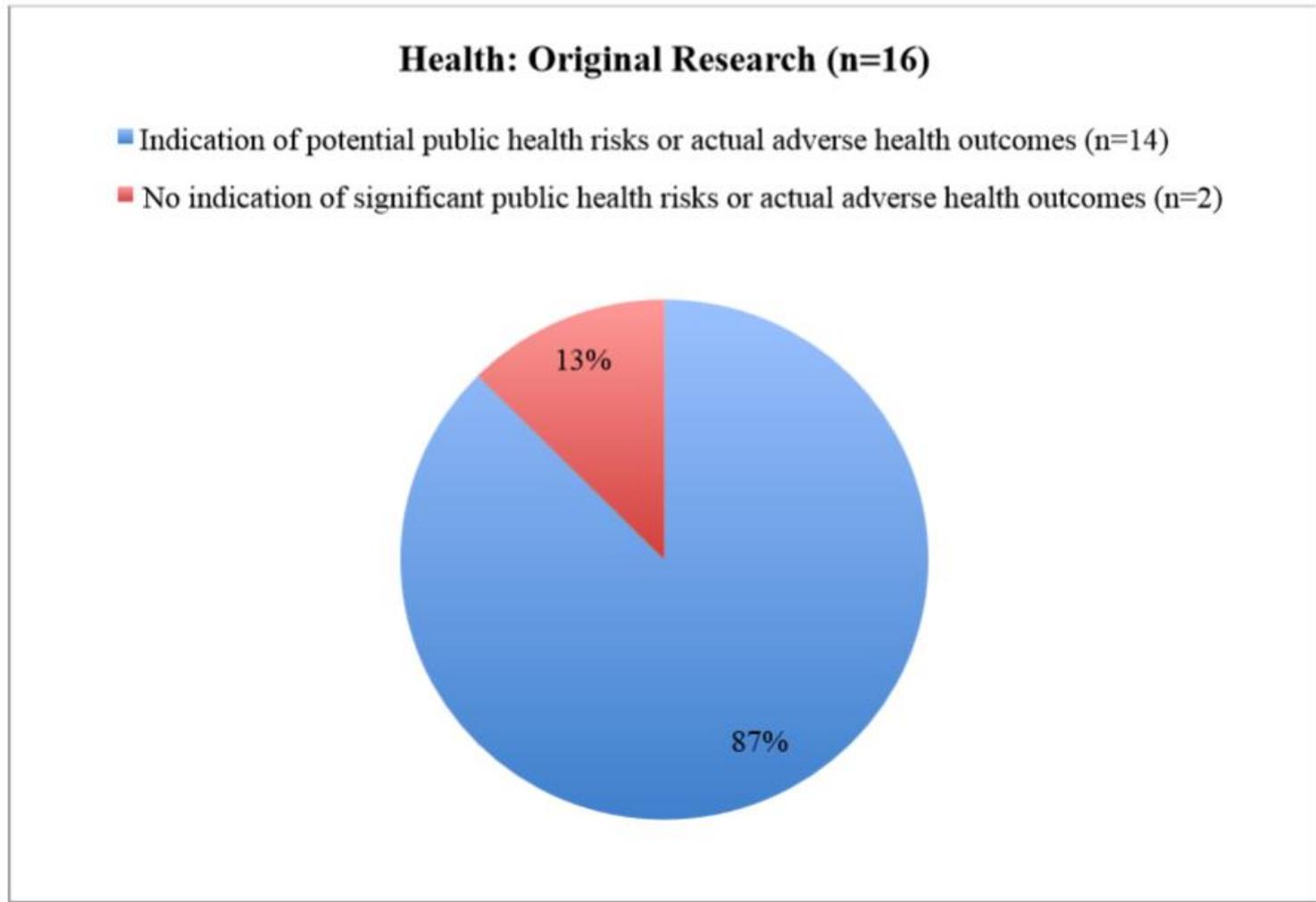
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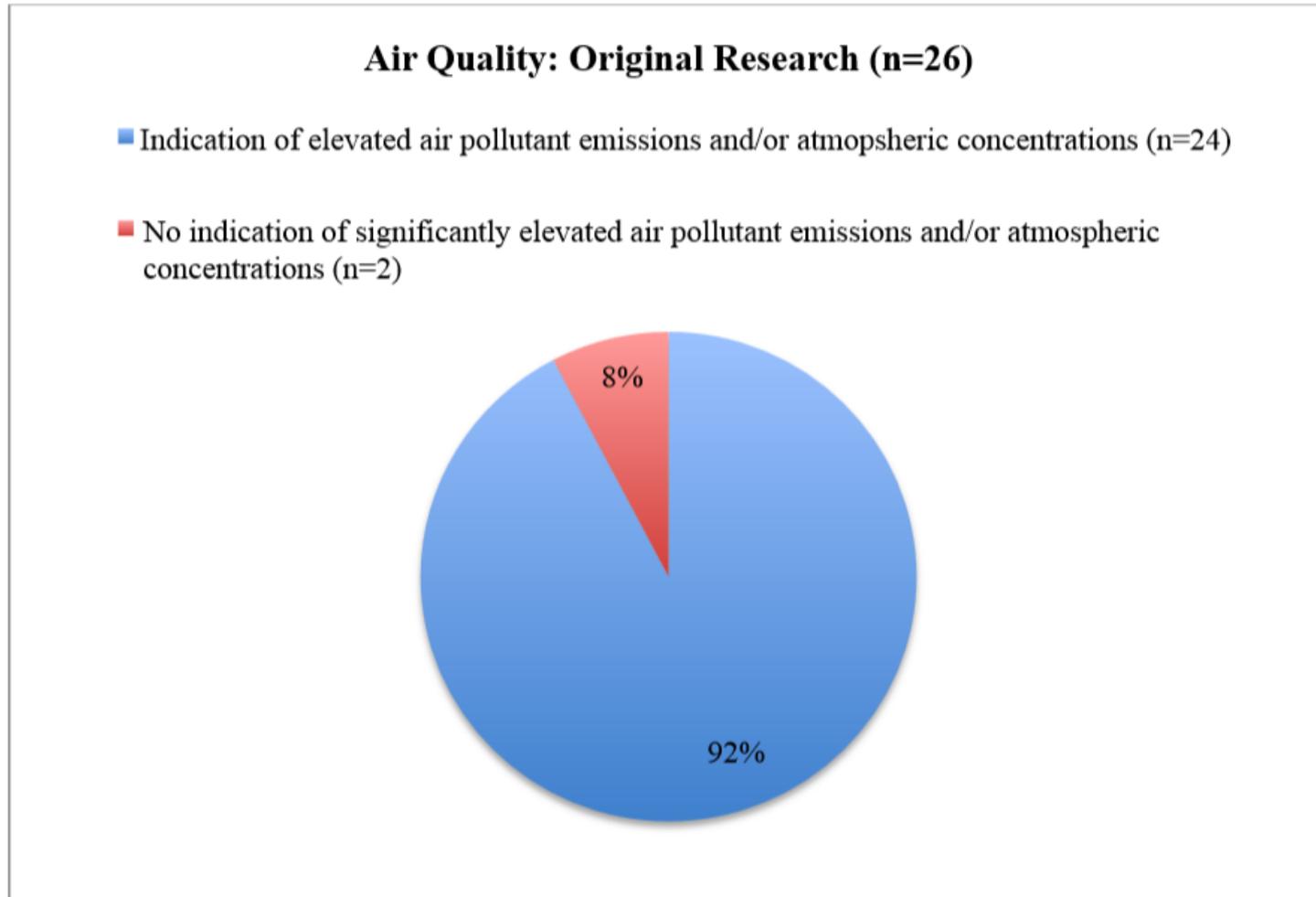
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# What Does the Science Say About Health Impacts?



