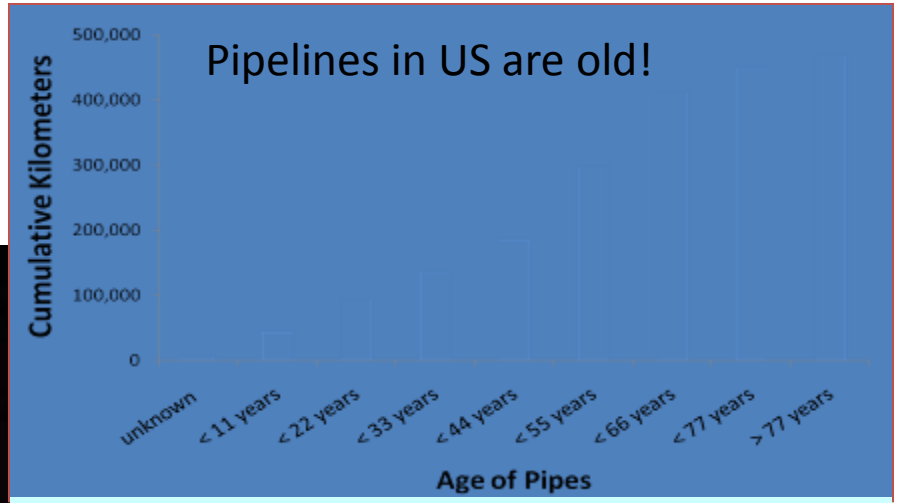
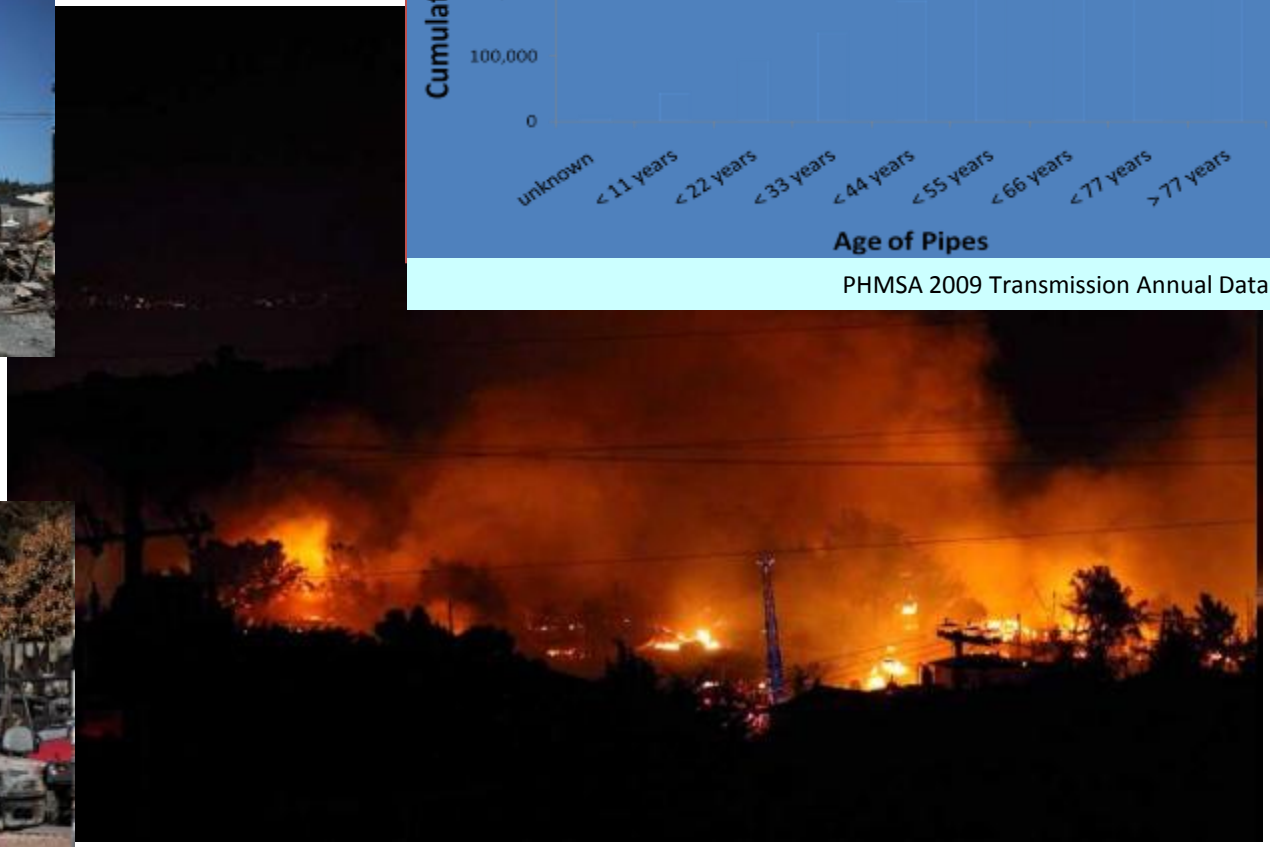
Pipeline accidents and explosions happen, due to large leaks….
….. small leaks are ubiquitous.



PHMSA 2009 Transmission Annual Data



Flames consume homes during a massive fire in a residential neighborhood September 9, 2010 in San Bruno, California. (Photo by Ezra Shaw/Getty Images)

Howarth et al. (2012-b) – Background paper for National Climate Assessment

Table 3. Unconventional gas (shale gas and gas from tight sands), estimates of methane emissions from upstream (at the well site) plus midstream (at gas processing plants), expressed as the percentage of methane produced over the lifecycle of a well. Studies are listed chronologically by date of publication. Modified from Howarth et al. (2012).

Howarth et al. (2011)	3.3 %	(mean; range = 2.2% to 4.3%)
EPA (2011)*	3.0 %	
Jiang et al. (2011)	2.0 %	
Hultman et al. (2011)	2.8 %	
Burnham et al. (2011)	1.3 %	
Stephenson et al. (2011)	0.6 %	
Cathles et al. (2012)	0.9 %	
Petron et al. (2012)	4.0 %	("best estimate;" range = 2.3 to 7.7%)

Emissions at well site… shale gas and other unconventional gas

* The EPA (2011) estimate is as calculated in Howarth et al. (2012), using national emissions from EPA reports and national gas production data from US Department of Energy reports.

