The Environmental Footprint of Shale Gas Extraction and Hydraulic Fracturing

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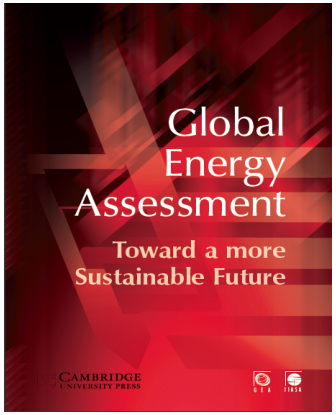
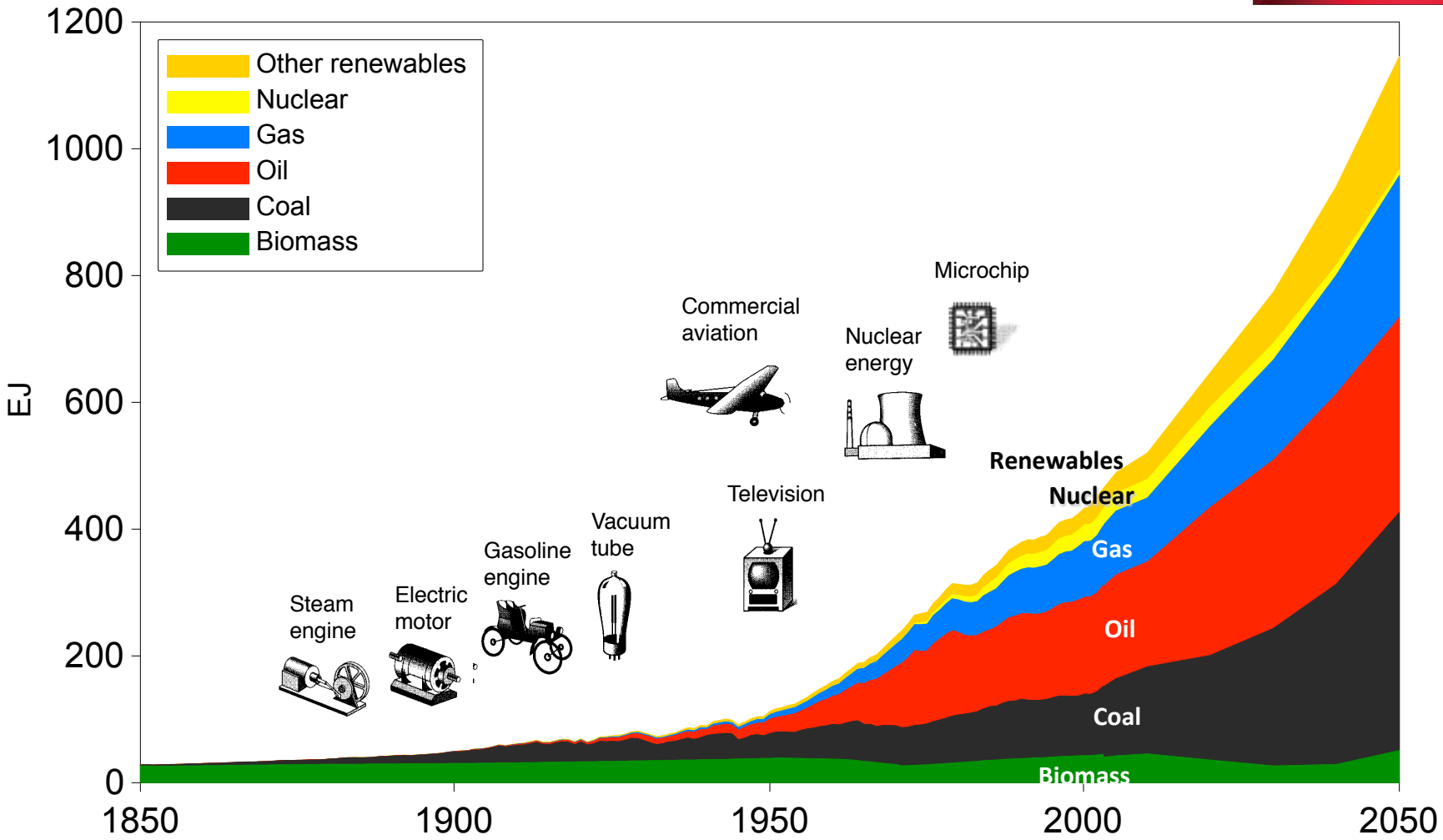
Princeton Plasma Physics Lab

January 9th, 2013

Global Energy Use:
Where will future energy come from?

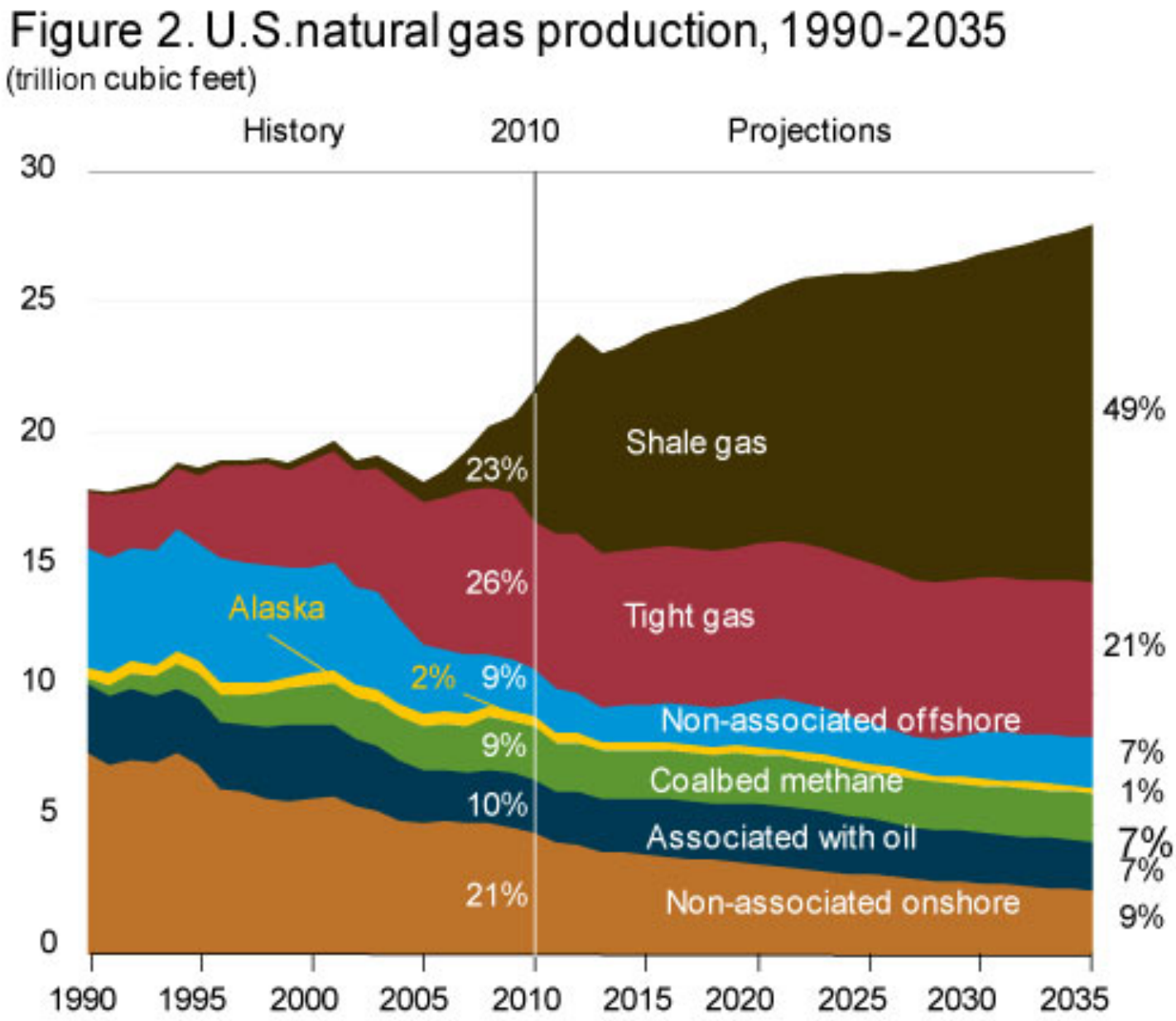


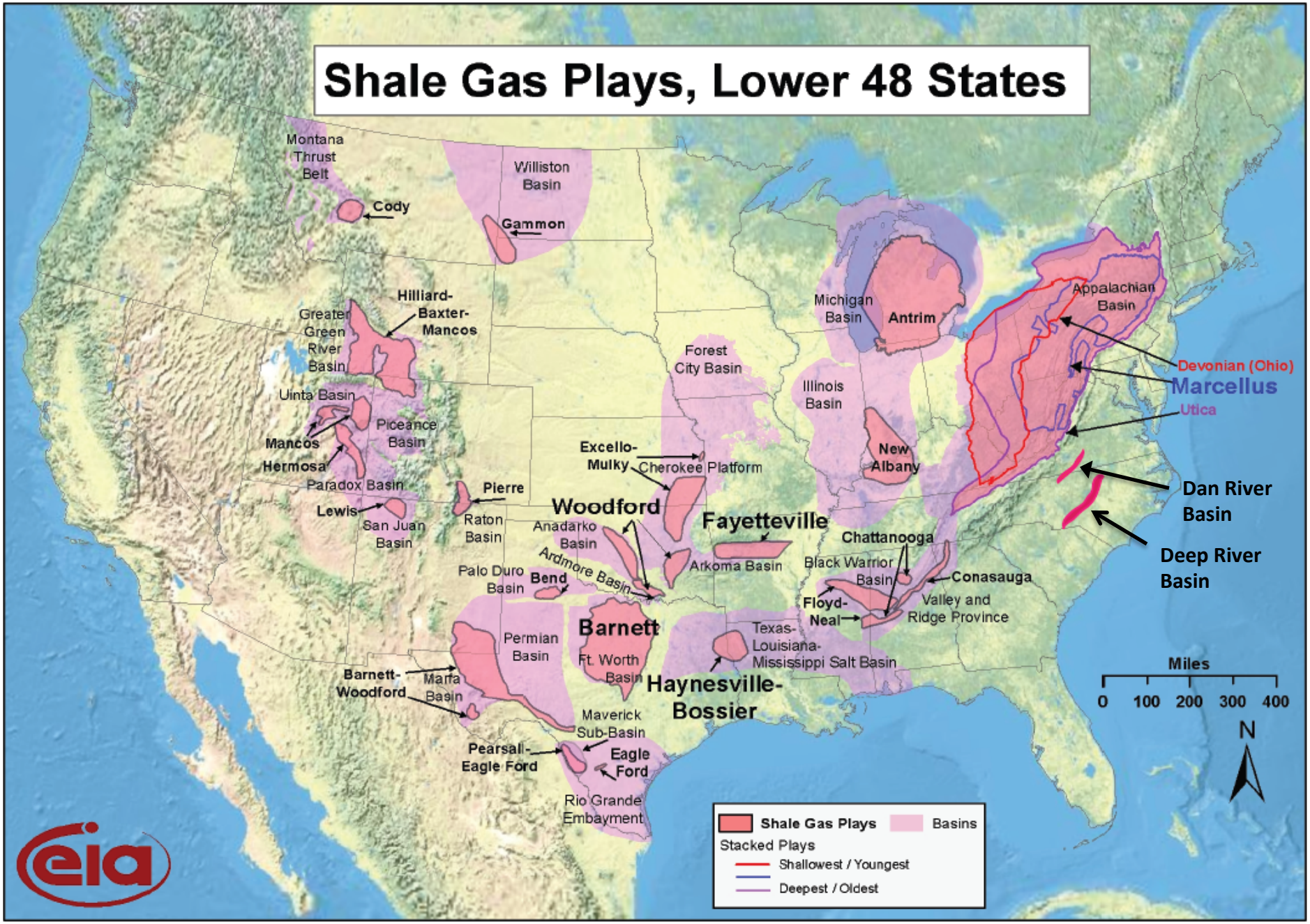


Unconventional oil is 5-X more abundant than conventional oil

In 2010 the USGS doubled its estimate of “technically recoverable” heavy oil in the Orinoco to 513 billion barrels. Saudi Arabia has 264 billion barrels of oil reserves.