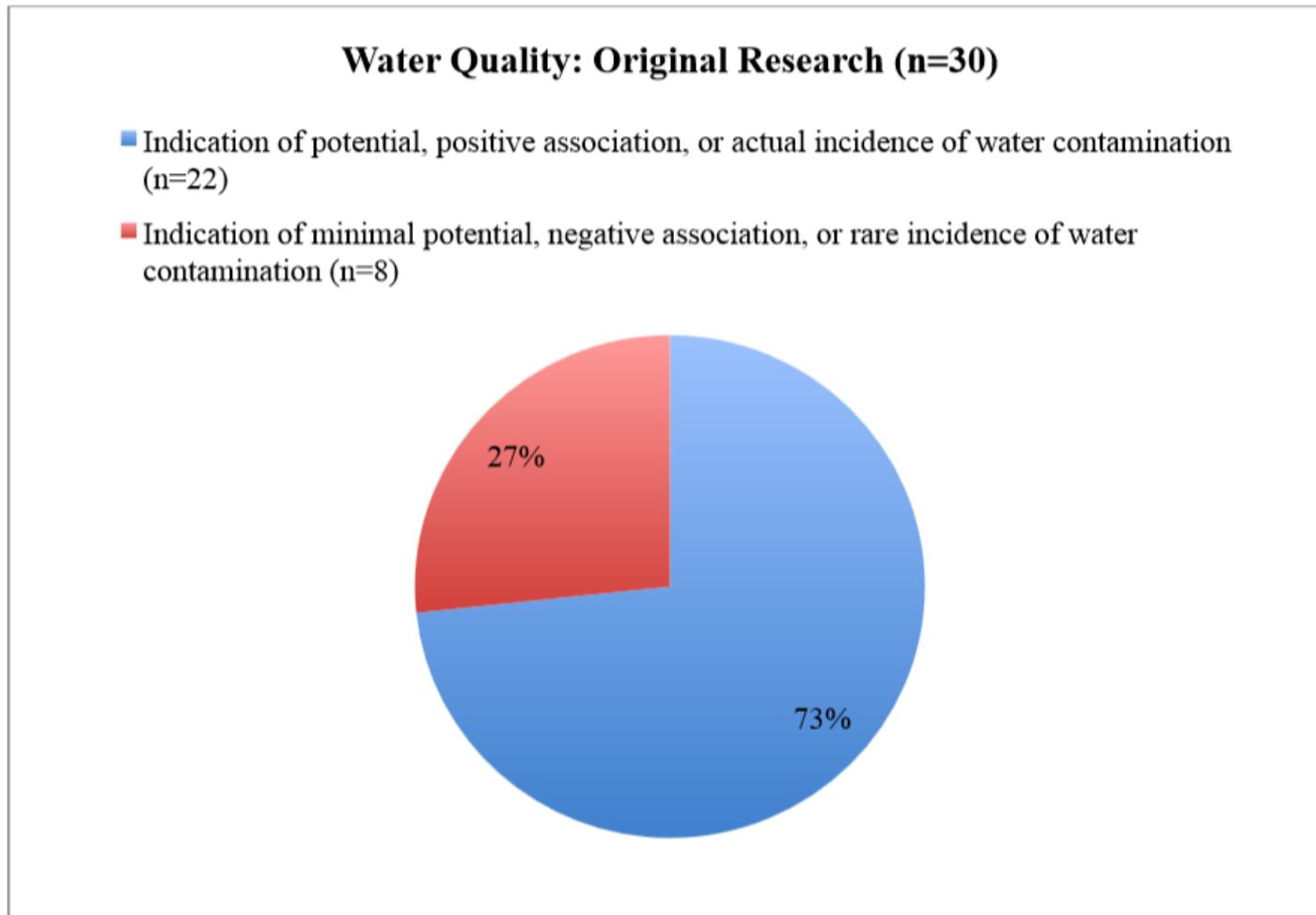
**Figure 2.** Peer-reviewed publications on the human health dimensions of shale gas development (original research)

# What Does the Science Say About Air Quality Impacts?



**Figure 5.** Peer-reviewed publications on shale and tight gas development and air pollutant emissions/air quality degradation (original research)

# What Does the Science Say About Water Quality Impacts?



**Figure 4.** Peer-reviewed publications on shale gas development and water quality contamination (original research)

# Summary

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# Don't Take My Word for It: James Hansen on Shale Gas as a Bridge Fuel



Dr. James Hansen speaking at the COP21 Paris climate talks Dec. 2. Photo credit: Stefanie Spear

“If gas were truly used as a very temporary bridge to replace coal ... **But that’s not what’s happening.** If you build a new power plant, you don’t plan to shut it down in 10 years. There’s way too much gas in the ground. **It would put us way over 2C, 3C, 4C.** There’s a huge amount of gas in the ground. What political leaders have not been willing to do is face the truth that you can’t burn all of that. They’re allowing, even bragging about, having found the technology to get more of the gas out of the ground with fracking.”

# The So-Called Bridge to A Sustainable Future

I am a civil engineer.