Howarth et al. (2012-b) – Background paper for National Climate Assessment

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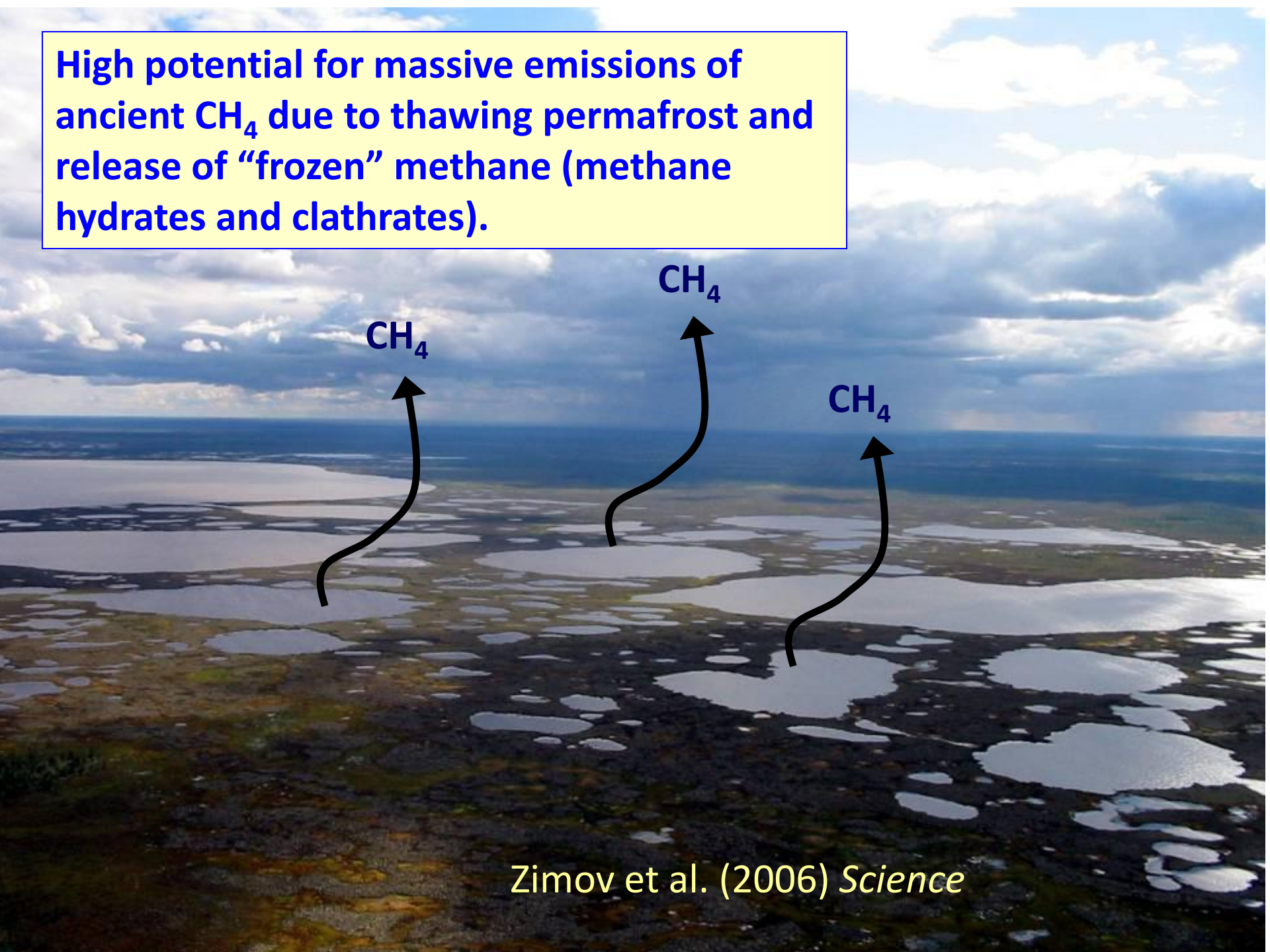
Petron et al. (2012)	4.0 %	("best estimate;" range = 2.3 to 7.7%)

Direct, landscape scale measurements!!

* The EPA (2011) estimate is as calculated in Howarth et al. (2012), using national emissions from EPA reports and national gas production data from US Department of Energy reports.

Time frame for comparing methane and carbon dioxide:

• Hayhoe et al. (2002)	0 to 100 years
• Lelieveld et al. (2005)	20 & 100 years
• Jamarillo et al. (2007)	100 years
• Howarth et al. (2011)	20 & 100 years
• Hughes (2011)	20 & 100 years
• Venkatesh et al. (2011)	100 years
• Jiang et al. (2011)	100 years
• Wigley (2011)	0 to 100 years
• Fulton et al. (2011)	100 years
• Stephenson et al. (2011)	100 years
• Hultman et al. (2011)	100 years
• Skone et al. (2011)	100 years
• Burnham et al. (2011)	100 years
• Cathles et al. (2012)	100 years


High potential for massive emissions of ancient CH_4 due to thawing permafrost and release of "frozen" methane (methane hydrates and clathrates).
CH_4
CH_4
CH_4
Zimov et al. (2006) *Science*

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A

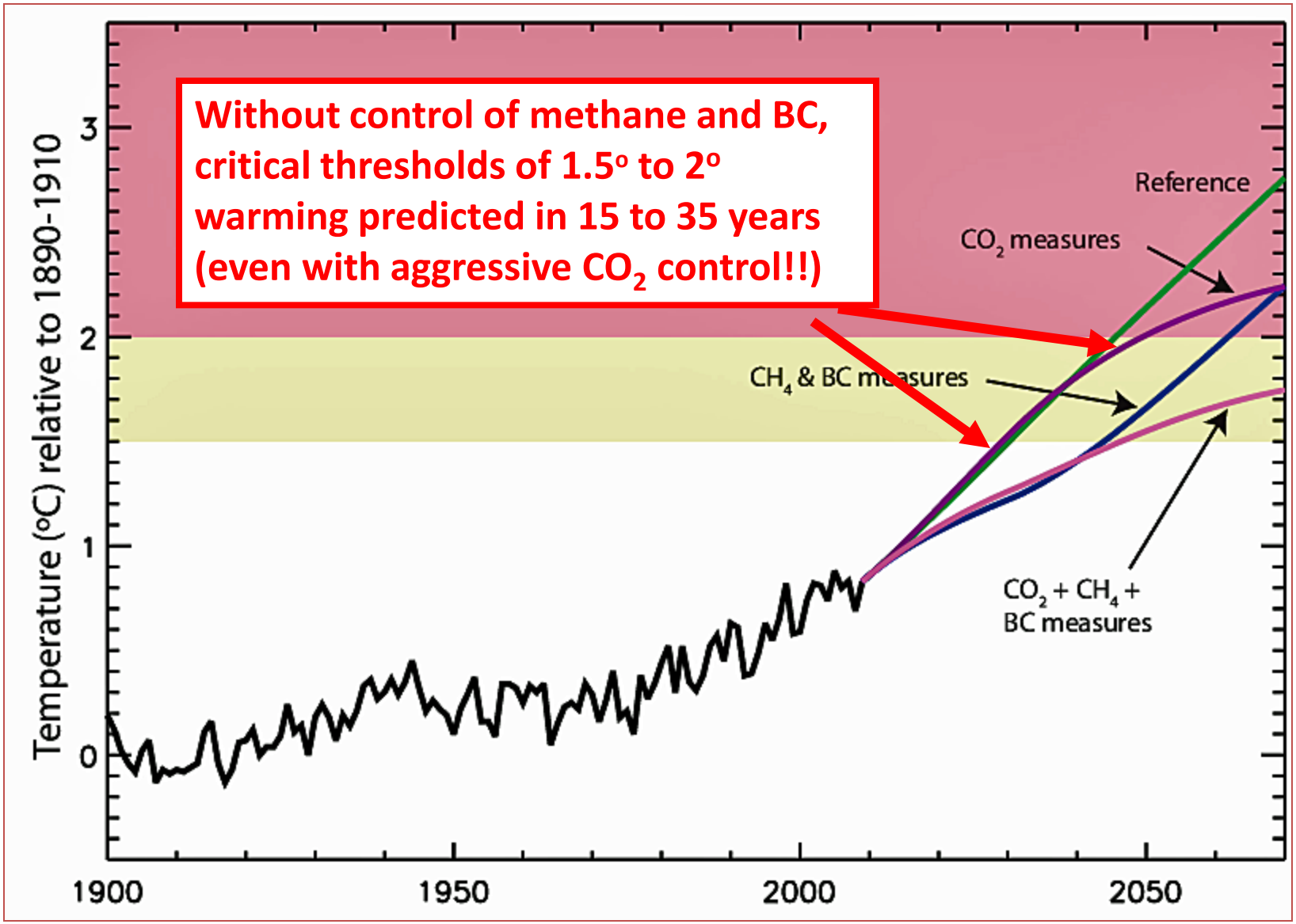
Phil. Trans. R. Soc. A (2007) **365**, 1925–1954
doi:10.1098/rsta.2007.2052
Published online 18 May 2007

Climate change and trace gases

By James Hansen[1,*], Makiko Sato[1], Pushker Kharecha[1], Gary Russell[1], David W. Lea[2] and Mark Siddall[3]