Unconventional gas is booming, too.

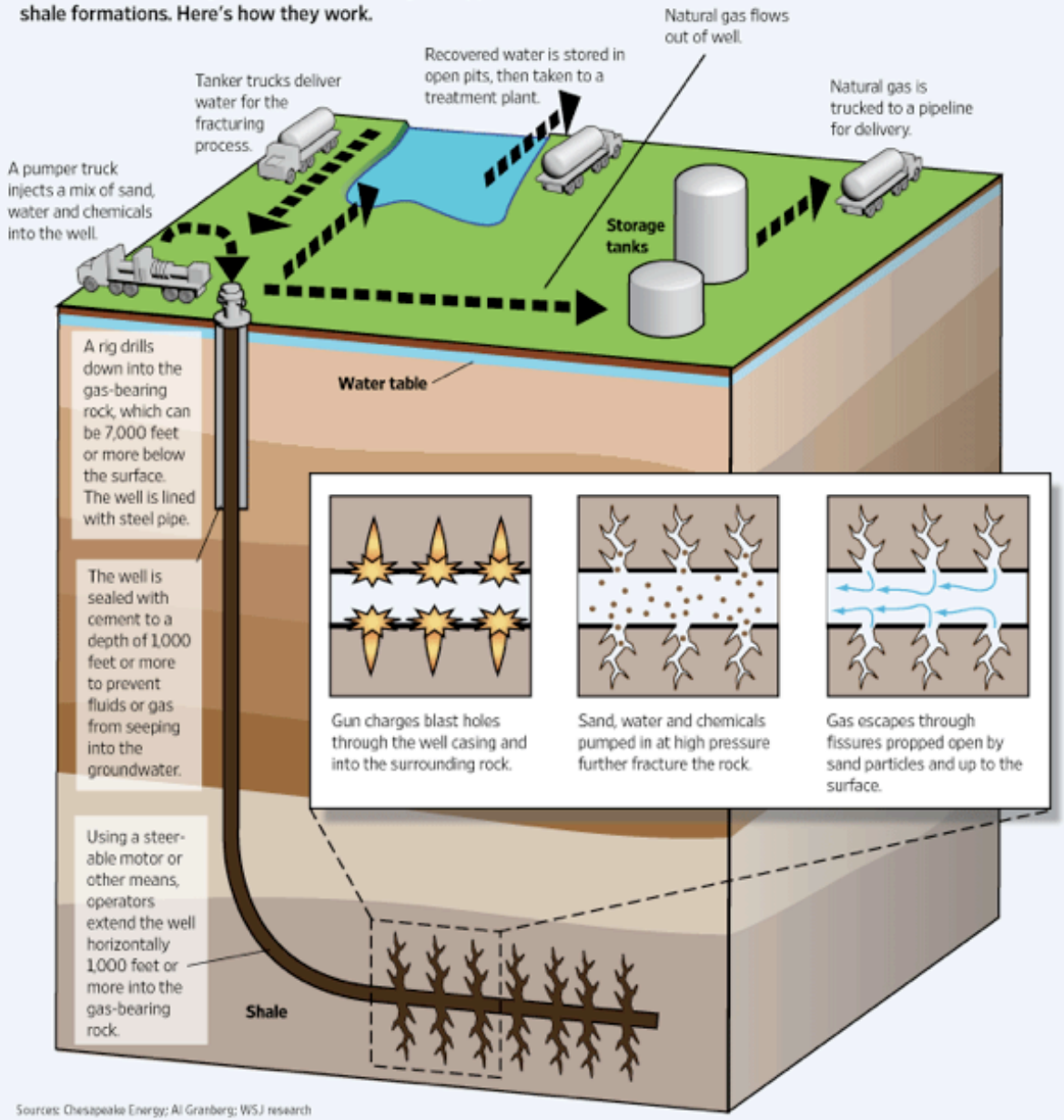




Source: Energy Information Administration based on data from various published studies.
Updated: March 10, 2010

Tapping the Gas

Horizontal drilling and hydraulic fracturing have made it feasible to extract huge amounts of natural gas trapped in shale formations. Here's how they work.



Sources: Chesapeake Energy; Al Granberg; WSJ research

Diverse Views (to put it mildly)

Some objectives of our research at Duke:

1) Stray-gas forensics

2) Evaluate the quality and fate of fracturing fluids and waste waters:

   What are the salinity, toxicity, and radioactivity variations of produced waters in shale gas basins across the U.S.?

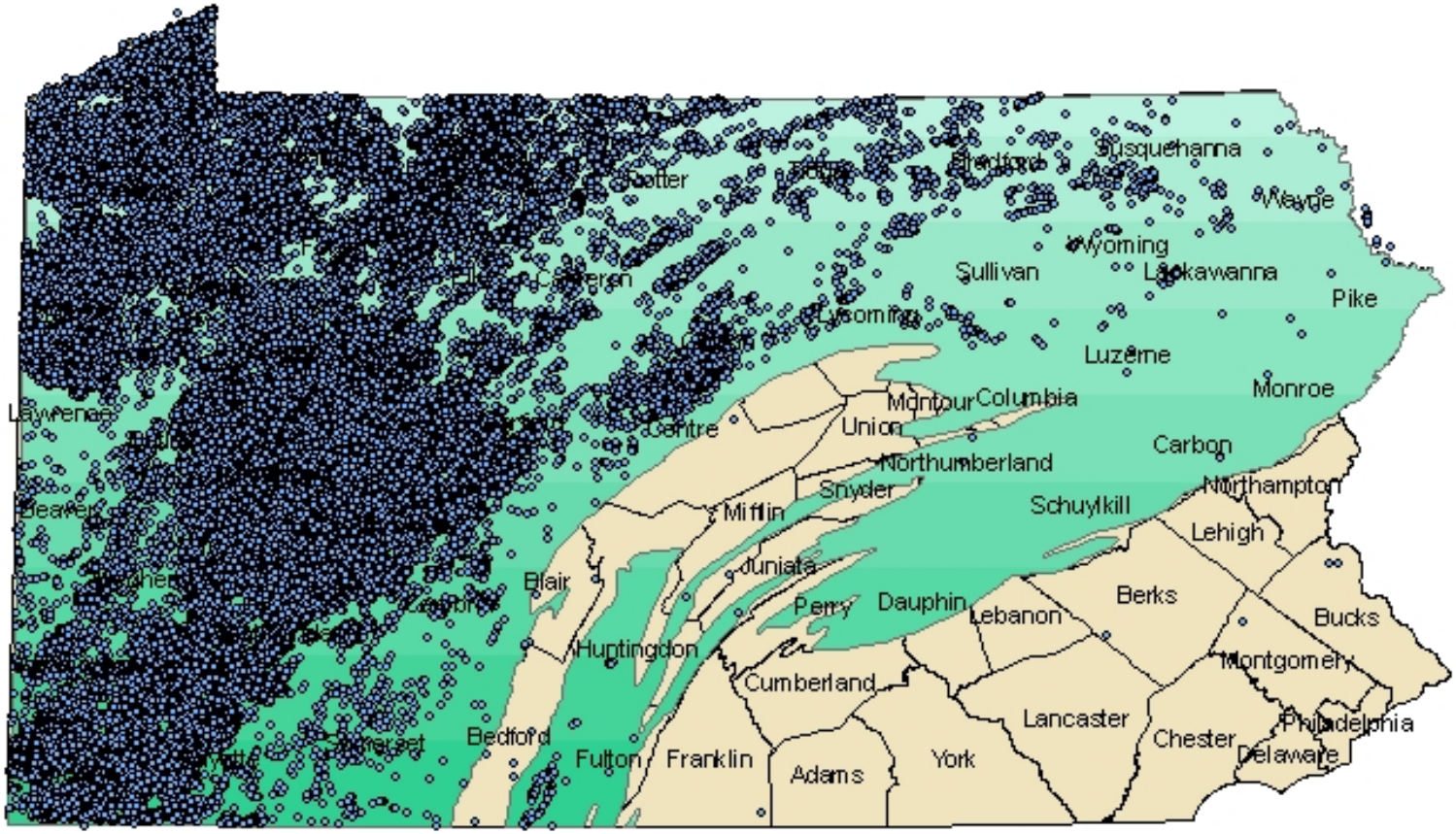
3) Establish geochemical and isotopic tools for tracing gases, fracturing fluids, and produced waters in the environment:

   Using geochemical tools such as chemical and isotopic fingerprints.

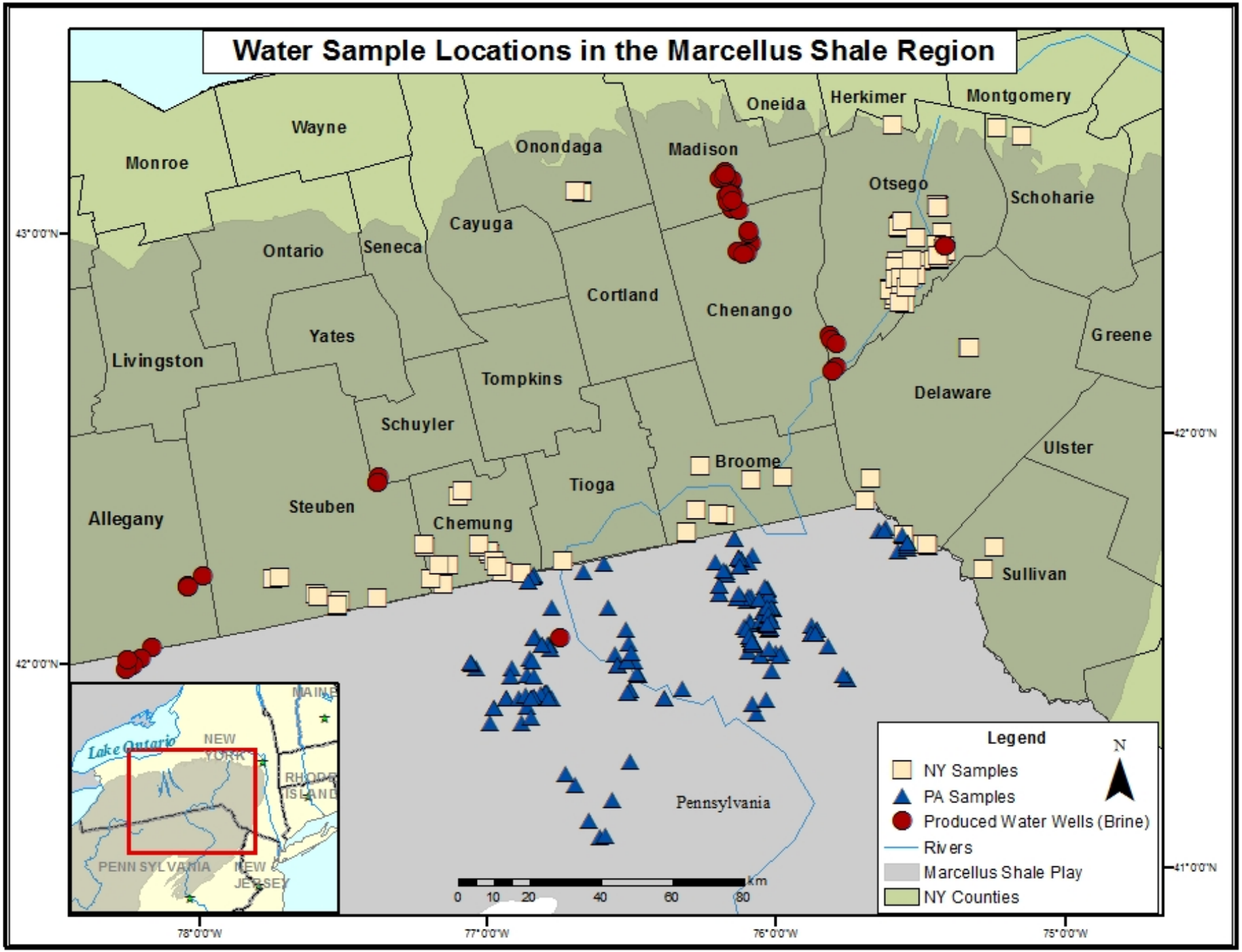
4) Greenhouse gas footprint of energy production

Build predictive frameworks for where problems may occur and help solve those problems.