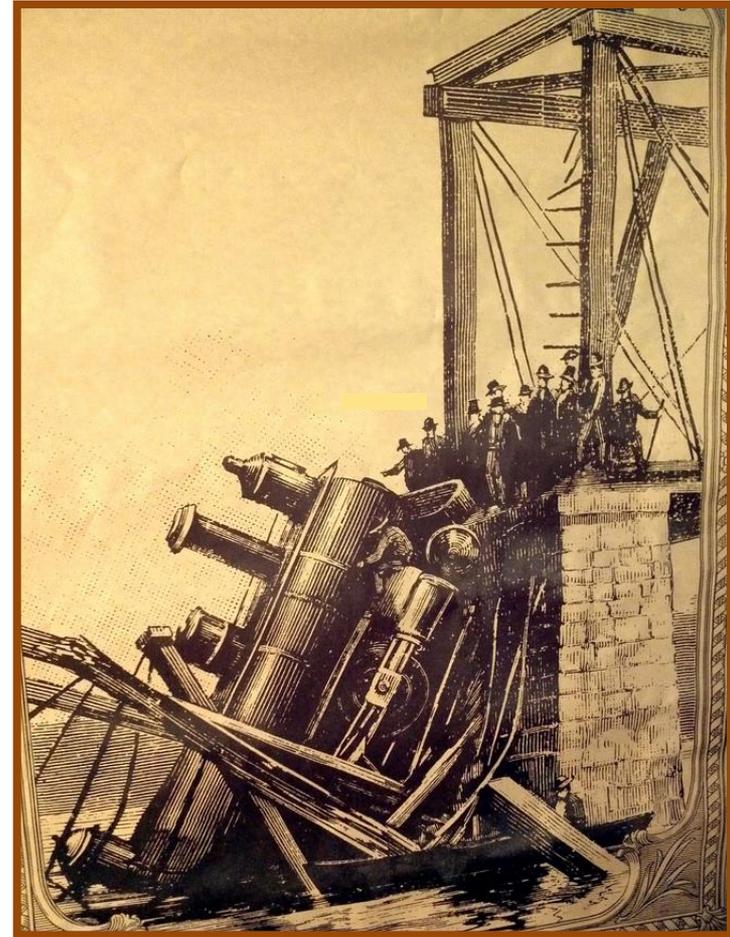
Civil engineers know bridges.

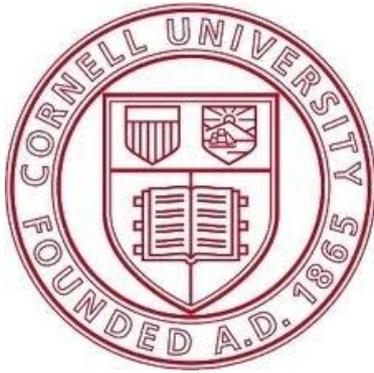
A bridge has an abutment at one end,  
where you are.

A bridge has another abutment at the  
other end, where you want to go.

The bridge spans over that danger into  
which you do not want to fall.

**The so-called shale gas/oil bridge is the only one ever conceived where the bridge is constructed of the danger into which you do not want to fall.**





# Thank You for Attending and Participating

*(THE REST OF THE SLIDES THAT FOLLOW ARE NOT A PART  
OF THE MAIN PRESENTATION, BUT WE THOUGHT YOU  
MIGHT BE INTERESTED)*

# The Boom, the Flash, the Bust

LONDON – The world’s biggest oil companies are slashing jobs and backing off major investments as the price of crude falls to new lows – and there may be more pain to come. Companies like **BP**, which said Tuesday it is **cutting 4,000 jobs**, are slimming down to cope with the slump in oil, whose price plummeted to its lowest

## **Oil Jobs Lost: 250,000 And Counting, Texas Likely To See Massive Layoffs Soon**

<http://oilprice.com/Energy/Energy-General/Oil-Jobs-Lost-250000-And-Counting-Texas-Likely-To-See-Massive-Layoffs-Soon.html>

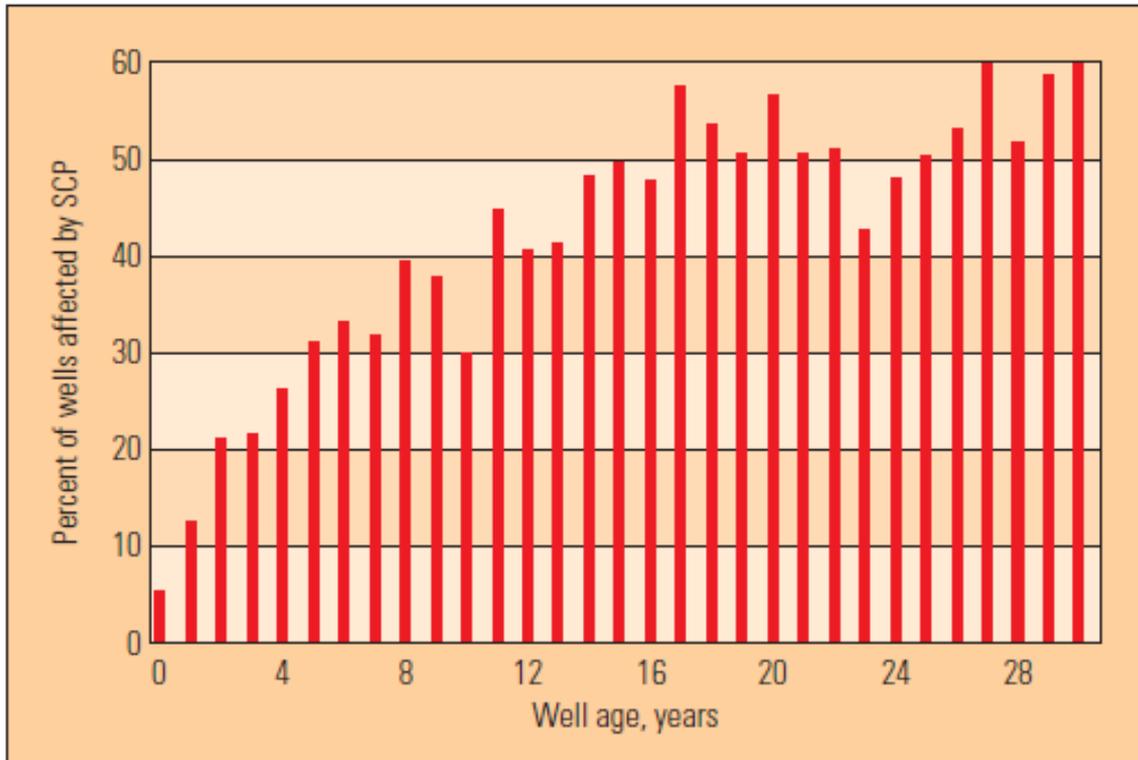
Christmas. That was up from 14,000 the year before.