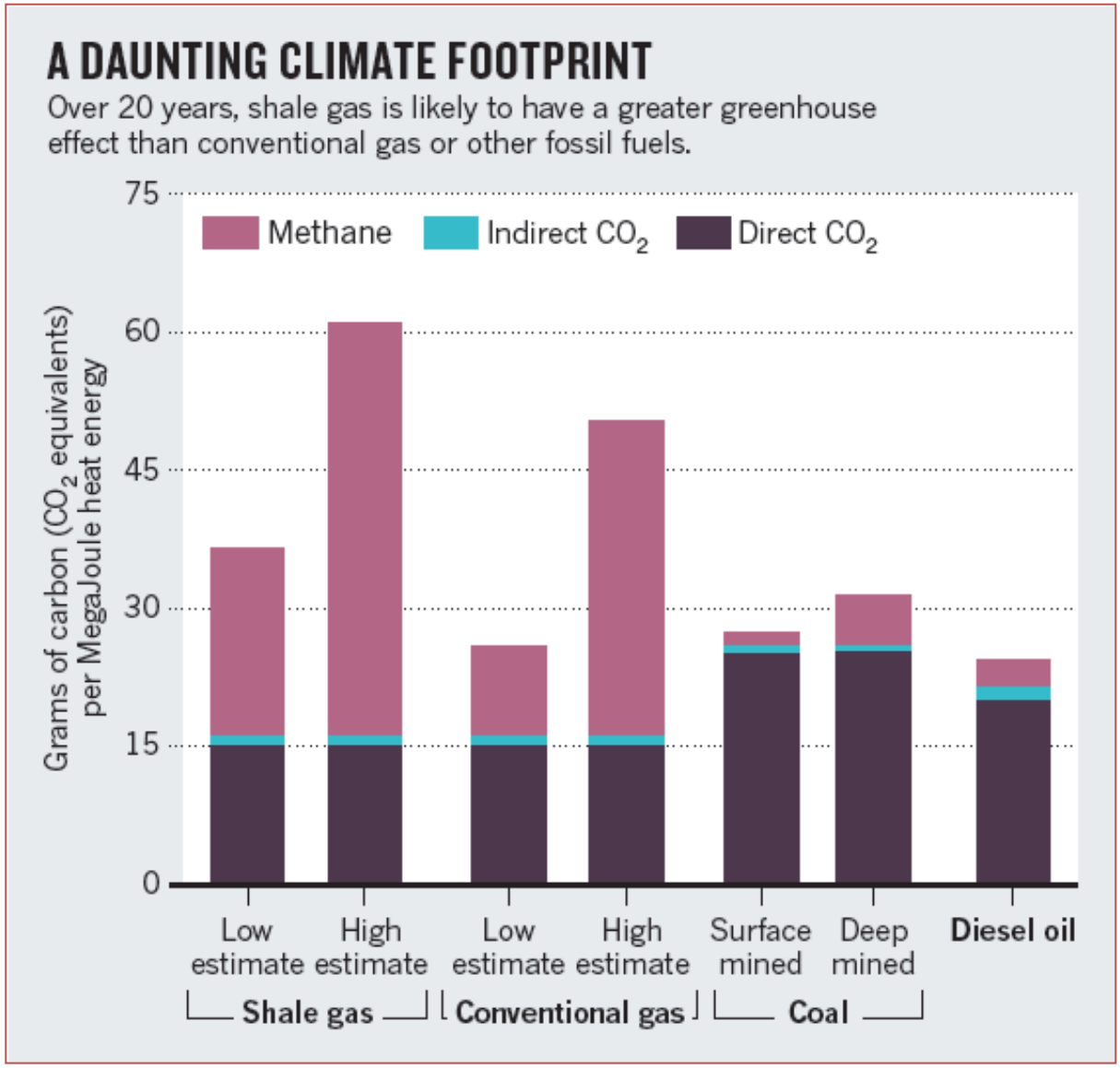
[1]*NASA Goddard Institute for Space Studies and Columbia University Earth Institute, 2880 Broadway, New York, NY 10025, USA*
[2]*Department of Earth Science, University of California, Santa Barbara, CA 93106, USA*
[3]*Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964, USA*

Hansen et al. (2007) identified critical threshold in climate system, to avoid melting of natural methane hydrates, leading to runaway positive feedback of global warming = 1.8° C.

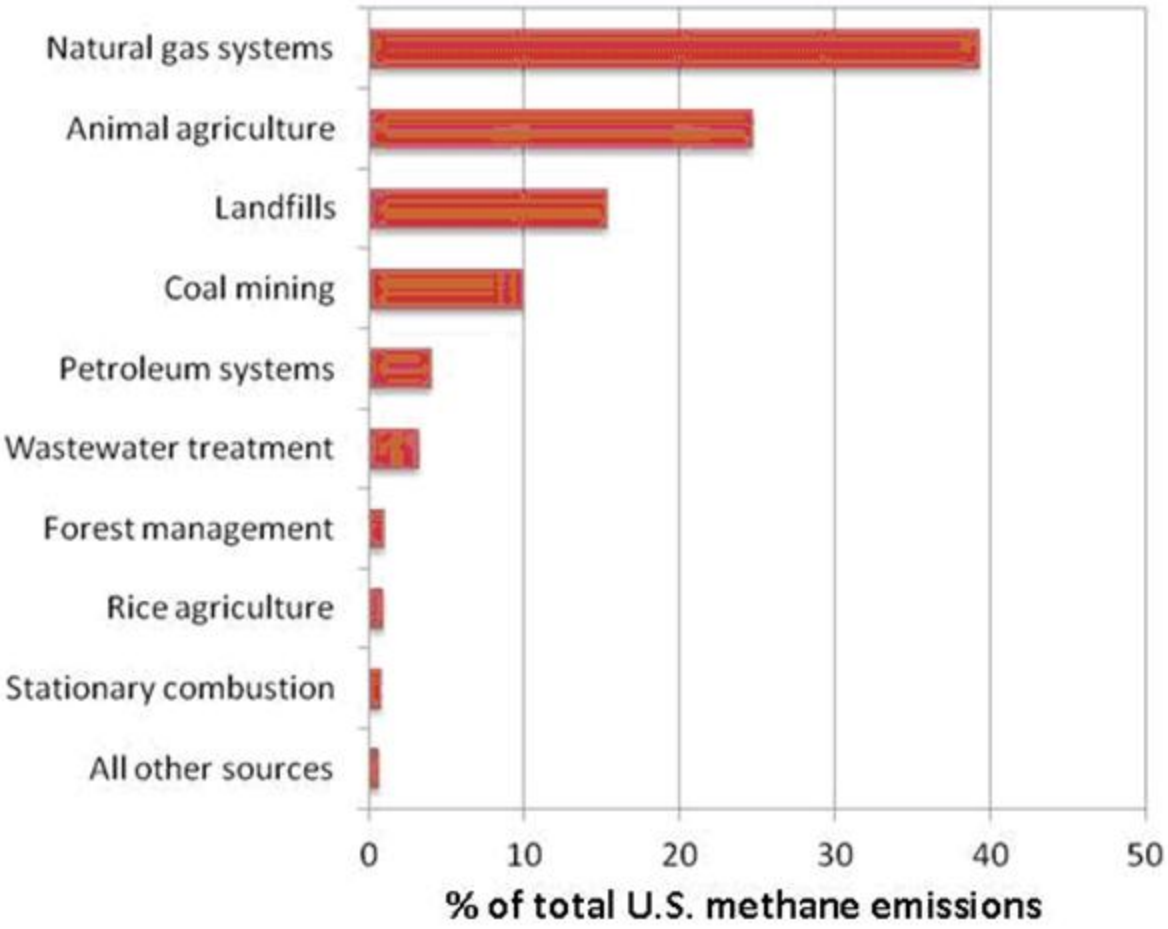


Shindell et al. 2012 *Science*

Greenhouse gas footprint of shale gas compared to other fossil fuels (20-year integrated global warming potential for methane)



Howarth & Ingraffea, *Nature*, 15 September 2011



(Howarth et al. 2012, based on 2011 EPA data for 2009)

Percentage contribution of methane to the total greenhouse gas inventory of the US (2009 data)

	20-yr integrated time frame	100-yr integrated time frame
Methane from all sources	44%	19%
Methane from natural gas	17%	7.4%

(Howarth et al. 2012)

Percentage contribution of methane to the total greenhouse gas inventory of the US (2009 data)

	20-yr integrated time frame	100-yr integrated time frame
Methane from all sources	44%	19%
Methane from natural gas	17%	7.4%

Shale gas a very small part of gas in 2009… As shale gas increasingly replaces conventional gas, methane emissions will grow! (40% to 60% greater emissions from shale gas).