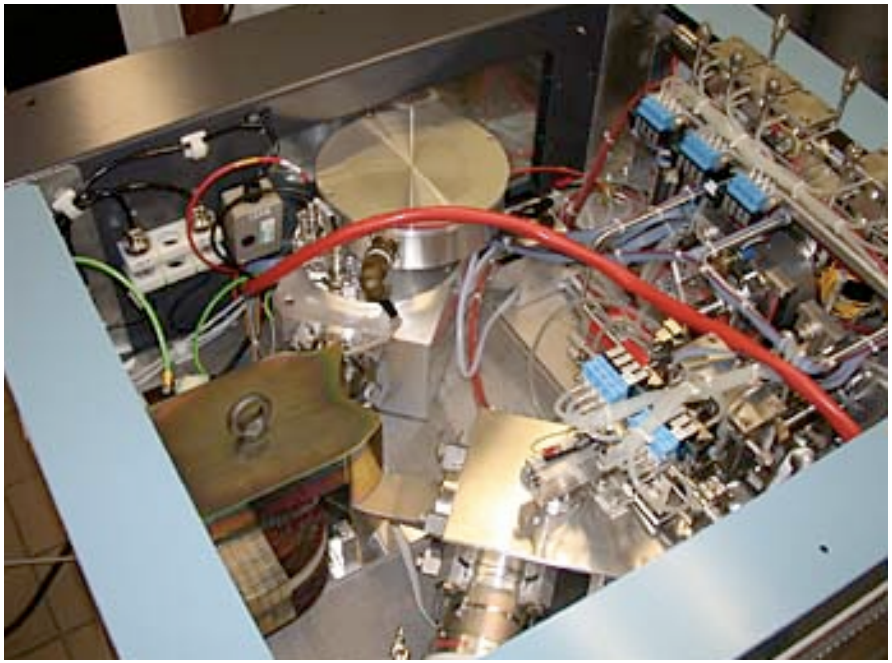
Oil and Gas Wells and the Middle Devonian Marcellus Formation



Pennsylvania Dept of Env. Protection

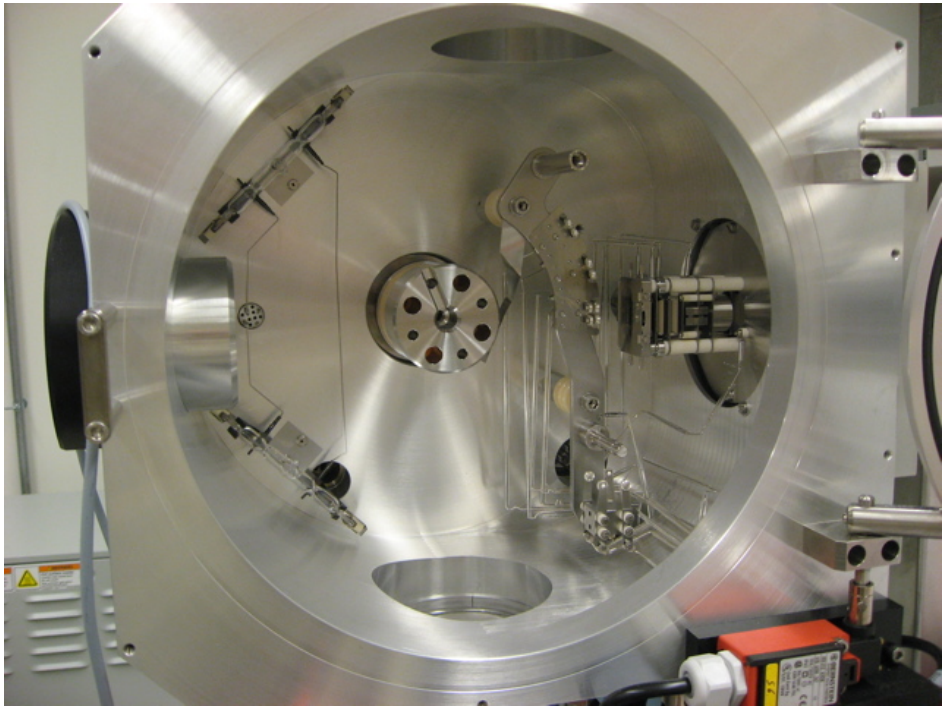

Water Sample Locations in the Marcellus Shale Region
Monroe
Wayne
Onondaga
Madison
Oneida
Herkimer
Montgomery
Otsego
Schoharie
Ontario
Seneca
Cayuga
Cortland
Chenango
Yates
Livingston
Tompkins
Greene
Delaware
Schuyler
Ulster
Broome
Tioga
Steuben
Allegany
Chemung
Sullivan
Pennsylvania
Lake Ontario
NEW YORK
MAINE
RHODE ISLAND
PENNSYLVANIA
NEW JERSEY
Legend
NY Samples
PA Samples
Produced Water Wells (Brine)
Rivers
Marcellus Shale Play
NY Counties
N
km
0 10 20 40 60 80
43°0'0"N
42°0'0"N
41°0'0"N
78°0'0"W
77°0'0"W
76°0'0"W
75°0'0"W

Some Analytical Capabilities



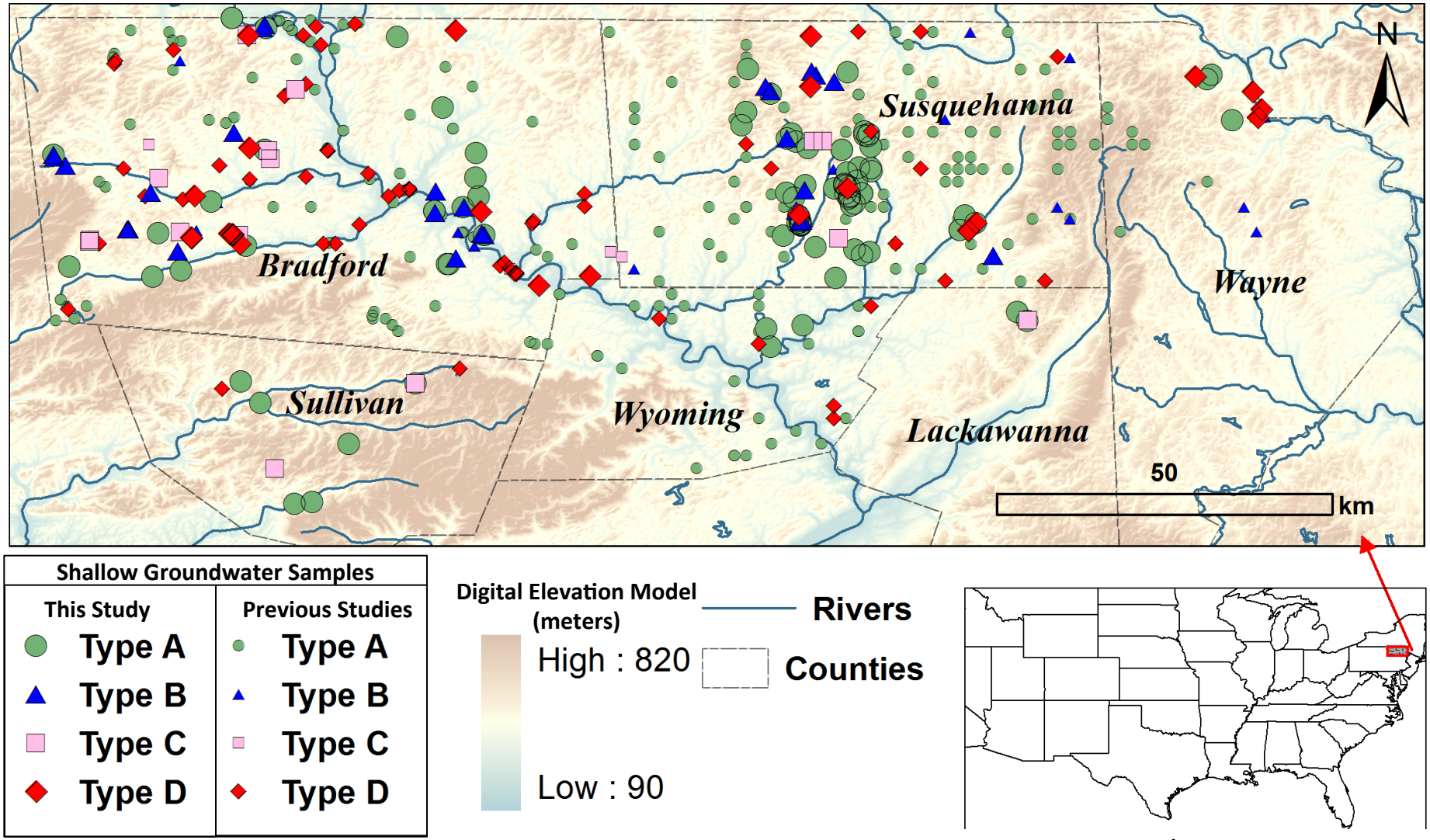
e.g., C, H, O, B, Sr isotopes

Radionuclides (Ra, U, Pb)



Natural brine migration pathways versus contamination from drilling

~430 shallow groundwater samples (160 of ours, 270 historical);
65 new samples for deeper brines



Warner et al. 2012 PNAS

New Paper for PA, Warner et al. 2012 *Proc Nat Acad Sci. USA*

PNAS

Geochemical evidence for possible natural migration of Marcellus Formation brine to shallow aquifers in Pennsylvania

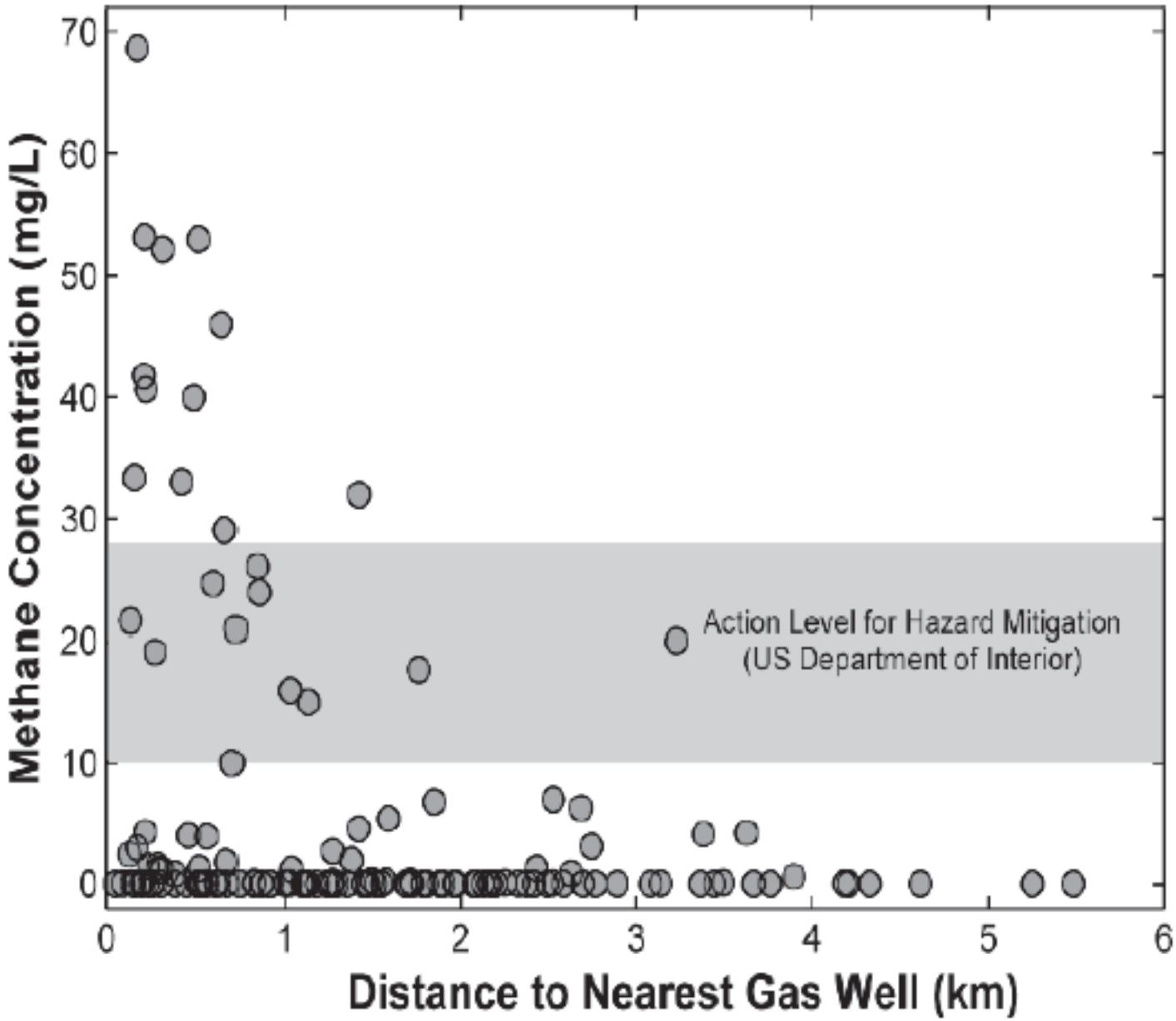
Nathaniel R. Warner[a], Robert B. Jackson[a,b], Thomas H. Darrah[a], Stephen G. Osborn[c], Adrian Down[b], Kaiguang Zhao[b], Alissa White[a], and Avner Vengosh[a,1]