[http://www.observerreporter.com/20160112/as\\_oil\\_plunges\\_energy\\_companies\\_cut\\_jobs\\_postpone\\_projects\\_](http://www.observerreporter.com/20160112/as_oil_plunges_energy_companies_cut_jobs_postpone_projects_)

**“After cutting 20,000 jobs this year, Schlumberger warns of new layoff round...”**

<http://petroglobalnews.com/2015/12/schlumberger-warns-of-new-layoff-round/>

# Industry-Reported Data On Loss of Wellbore Integrity: Offshore Wells

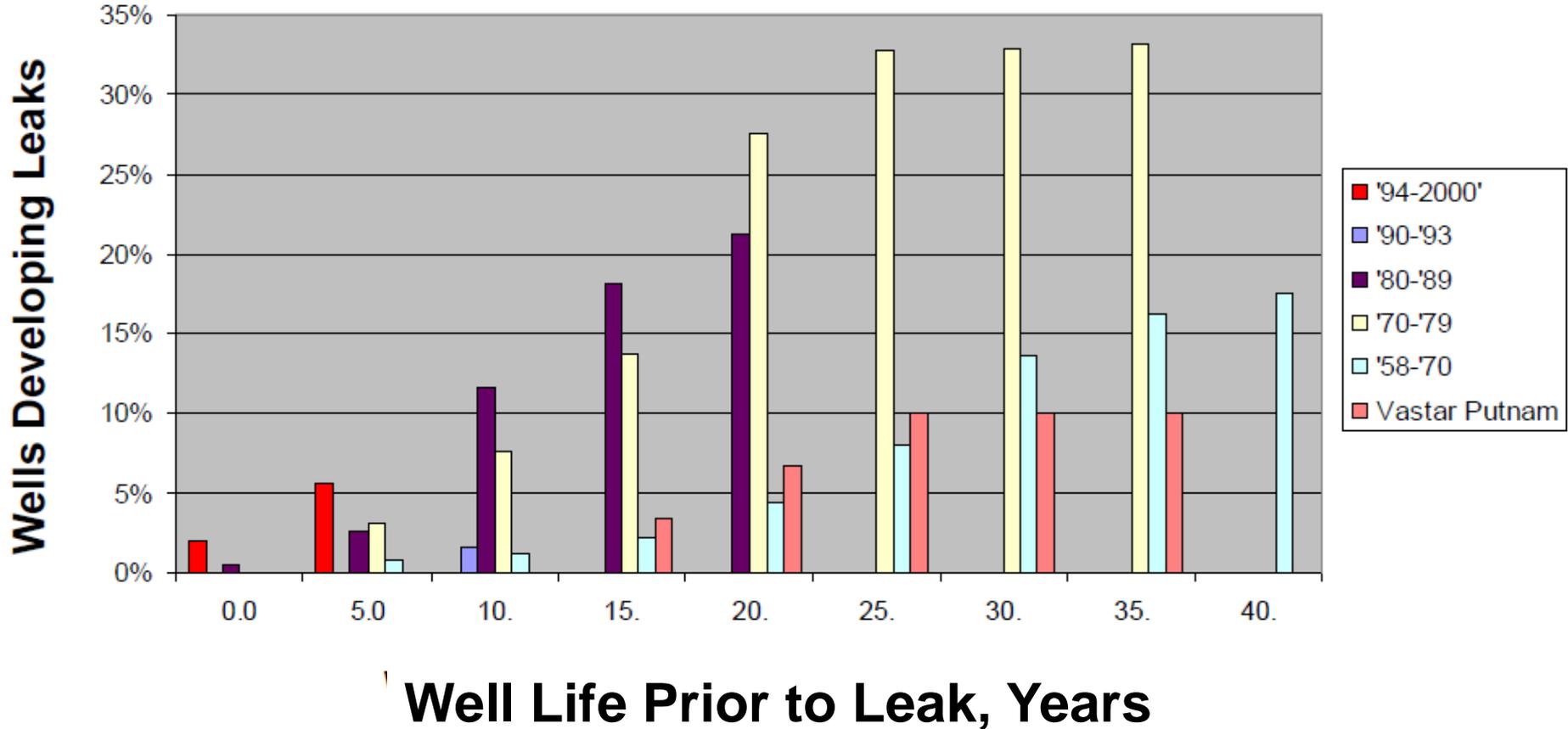


SCP=Sustained Casing Pressure. Also called sustained annular pressure, in one or more of the casing annuli.

- About 5% of wells fail soon
- More fail with age
- Most fail by maturity

^ Wells with SCP by age. Statistics from the United States Mineral Management Service (MMS) show the percentage of wells with SCP for wells in the outer continental shelf (OCS) area of the Gulf of Mexico, grouped by age of the wells. These data do not include wells in state waters or land locations.

# Worldwide Leaky Well Industry Statistics



From George E King Consulting Inc.: <http://gekengineering.com/id6.html>

# So, We Decided To Do Our Own Study Of Onshore Gas/Oil Wells in Pennsylvania

- Created database of **75,000 inspection and violation records** for over **41,000 gas and oil wells drilled** in Pennsylvania, 1/1/2000-12/31/2012
- Mined the retrospective data to identify all wells with wellbore integrity problems
- Statistically analyzed results to estimate future hazard: Cox Proportional Hazard Model
- Peer-reviewed results published in Ingraffea et al., PNAS, 2014.

# Results – The Retrospective Data

	Cumulative Indicator Count	Cumulative Spuds Inspected	% Wells with Indicator
Conventional	280	26,915	1.00%
Unconventional	355	5,763	6.20%
Statewide Total	635	32,678	1.90%

While the overall impairment rate inferred from inspection records is < 2%, **unconventional wells show a much higher rate of 6.2%**, heavily influenced by impairments in the NE region, which are ~5x higher than rest of state.