(Howarth et al. 2012)

Can methane emissions be reduced?

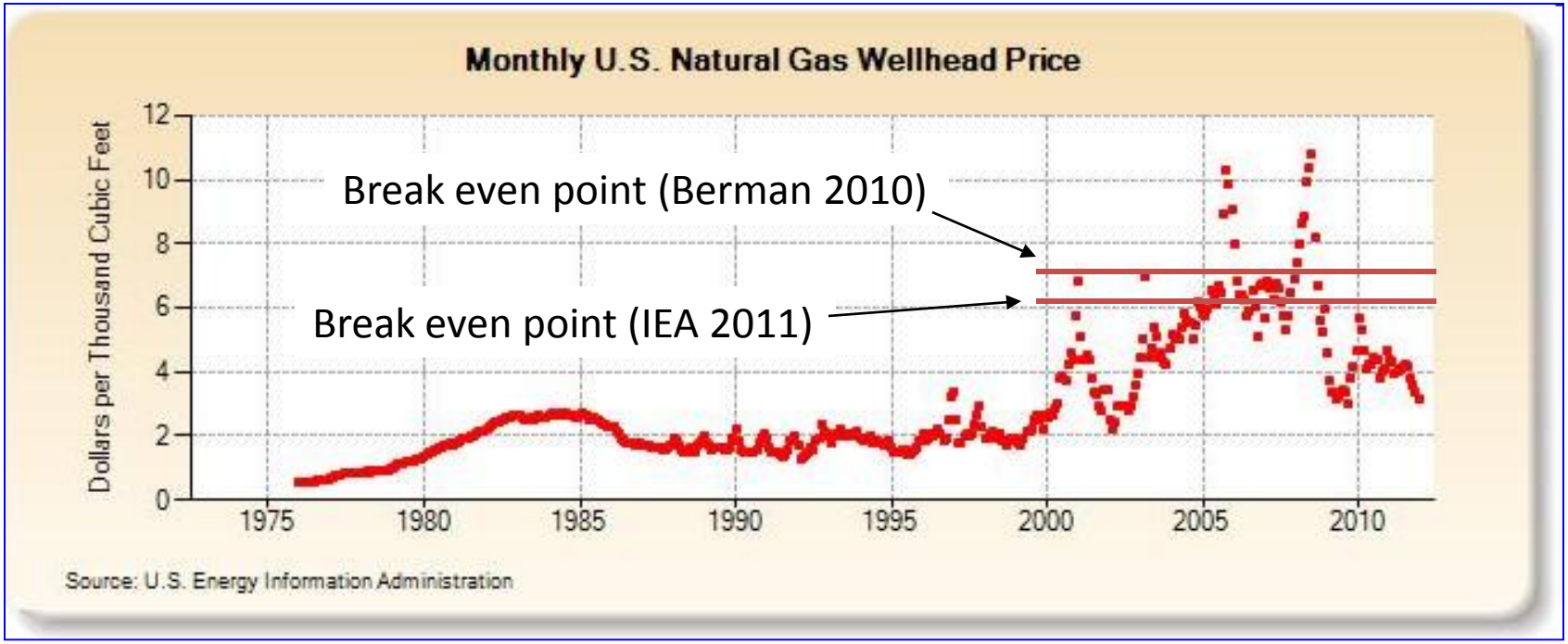
Yes, but:

-- a lot are purposeful venting (economic decision)

-- leakage from old tanks and pipelines would be very expensive to fix. Is it worth the investment for a "transitional fuel?"

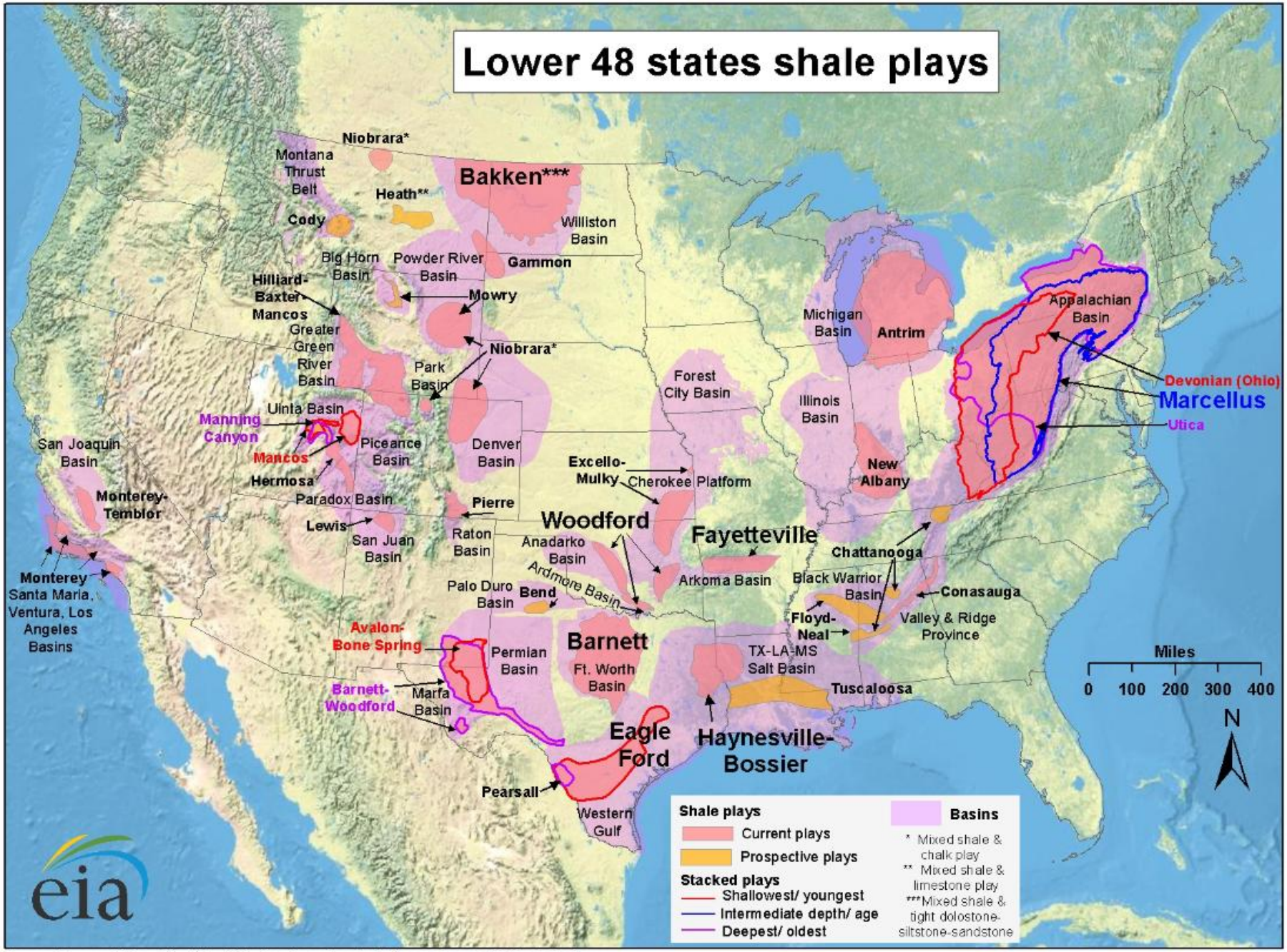
-- would require regulation; industry is strongly opposed to regulation, and has a history of getting around regulation when imposed.