[a]Division of Earth and Ocean Sciences, Nicholas School of the Environment, Duke University, Durham, NC 27708; [b]Center on Global Change, Nicholas School of the Environment, Duke University, Durham, NC 27708; and [c]Geological Sciences Department, California State Polytechnic University, Pomona, CA 91768

Edited by Karl K. Turekian, Yale University, North Haven, CT, and approved May 10, 2012 (received for review January 5, 2012)

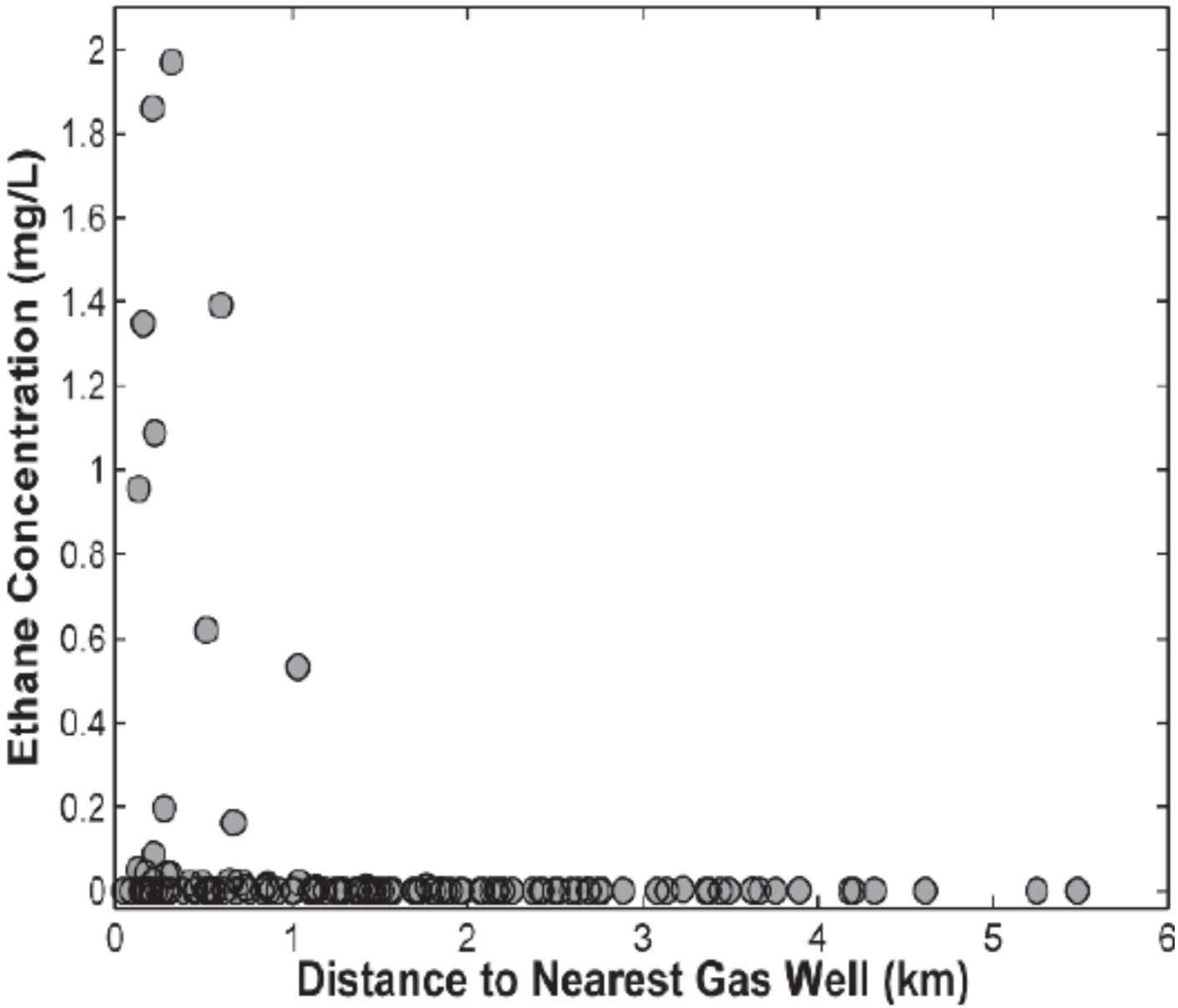
No evidence for contamination of brines or metals from deep formation waters associated with shale-gas extractions. However, the paper shows evidence for a minority of homeowners (~15%) whose water appears similar to deep Marcellus-like water.

No Evidence for Brines or Fracturing Fluids, but Methane Concentrations in Drinking Water Were Higher Near Gas Wells

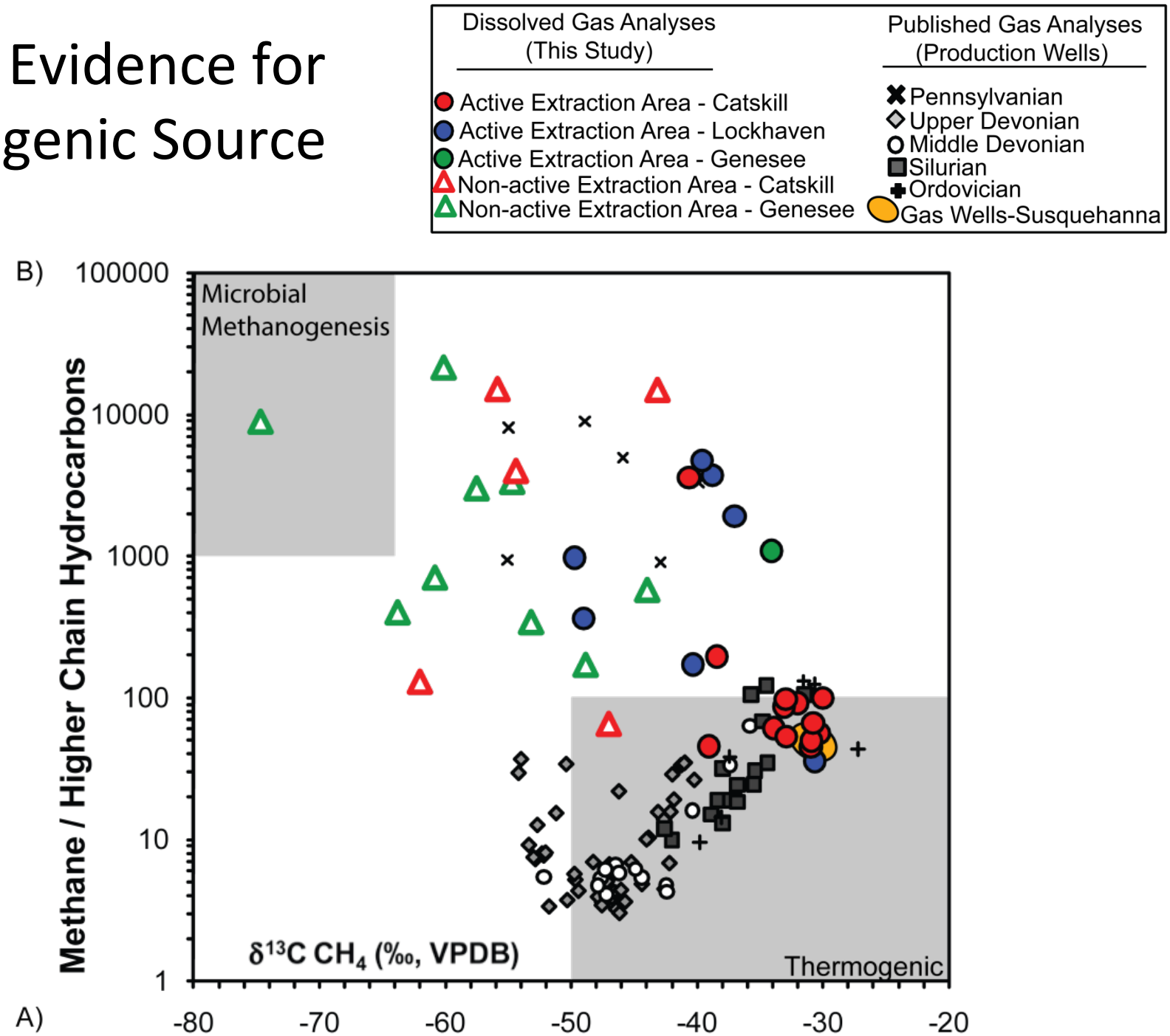


Osborn et al. 2011 PNAS & more samples

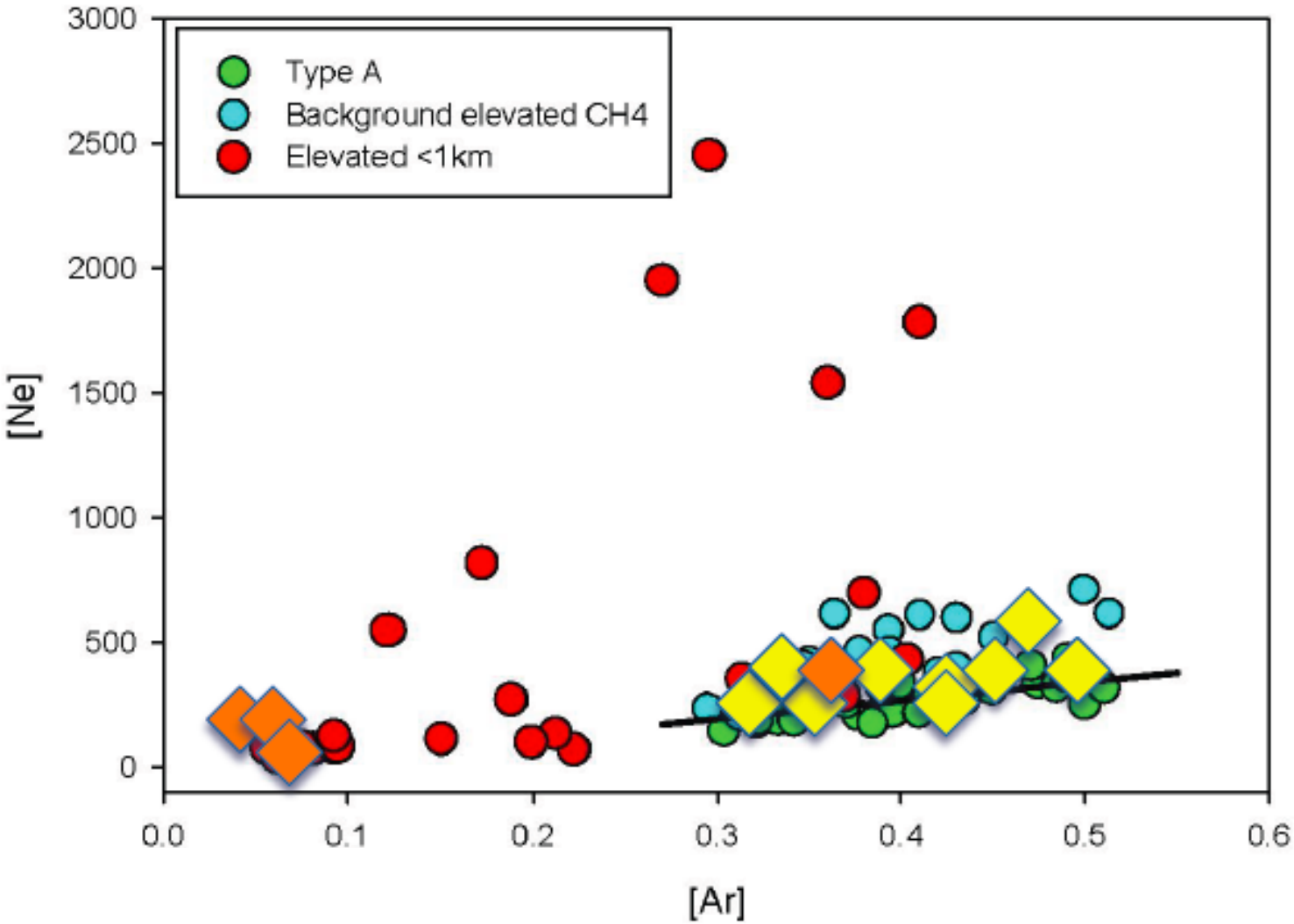
Higher ethane concentrations are even harder to explain…