Wells spudded	Non-NE counties		NE counties	
	Conventional	Unconventional	Conventional	Unconventional
Pre-2009	0.73%	1.49%	5.21%	9.84%
Post-2009	2.08%	1.88%	2.27%	9.14%

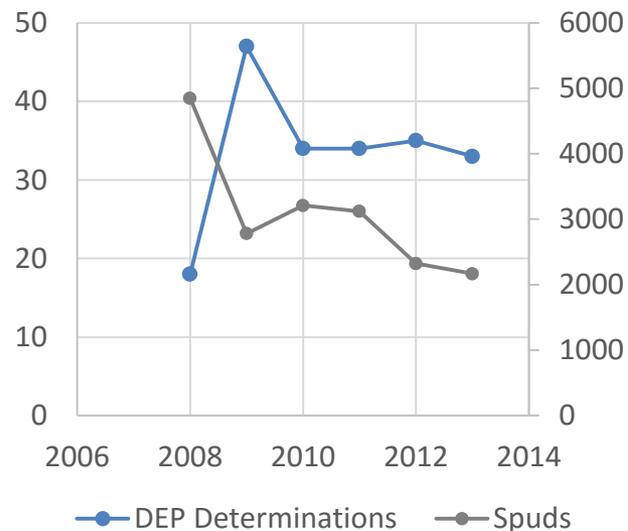
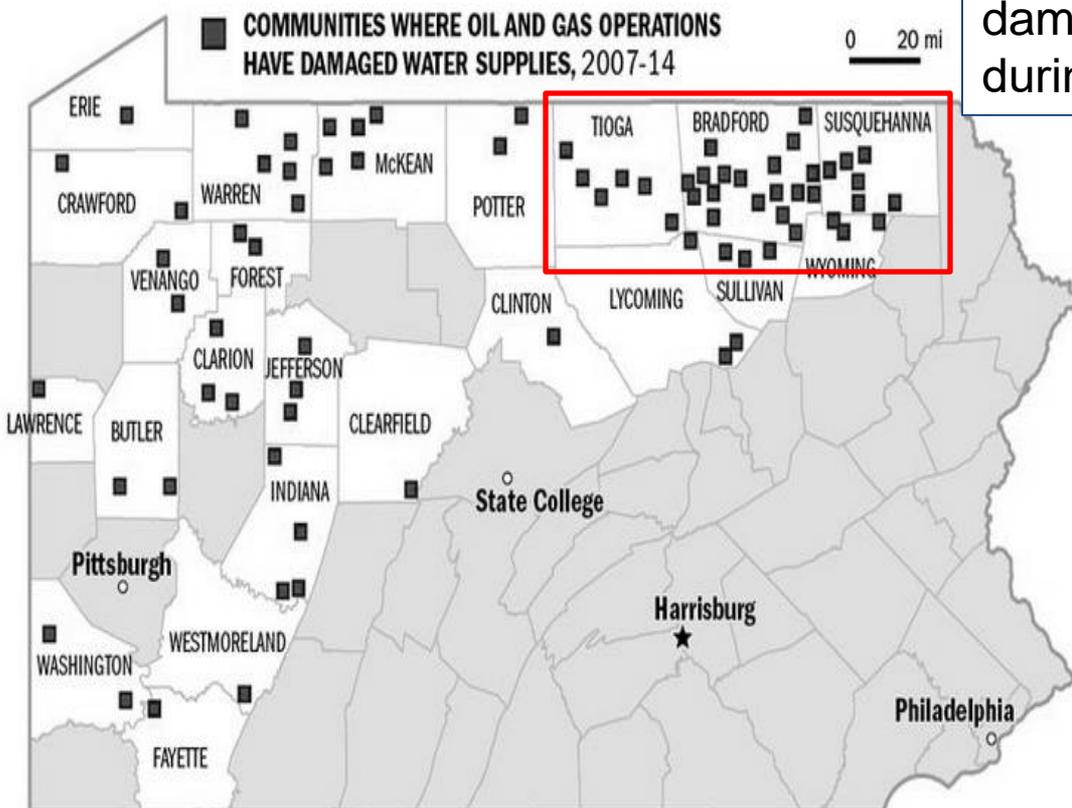
Statewide, rate of loss of structural integrity for conventional and unconventional wells spudded between 2000–2012 are 1.0% and 6.2%, respectively (weighted average = 1.9%).