Energy Information Agency, U.S. Department of Energy



On Feb. 29, 2012 = $2.52 per 10^3 ft^3

http://www.eia.gov/dnav/ng/hist/n9190us3m.htm
(downloaded March 1, 2012)

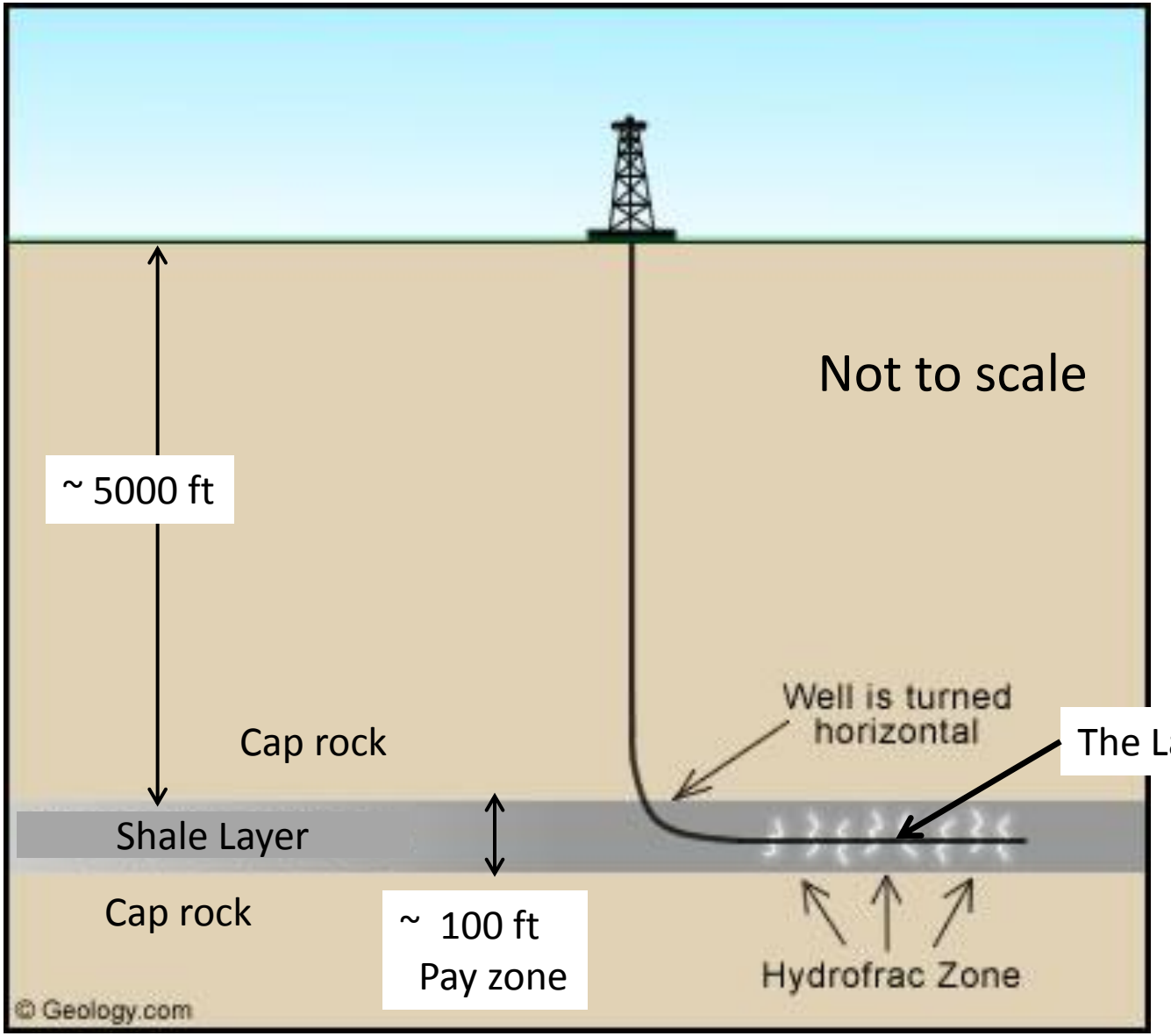


Source: Energy Information Administration based on data from various published studies.
Updated: May 9, 2011

Why Is Shale Gas Development "Unconventional"? Why an SGEIS?

- Because it requires 4 technologies only recently combined to make gas production from shales technically and economically feasible.
- Directional drilling: needed to access a thin layer of shale with long laterals.
- High frac fluid volumes: needed to stimulate gas release from many existing fractures.
- Slickwater: needed to control the amount of power needed to pump large volumes of frac fluids, at high pressures, quickly, over long distances, through small diameter casing.
- Multi-well Pads and Cluster Drilling: needed to access as much of the gas inventory as possible, under constraints of leasing and capital.

High Volume, Slickwater Fracing from Long Laterals (HVSFLL): The Concept



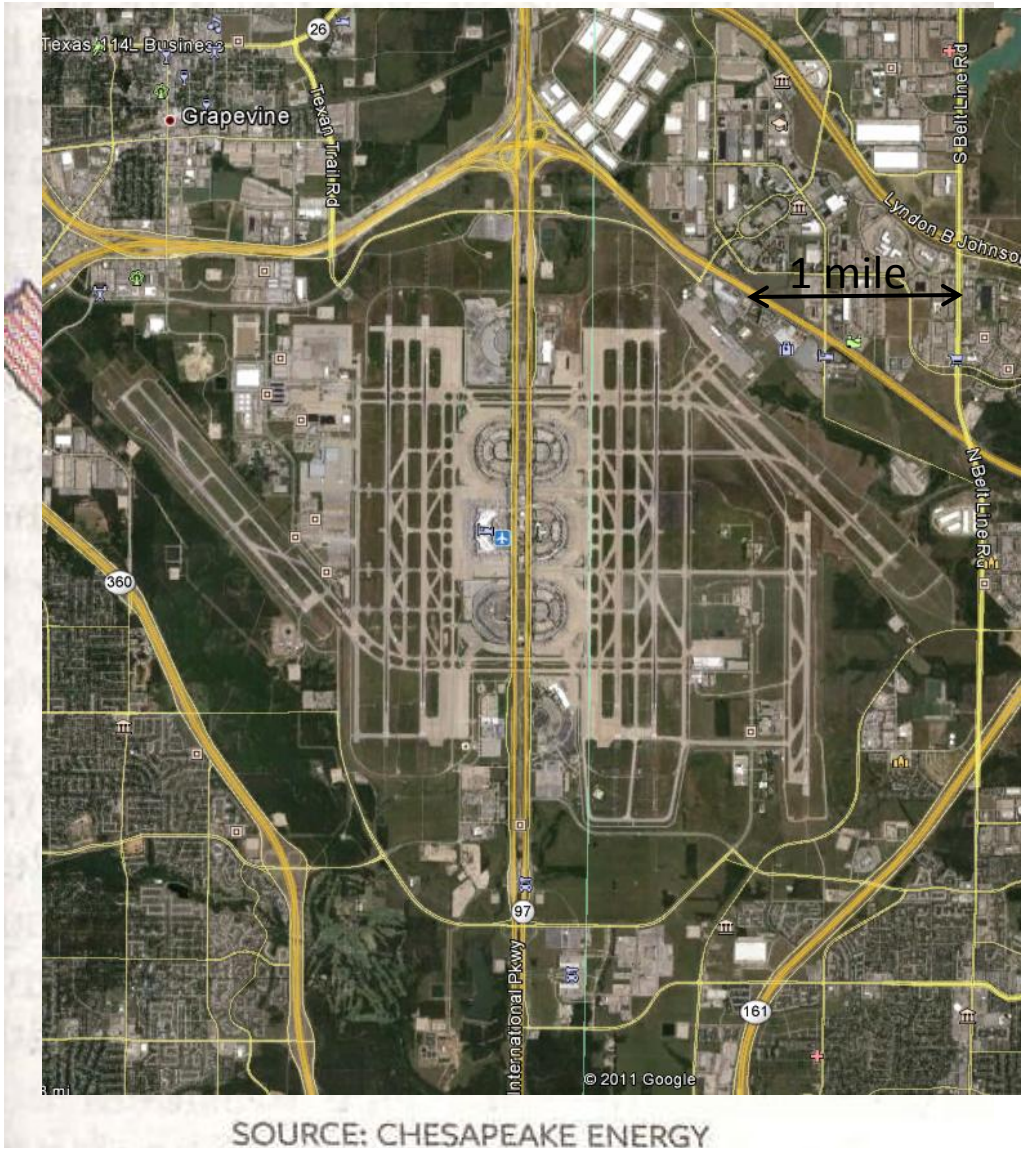
Gas Producing Shales are Heavily Fractured Naturally

Geneseo-Burket (Devonian black shale)

Taughannock Falls State Park, Trumansburg, N.Y.