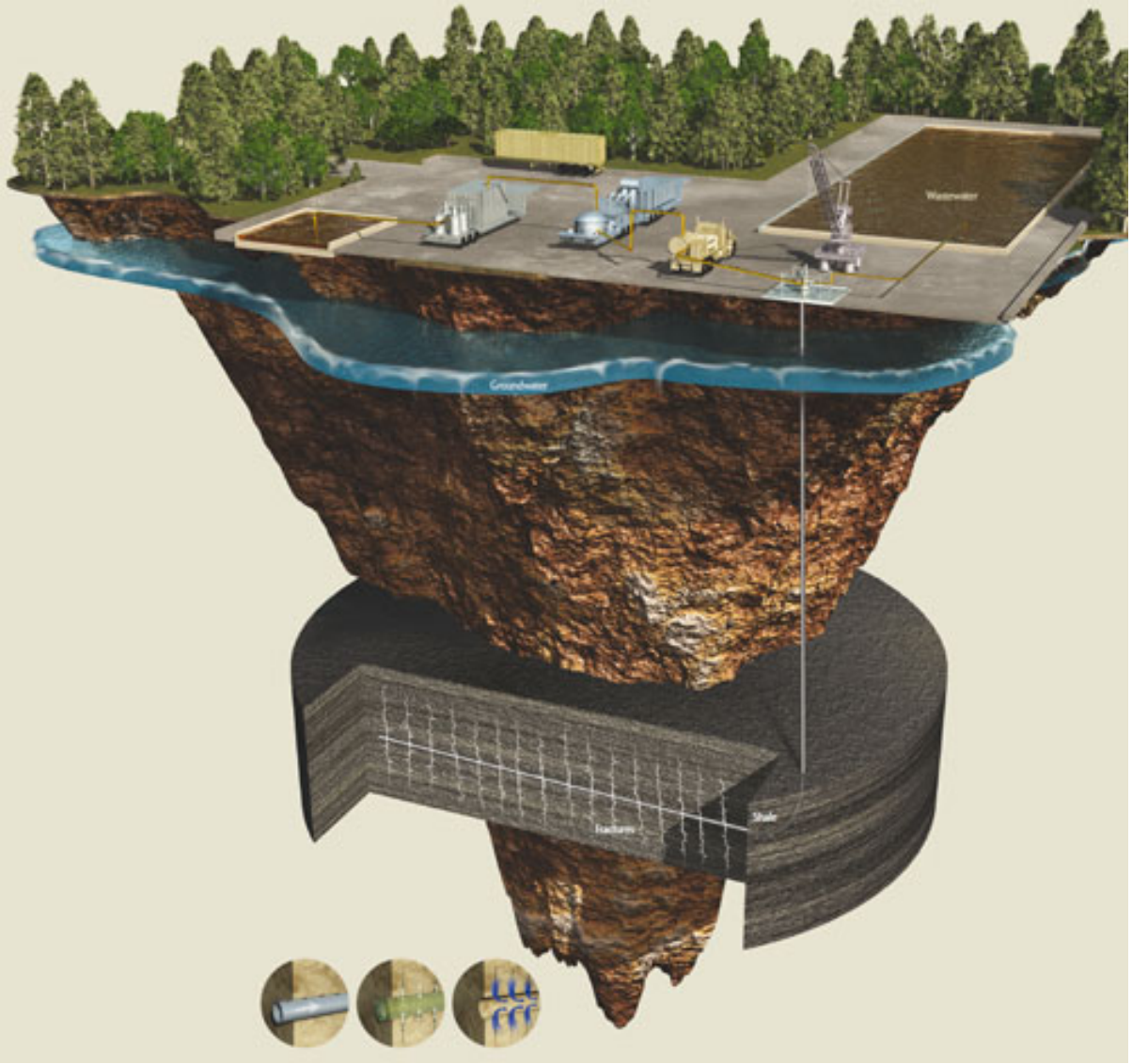
Further Evidence for Thermogenic Source



As inert geochemical tracers, noble gases provide additional information

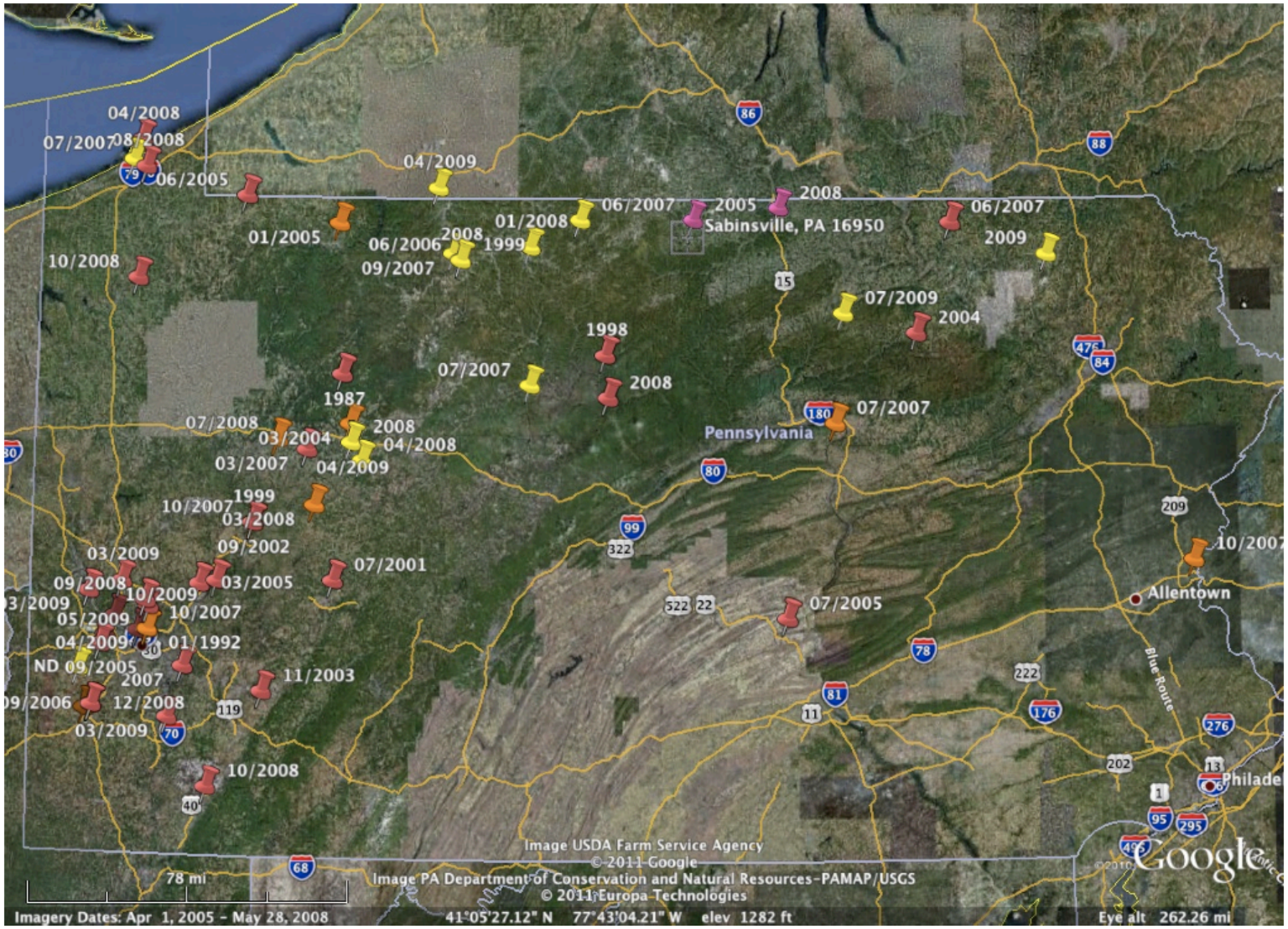


What is the Mechanism of Gas Migration?



Scientific American, 11/11

Extensive Stray Gas Events Associated with Oil and Gas Wells in PA Over the Last Decade



PA Dept of Env. Protection

February, 2012

Governor Corbett signs Marcellus Shale bill into law

Images

Print Story

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Published: 2/13 7:18 pm

Updated: 2/13 7:20 pm

3 recommendations. Sign Up to see what your friends recommend.

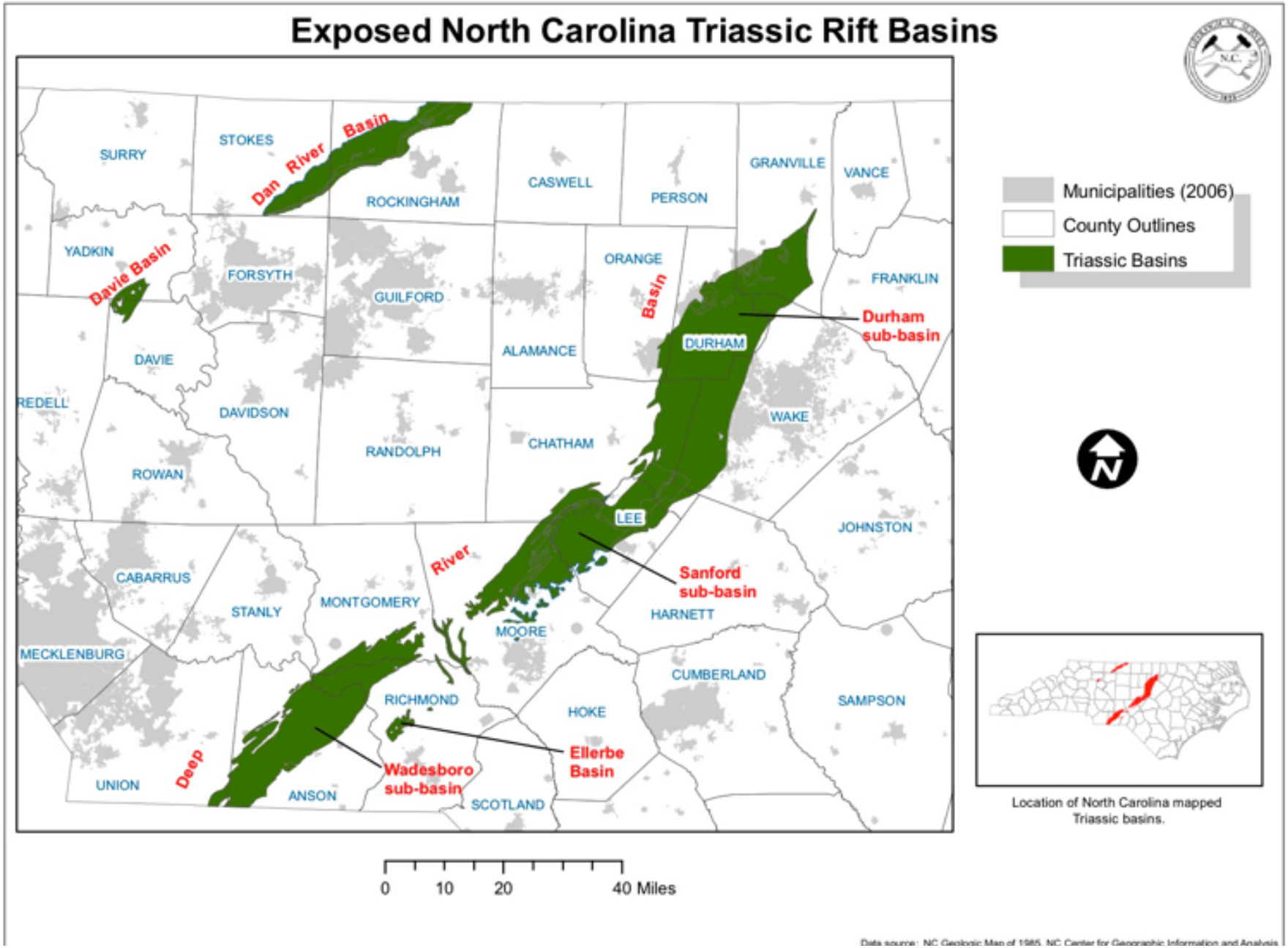
Tweet 6

Governor Tom Corbett Monday signed House Bill 1950, the Marcellus Shale bill, into law. The bill enhances protection of our natural resources through stronger environmental standards, authorizes counties to adopt an impact fee, and builds upon efforts to help move Pennsylvania toward energy independence.