# The Groundwater Issue: 260 Positive Determination Letters from New PADEP Database

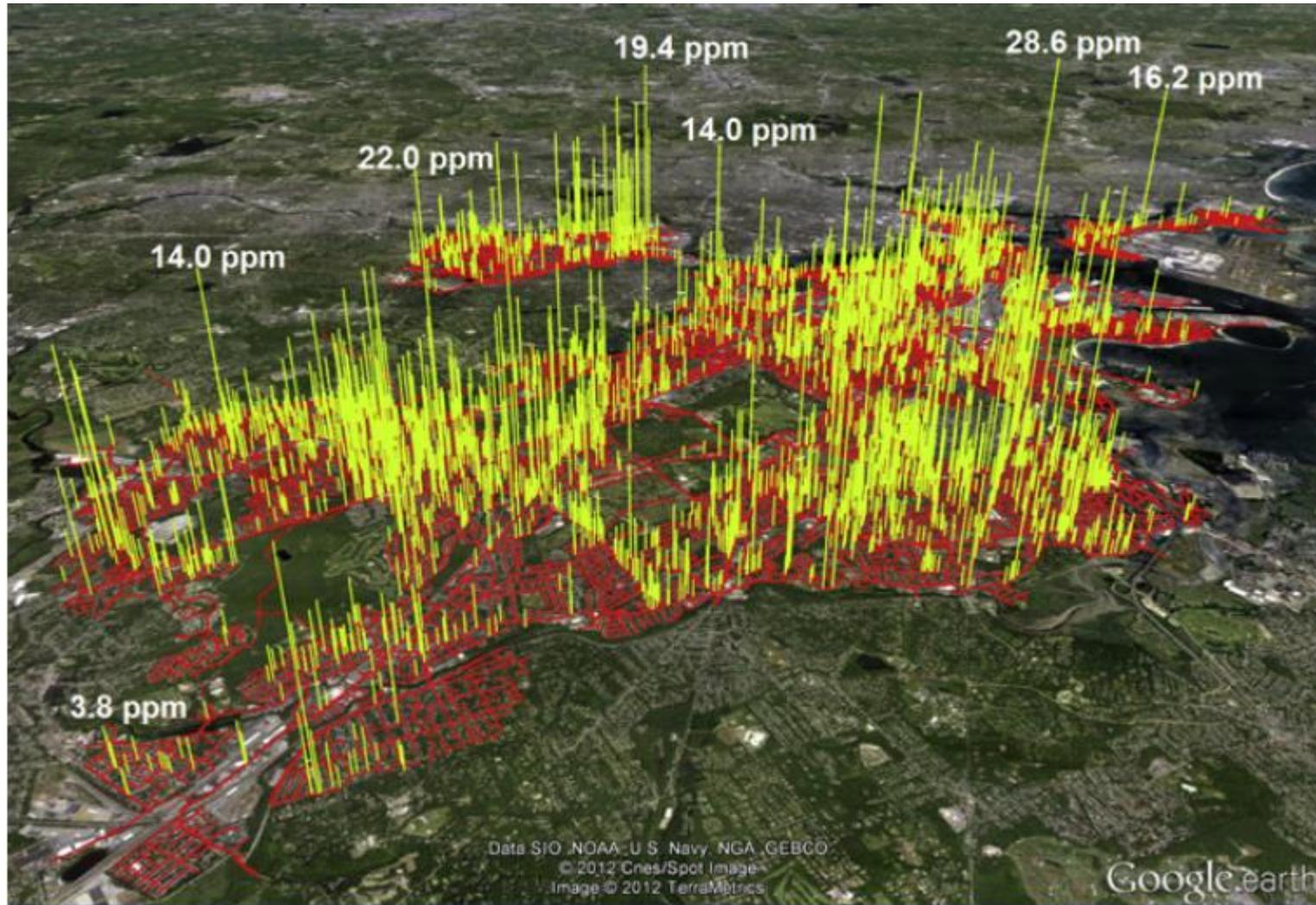
## Drilling-related water impacts

Since 2007 the state has determined oil and gas operations have either polluted the flow to water supplies in 77 communities.

“Pennsylvania regulators found an array of contaminants in the roughly 240 private water supplies they said were damaged by oil and gas operations during the past seven years.”