Photo Courtesy T. Engelder

Example of Spatially Intense Development: Dallas/Fort Worth Airport Property, Barnett Shale Play



SOURCE: CHESAPEAKE ENERGY

- 53 pads on 18,076 acres, 30 square miles
- Each red line is a well lateral
- Each red dot is a pad
- Almost complete coverage
- Patchwork, mostly ideal units
- One leaser, one developer

Unconventional Development of Gas from Shale Is New Technology

Hydraulic Fracturing Technological Milestones [14]	
Early 1900s	Natural gas extracted from shale wells. Vertical wells fracked with foam.
1983	First gas well drilled in Barnett Shale in Texas
1980-1990s	Cross-linked gel fracturing fluids developed and used in vertical wells
1991	First horizontal well drilled in Barnett Shale
1991	Orientation of induced fractures identified
1996	Slickwater fracturing fluids introduced
1996	Microseismic post-fracturing mapping developed
1998	Slickwater refracturing of originally gel-fracked wells
2002	Multi-stage slickwater fracturing of horizontal wells
2003	First hydraulic fracturing of Marcellus shale [15]
2005	Increased emphasis on improving the recovery factor
2007	Use of multi-well pads and cluster drilling

From NYS SGEIS revised draft, page 5-5, 2011

About ½ of all unconventional shale gas globally produced in the last 3 years

How Much Water For Each Well?

- Depends on length of lateral, number of frac stages
- Typically, much more than 1 million gallons

Chesapeake Energy is averaging 5.5 million gallons/well in PA Marcellus play.

http://hydraulicfracturing.aitrk.com/Pages/information.aspx

What Else Goes Down The Well With The Water?

Proppant: Sand or coated ceramic beads, transported into the fractures to keep them open after fracturing pressure release.

Gelling Agents: Increase fluid viscosity to help proppant transport.

Biocides: Kill bacteria that harm the gelling agents, can sour well.

Breakers: Decrease viscosity of the fracturing fluid, after the fracturing process, to improve flowback.

Fluid-Loss Additives: Decrease leakoff of fracturing fluid into the rock.

Anti-Corrosives: Protect metallic elements in the well.

Friction Reducers: Allow high pressures and flow rates.

http://www.epa.gov/OGWDW/uic/pdfs/cbmstudy_attach_uic_ch04_hyd_frac_fluids.pdf

See Table 6.1 NYS dSGEIS, page 6-19

What Comes Back Up? Called FLOWBACK

- When the fracturing process is completed, the pressure is released, and much of the fracturing fluid backflows to the wellhead, during the flowback period, and afterwards*.

- The backflow will:
  - be highly saline, e.g. sodium and calcium salts;
  - contain some heavy metals, e.g. barium, strontium;
  - contain frac fluid additives;
  - contain NORM, primarily Radium-226

See Table 5.10, NYS dSGEIS, page 5-106

Where Does The FLOWBACK Go?

Initially, it remains on site, in a collection pit, or tanks.

http://www.epa.gov/OGWDW/uic/pdfs/cbmstudy_attach_uic_ch04_hyd_frac_fluids.pdf

Where Does The FLOWBACK Go?

http://www.donnan.com/Marcellus-Gas_Hickory.htm

Flowback Disposal Possibilities

- EPA-regulated Class II “brine” injection well
- Sewage treatment plant (POTW)
- Industrial waste treatment facility
- Road spreading
- Recycling/Reuse

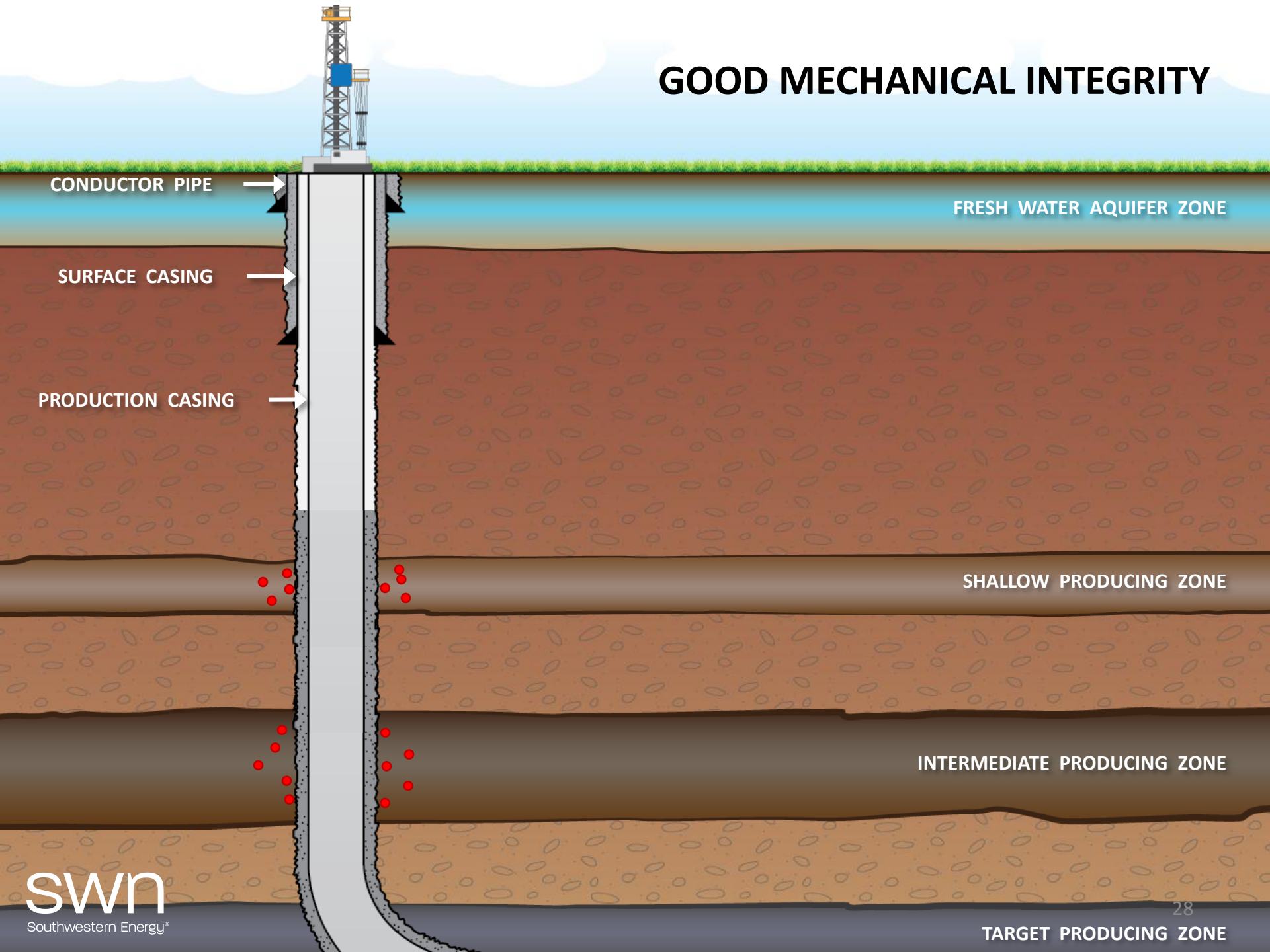
Gas Is Supposed to Rise Inside the Production Casing, Not Outside