Some of its changes (including recommendations from Jackson et al. 2011):

1) Restrict drilling within 1000 ft of a public water supply.
2) Double the distance from 250 feet to 500 feet to separate a gas well from a private water well,
3) Extend a well operator's presumptive liability for pollution or water loss from 1,000 feet to 2,500 feet.

Baseline groundwater sampling in NC with USGS and DENR



How Are Pigs and Drilling Rigs Alike?

Op-Ed in Raleigh News & Observer and Charlotte Observer, 7/11; (Jackson & Osborn 2011). Follow-ups in Raleigh N&O, 3/12 (Jackson and Holman); Adair *et al*. 2012 Duke Env Law & Policy Forum

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Some of our shale gas recommendations for North Carolina:

1) Collect extensive pre-drilling data on water and air quality.
2) Use aggressive zoning and setbacks to protect property owners.
3) Plan for large water withdrawals and wastewater disposal *now*.
4) Require full disclosure of the chemicals in fracturing fluids.
5) Make sure fees cover long-term costs for monitoring.
6) Provide landowners with better information.

New Policy Paper: 2012 Duke Environmental Law and Policy Forum 22:257-301.

CONSIDERING SHALE GAS EXTRACTION IN NORTH CAROLINA: LESSONS FROM OTHER STATES

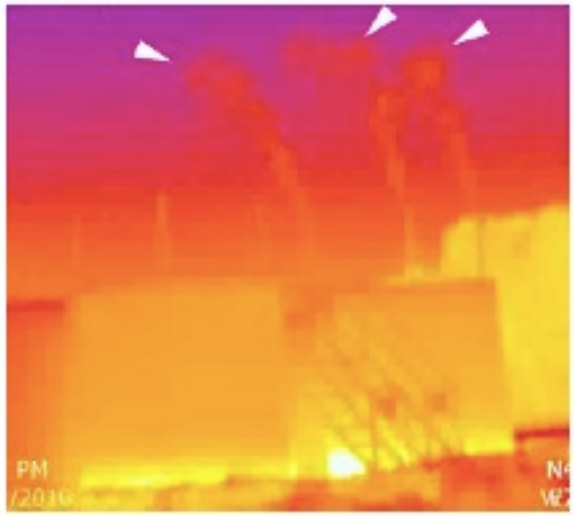
SARAH K. ADAIR, BROOKS RAINEY PEARSON, JONAS MONAST, AVNER VENGOSH & ROBERT B. JACKSON†

INTRODUCTION

In 2009, the North Carolina Geological Survey (NCGS) announced the existence of shale gas underlying the Deep and Dan River Basins in twelve North Carolina counties, including Lee, Chatham, and Moore.[1] Following NCGS's initial announcement, several small companies began leasing mineral rights from landowners in Lee County,[2] and the state legislature began to consider policy changes that would be necessary to develop the shale gas resource. To this end, on June 23, 2011, Governor Beverly Perdue signed Session Law 2011-276, which directs the North Carolina Department of Environment and Natural Resources (DENR) to conduct a study and hold public hearings on the issues of horizontal drilling and hydraulic fracturing for shale gas extraction.[3] Unlike

Some Additional Public Concerns

- Water for hydraulic fracturing, 3-5M gallons per well
- Drinking-water quality
- Disposal of produced waters (salinity – 10-times sea water, bromide, arsenic, barium, radioactivity, hydrocarbon residuals)
- Air quality and greenhouse gas interactions
- Earthquakes from hydraulic fracturing and disposal

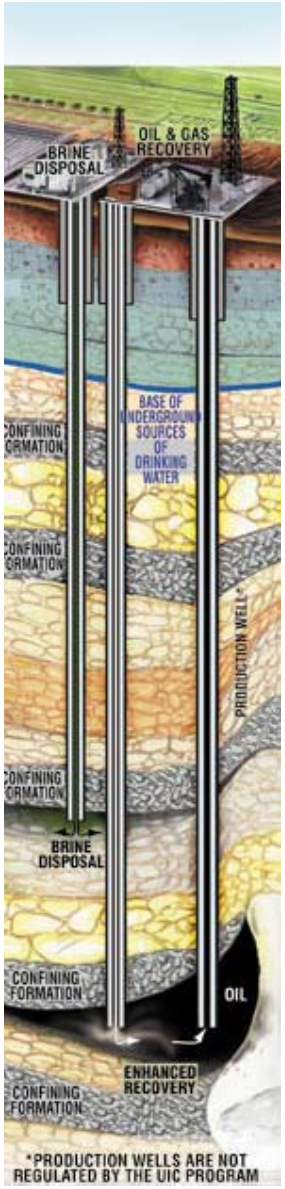


One of the biggest concerns for the public is organics from fracturing fluids in drinking water. It will take time and, likely, new test wells, to confirm (or refute) the presence of contamination documented by EPA scientists.

Pavillion, Wyoming

Photo: Wikipedia Commons

Management of produced water



- Deep inject for underground disposal (illegal in NC)
- Spray on lands (some states permit this – bad idea)
- Haul to a municipal wastewater treatment plant (no!)
- Haul to a commercial wastewater treatment facility
- Reuse for a future fracturing job with or without treatment (kudos to industry here).

Air Quality and Health Interactions

On-site Workers

Compressor Stations

Drilling & Well Completions

Holding Ponds

Winter Ozone Formation

Natural Gas as a “Bridge Fuel”

We have a supply of natural gas that can last America nearly 100 years. And my administration will take every possible action to safely develop this energy. Experts believe this will support more than 600,000 jobs by the end of the decade. And I'm requiring all companies that drill for gas on public lands to disclose the chemicals they use. Because America will develop this resource without putting the health and safety of our citizens at risk.

State of the Union 2012

Howarth et al: Greenhouse gas balance of shale gas

Shale gas 'worse than coal' for climate

BBC

By Richard Black
Environment correspondent, BBC News

Dot Earth

ANDREW REVKIN

January 6, 2012, 5:53 PM

On Shale Gas, Warming and Whiplash

By ANDREW C. REVKIN

Jan. 19, 4:00 p.m. | Updated below |

If you scan back you'll see what's becoming a pretty long series of headlines here dealing with a phenomenon I've noted since 2008 or so — a feeling of whiplash in tracking the flow of climate science and related news coverage

Where are some of the uncertainties:

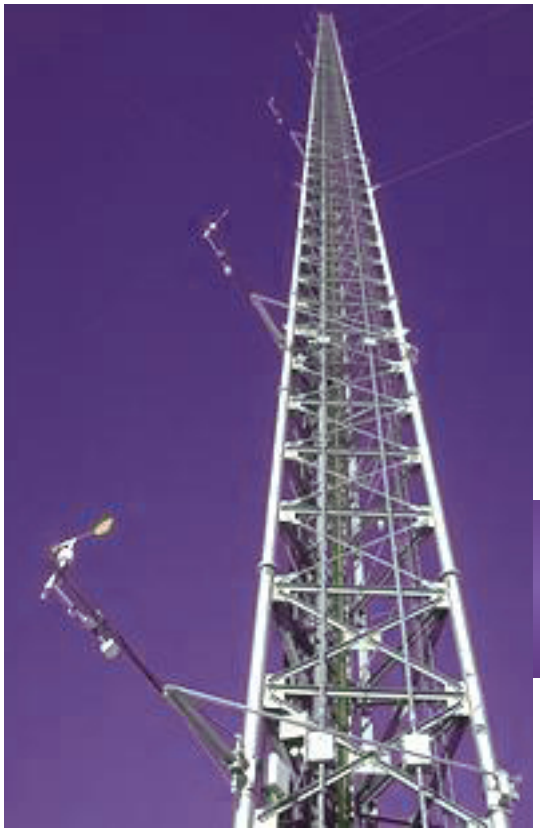
1) Time Scale (20 years or 100 years) and global warming potential

2) Losses during drilling and completion (CH4 vented or captured/burned?)

3) Losses during transmission

4) Average gas production from each well (i.e., the denominator…)

New data from Colorado show higher emissions than expected and possible health effects. We need time to see how general this result is (or isn't).



Petron et al. 2012

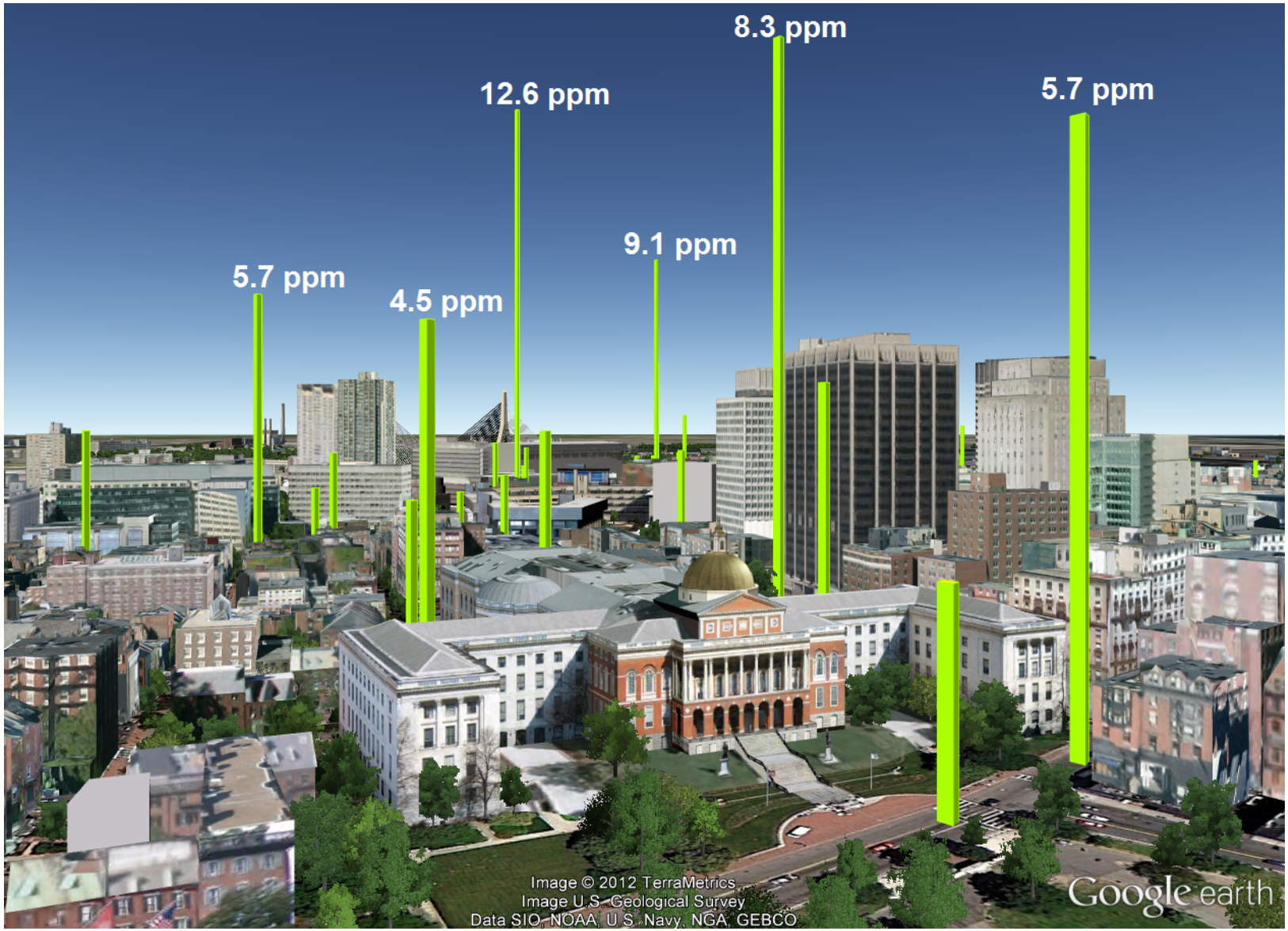
Journal of Geophysical Research Atmospheres