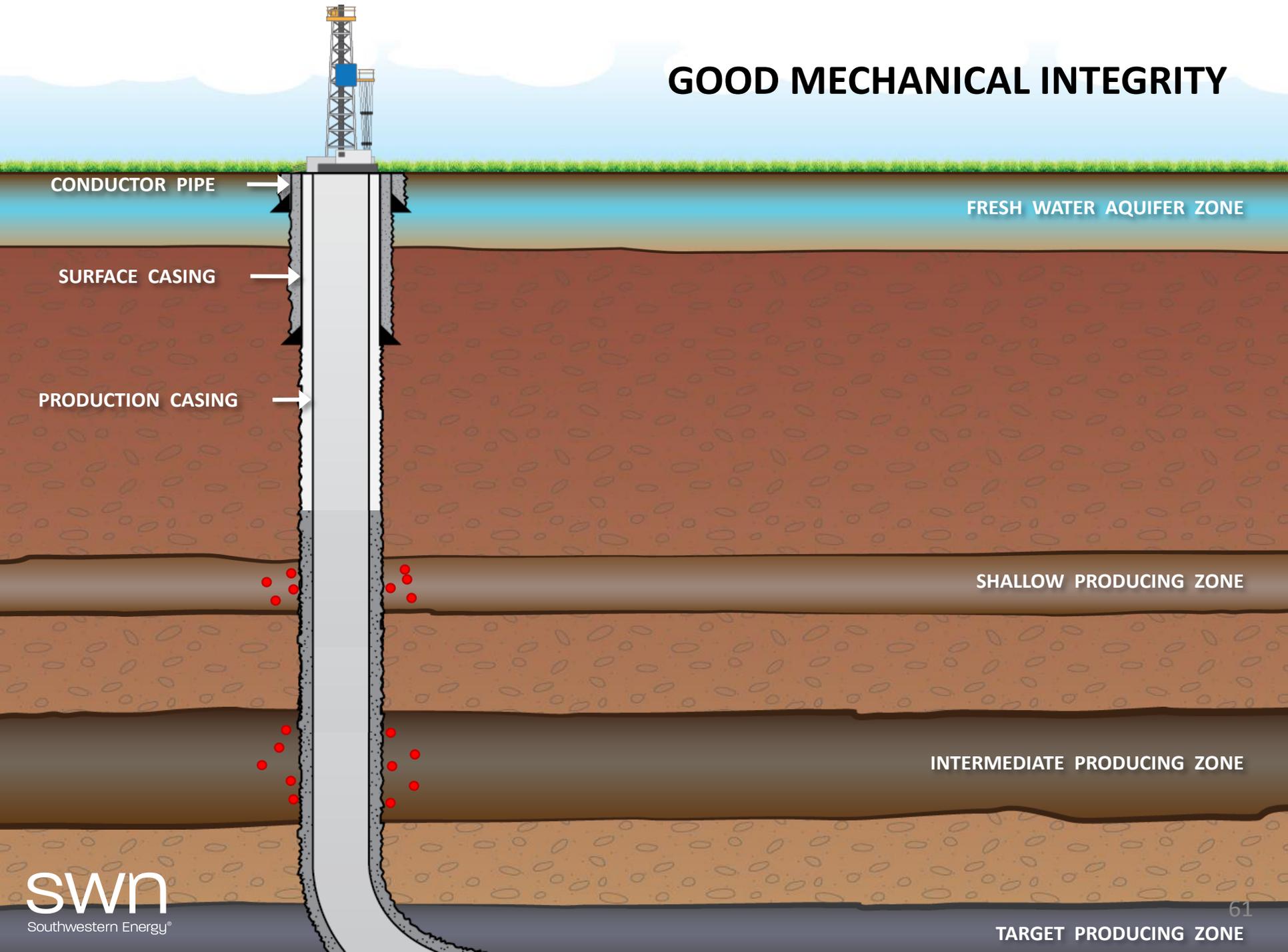


# Downstream Methane Leakage from Aging Urban Distribution Pipelines: Boston MA



*N.G. Phillips et al. / Environmental Pollution 173 (2013) 1–4*

# GOOD MECHANICAL INTEGRITY



CONDUCTOR PIPE

FRESH WATER AQUIFER ZONE

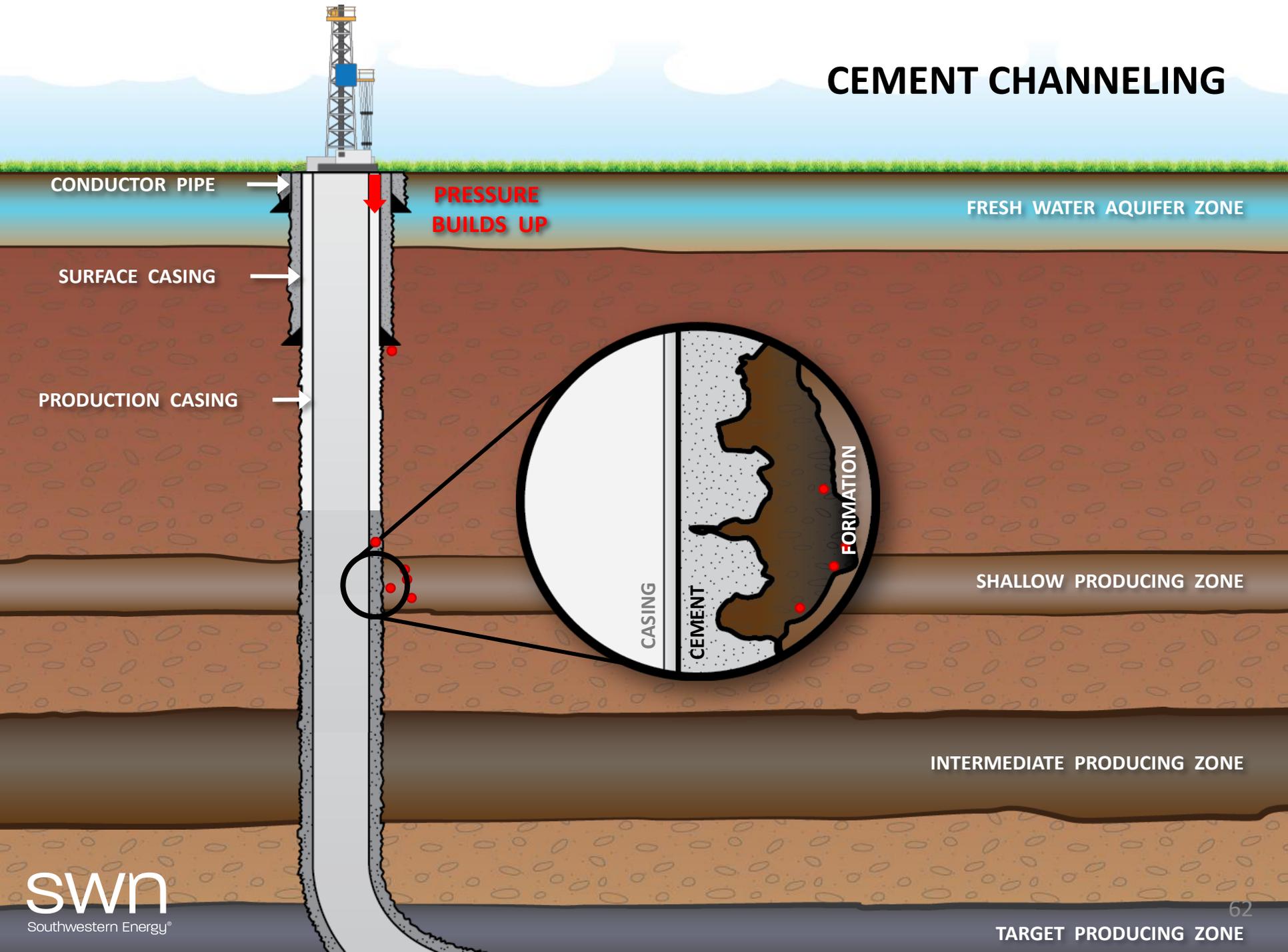
SURFACE CASING

PRODUCTION CASING

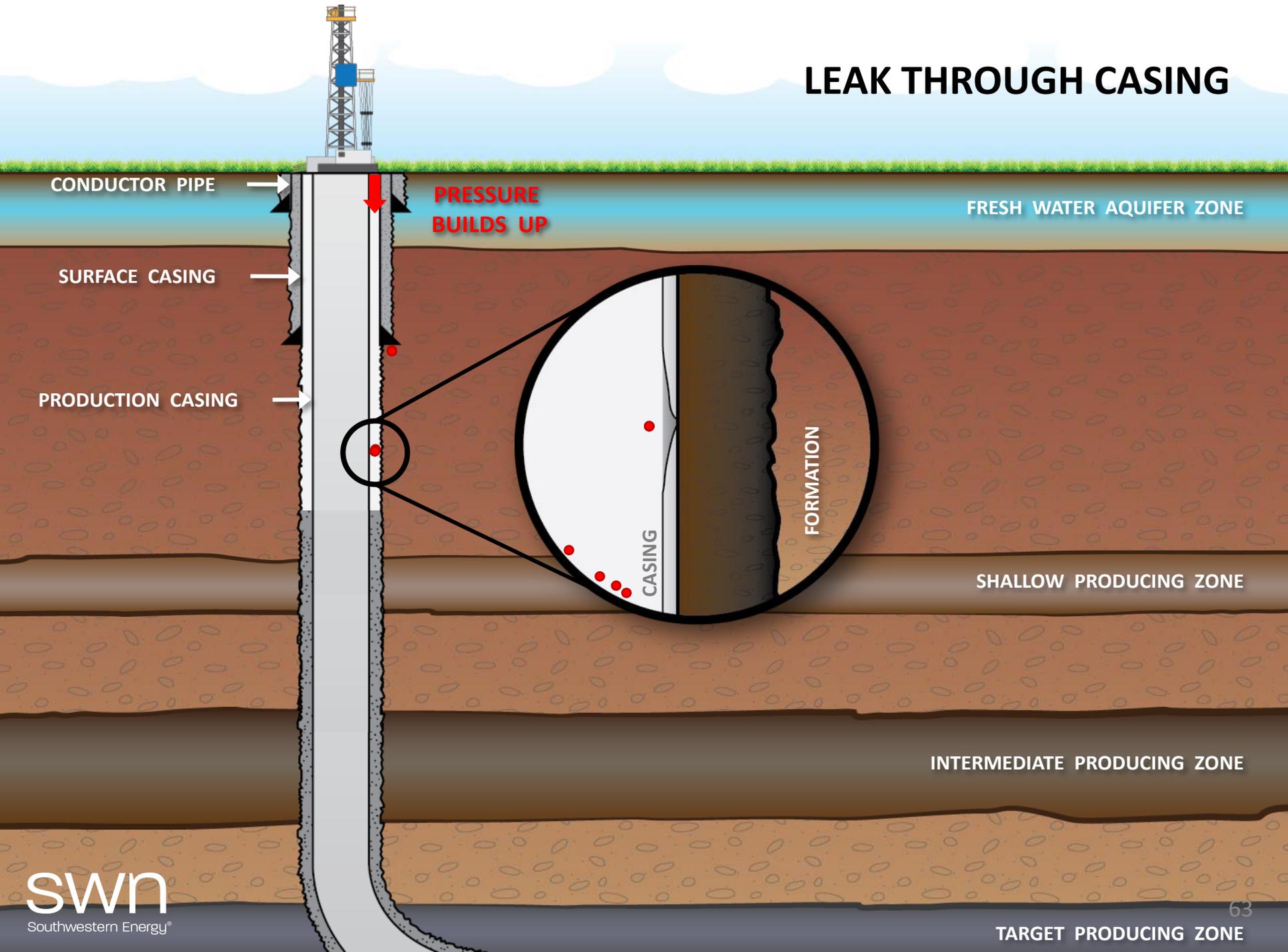
SHALLOW PRODUCING ZONE

INTERMEDIATE PRODUCING ZONE

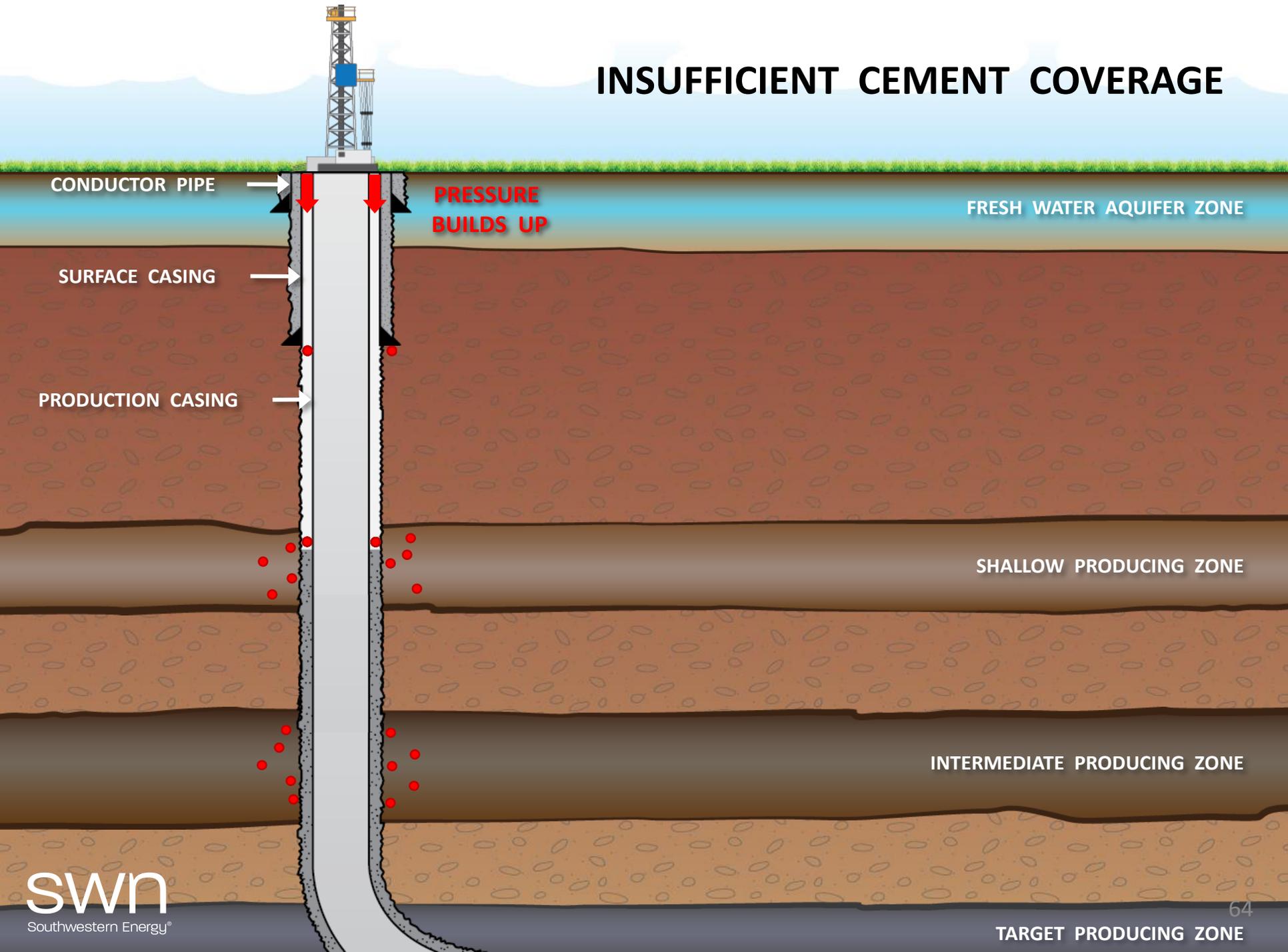
# CEMENT CHANNELING



# LEAK THROUGH CASING



# INSUFFICIENT CEMENT COVER



# Observation: What Does This All Look Like “Downhole”?



## Laboratory-Scale Experiment:

- A Block of Real Rock
- Apply earth-like pressure to all 6 sides
- Drill It, Right Down the Middle
- Case It
- Cement It
- Perforate it
- Frac It, with Red Dye in the Frac Fluid
- Break Open the Block
- See What Happened

# One Can See Perforations and Hydraulic Fractures



# Burn-Offs at MarkWest Gas Processing Plant, Houston, PA



9/18/11  
2:03pm

Photos courtesy of Robert Donnan



# Gangplank To a Warm Future

By Anthony R. Ingraffea

ITHACA, N.Y.

**M**ANY concerned about climate change, including President Obama, have embraced hydraulic fracturing for natural gas. In his recent climate speech, the president went so far as to lump gas with renewables as “clean energy.”

As a longtime oil and gas engineer who helped develop shale fracking techniques for the Energy Department, I can assure you that this gas is not “clean.” Because of leaks of methane, the main component of natural gas, the gas extracted from shale deposits is not a “bridge” to a renewable energy future — it’s a gangplank to more warming and away from clean energy investments.

Methane is a far more powerful green-