VIDEO of
Methane Bubbling
At Well Head

Bubbling in Muncy Creek, Lycoming County, PA: Example of Migration of Hydrocarbons

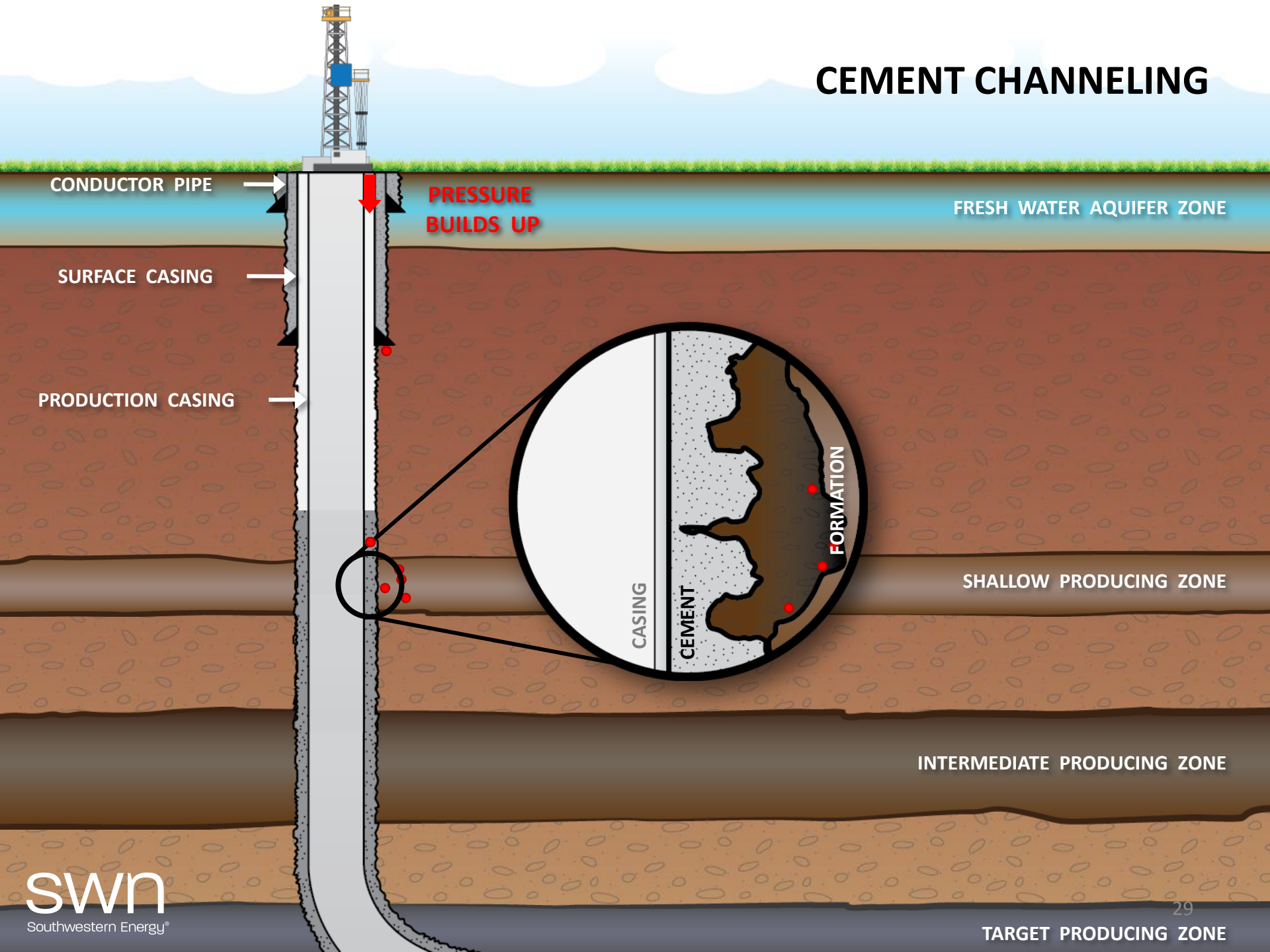
Video Courtesy of Ralph Kisberg, Responsible Drilling Alliance