Human Health Risk Assessment of Air Emissions from Development of Unconventional Natural Gas Resources

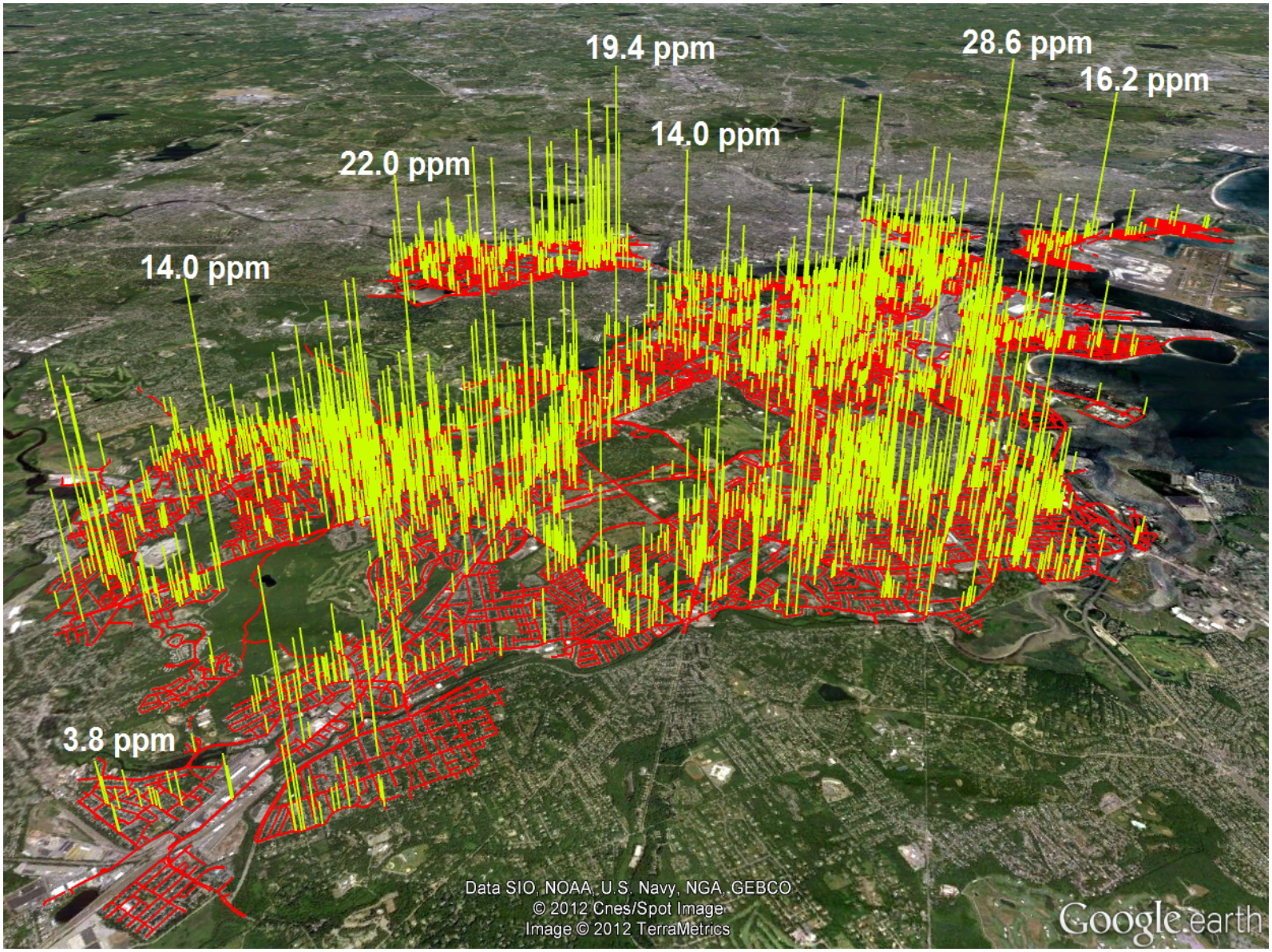
Methane losses from pipelines and pads (w/ Boston Univ.)

The MA State House

A closer look at CH_4 leaks in Boston



Boston overall



Red = roads driven; Yellow = leaks

Phillips et al. 2013 Env Pollution

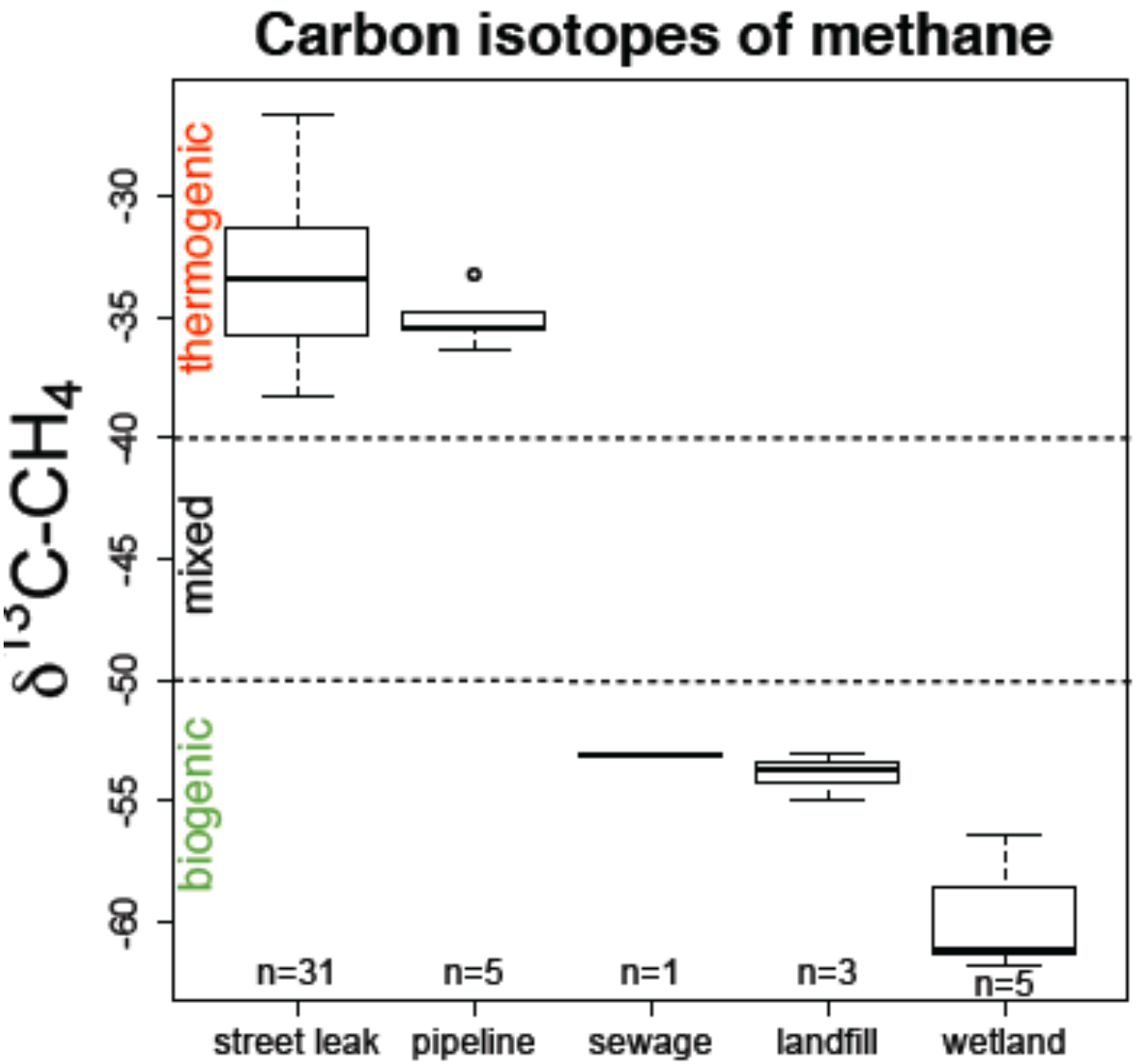
Some Quick Responses

Boston Mayor Tom Menino
Mayor Thomas Menino has written a strongly worded letter to the state Department of Public Utilities urging its chairwoman to step up scrutiny of utilities following a story in today's Globe about more than 3,300 natural gas leaks from the vast pipeline system under Boston.

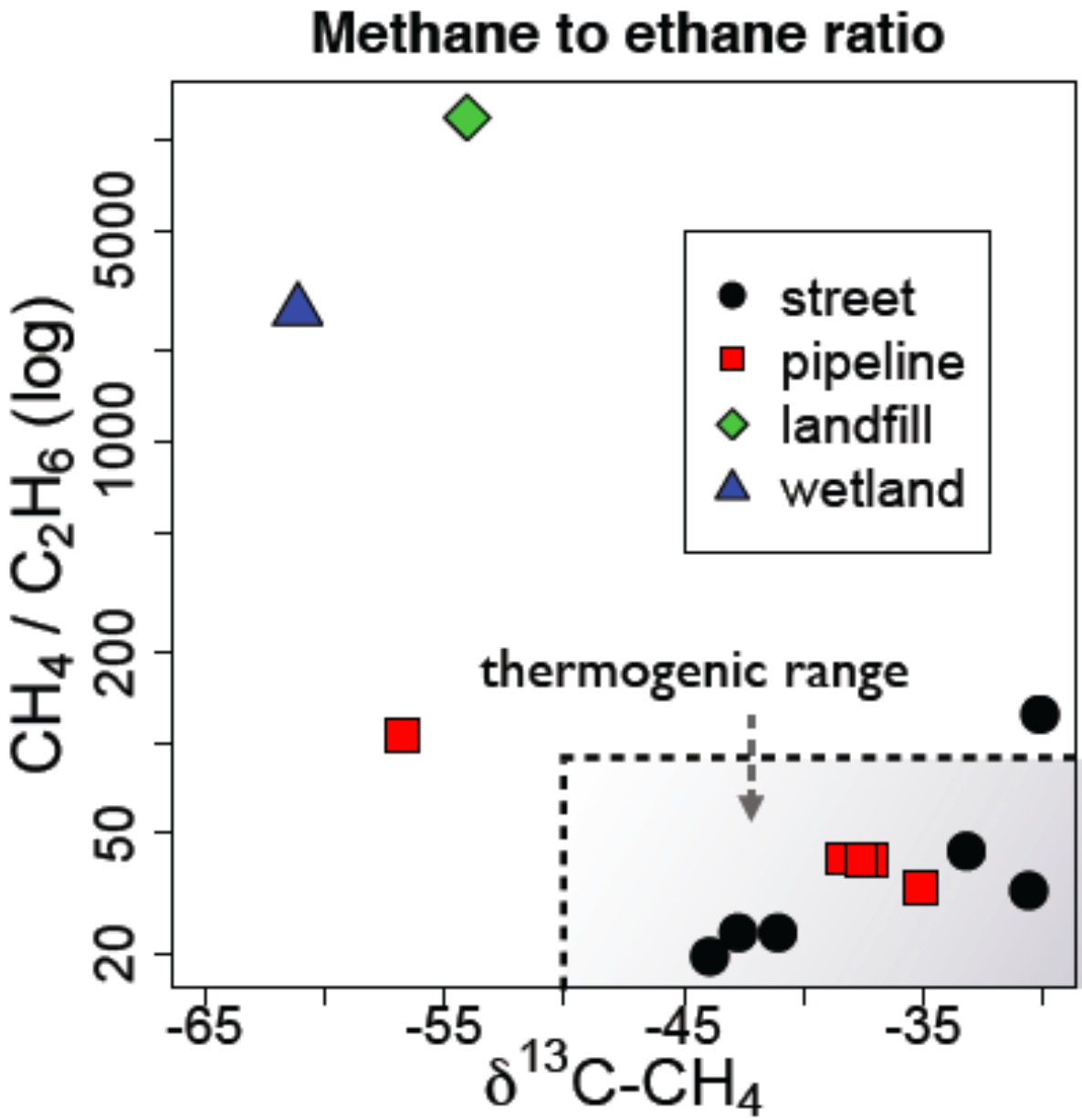
Congressman Ed Markey, MA 7th District
"This study shows that we need a plan to ensure leaks from aging natural gas pipelines in Boston and other cities and communities are repaired, so that we can conserve this important natural resource, protect the consumers from paying for gas that they don't even use, and prevent emissions of greenhouse gases into the environment," Markey wrote in a letter to the Pipeline and Hazardous Materials Safety Administration.

Boston Globe Editorial Page:
"A recent study found 3,300 gas leaks just in Boston. Utilities fix leaks they know about, but many go unnoticed. In the Commonwealth as a whole, the rate of "lost and unaccounted for" gas was more than twice the national average in 2010."

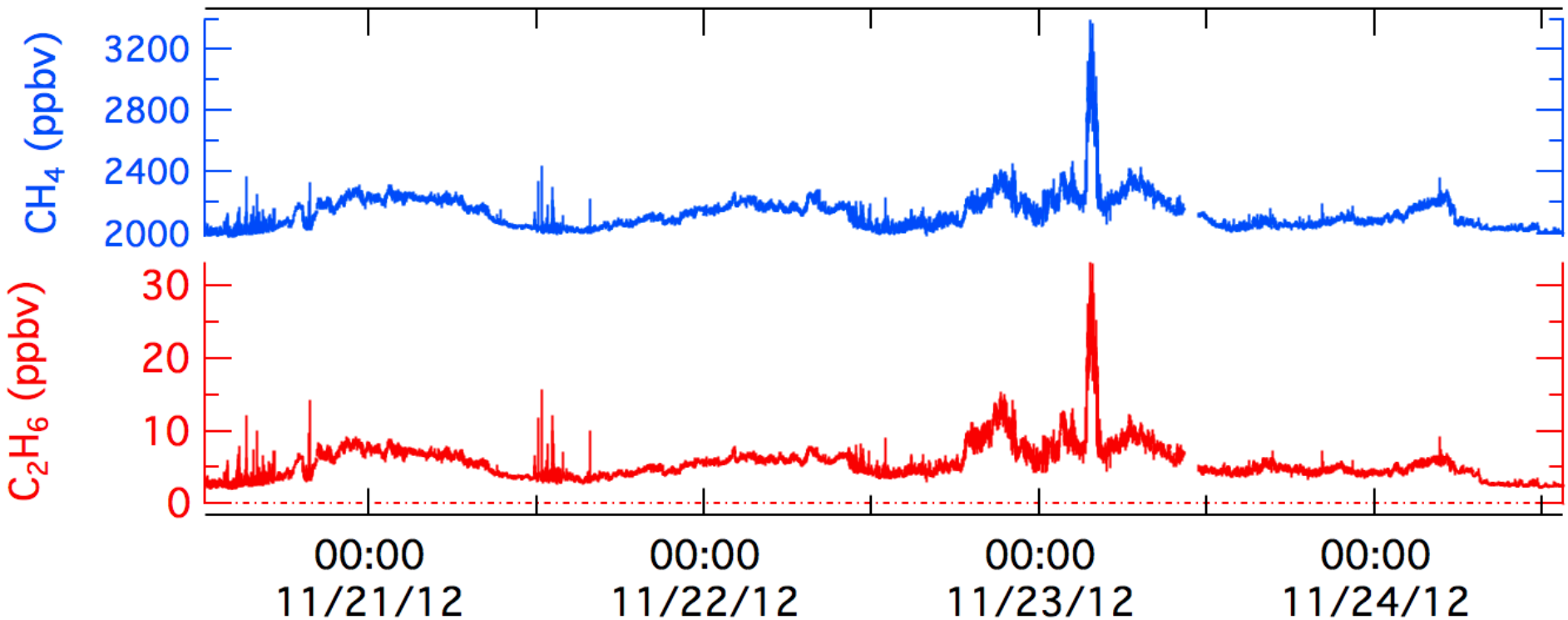
Isotopic Fingerprinting of the Gas



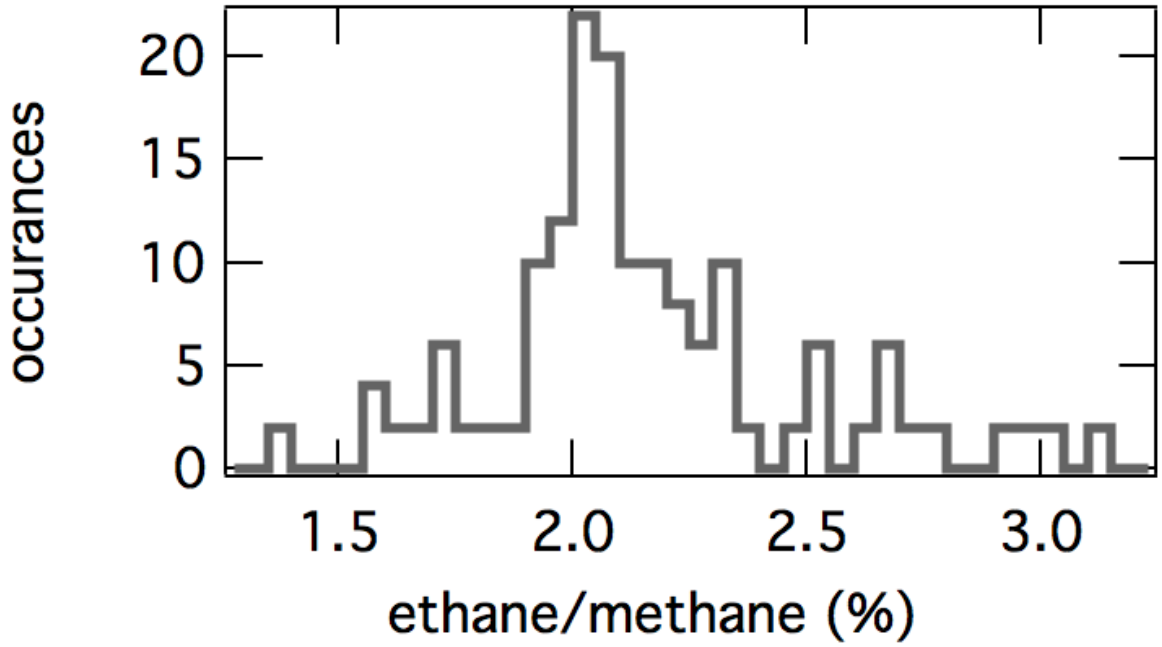
Heavier Gases Such as Ethane and Propane Are Useful, Too



Methane and Ethane Vary Together Over Boston…



in Ratios Consistent With Pipeline Concentrations

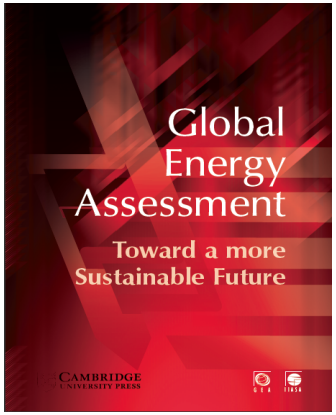
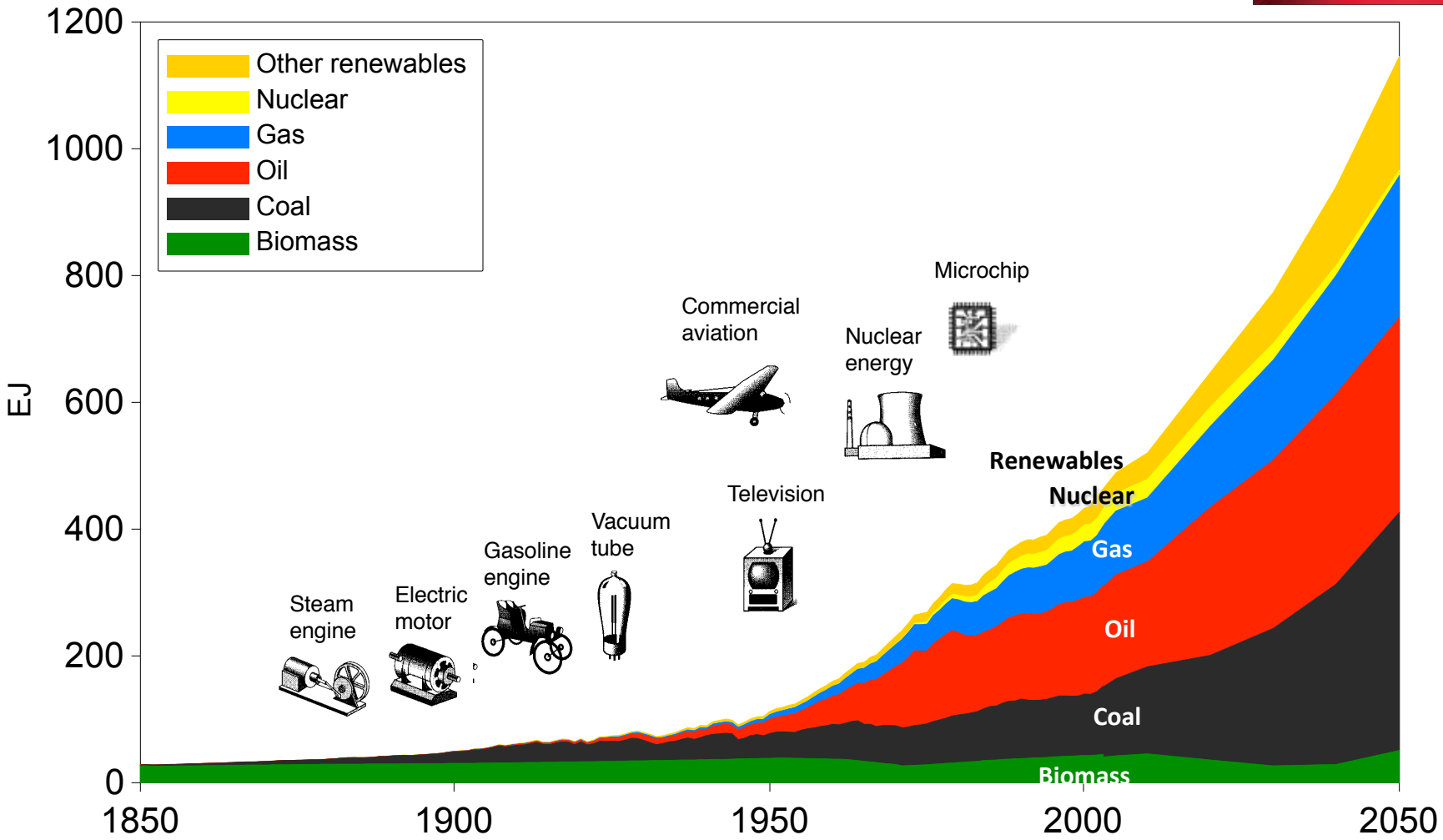


time segments with Δmethane > 200 ppbv

Take-Home Messages for the Leaks Work:

1) There is an immediate opportunity to tighten the natural gas supply chain, aligning financial incentives to do so.

2) Many justifications exist for fixing the leaks. Pick yours: Consumer safety, human health, air quality, money, climate change.

3) We've called for a national campaign to map every city in the country, moving internationally as well.

Where Will Our Energy Come From?