GOOD MECHANICAL INTEGRITY



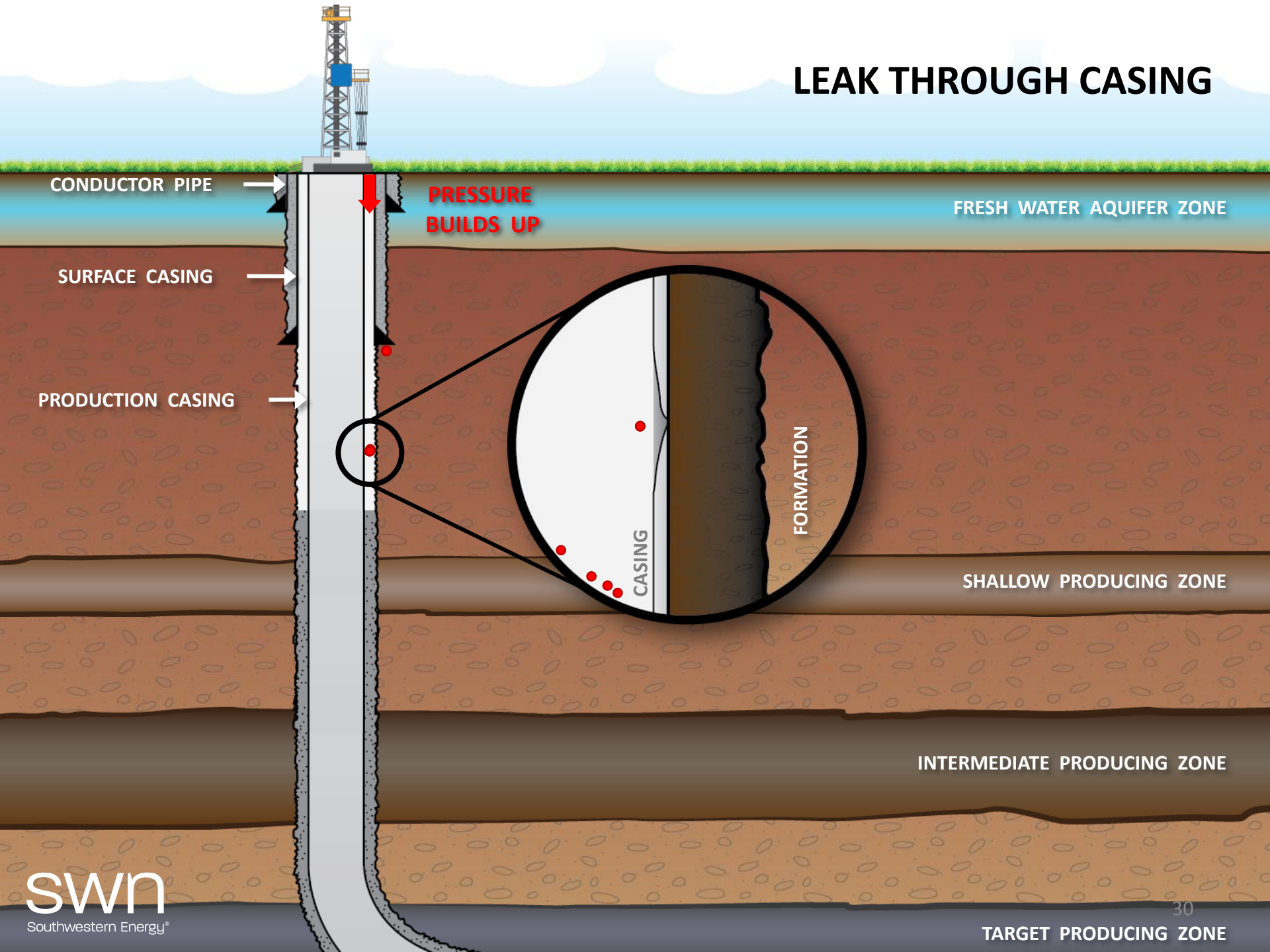
swn
Southwestern Energy®

CEMENT CHANNELING



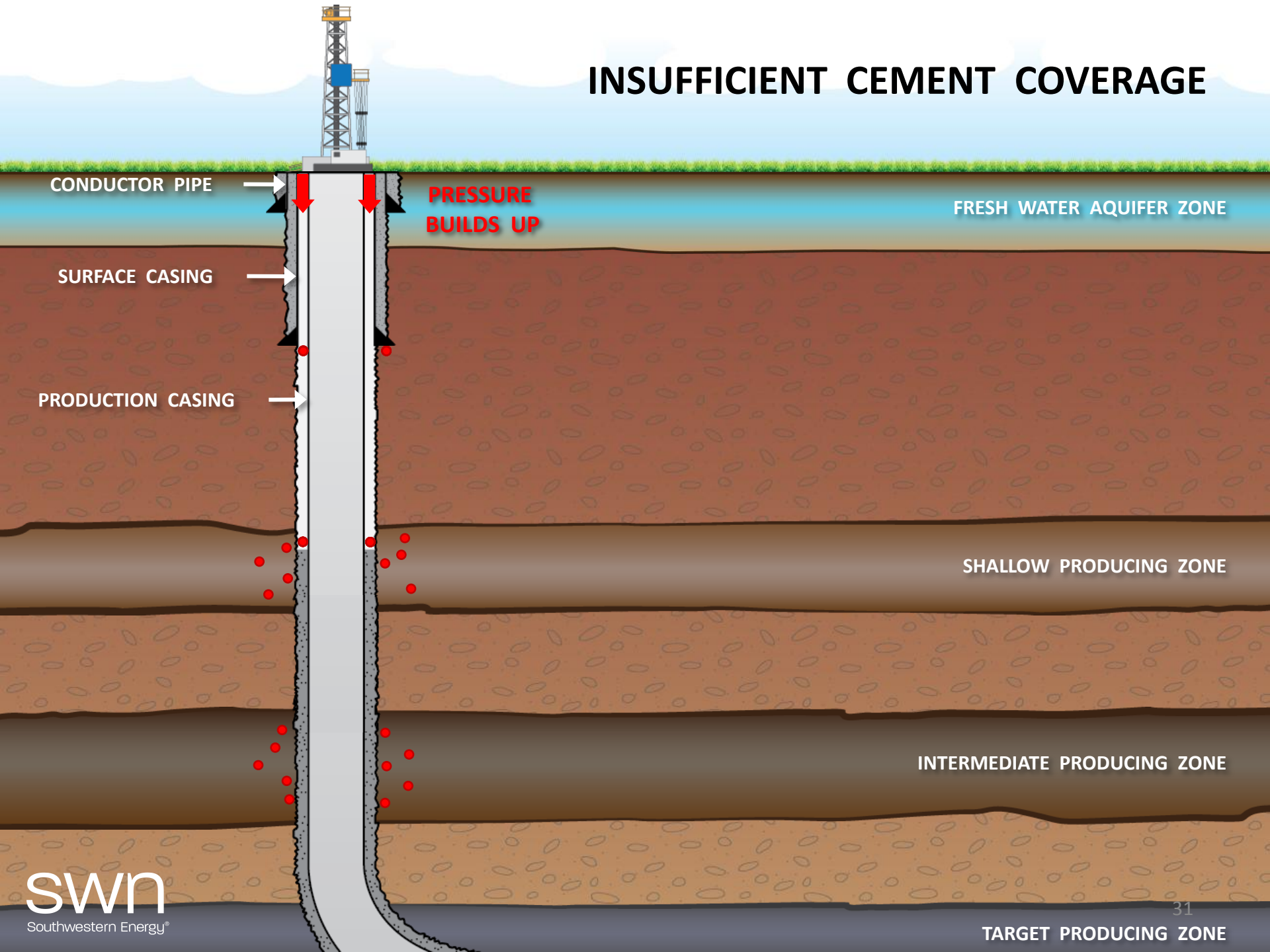
swn
Southwestern Energy®

LEAK THROUGH CASING



swn
Southwestern Energy®

INSUFFICIENT CEMENT COVERAGE



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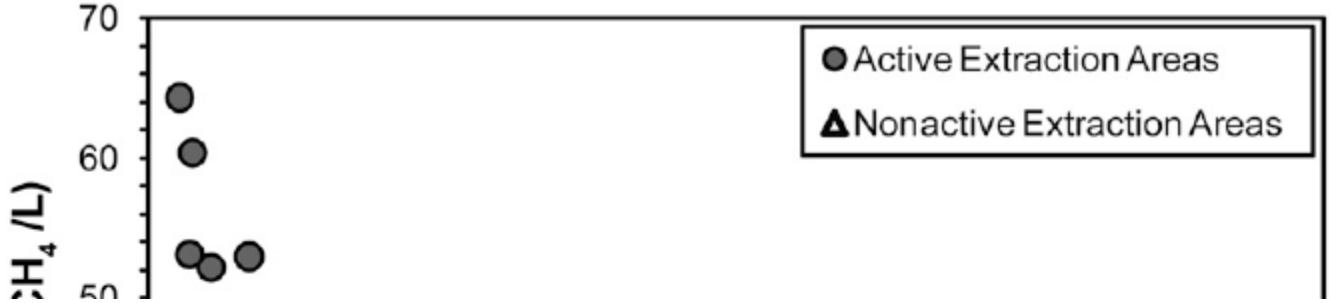
New Scientific Data on Methane Contamination of Water Wells

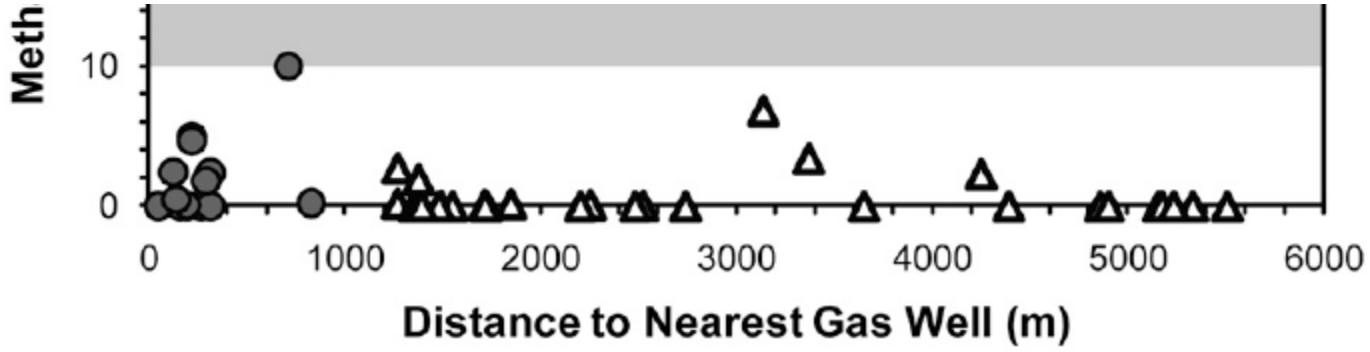


Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing

Stephen G. Osborn[a], Avner Vengosh[b], Nathaniel R. Warner[b], and Robert B. Jackson[a,b,c,1]

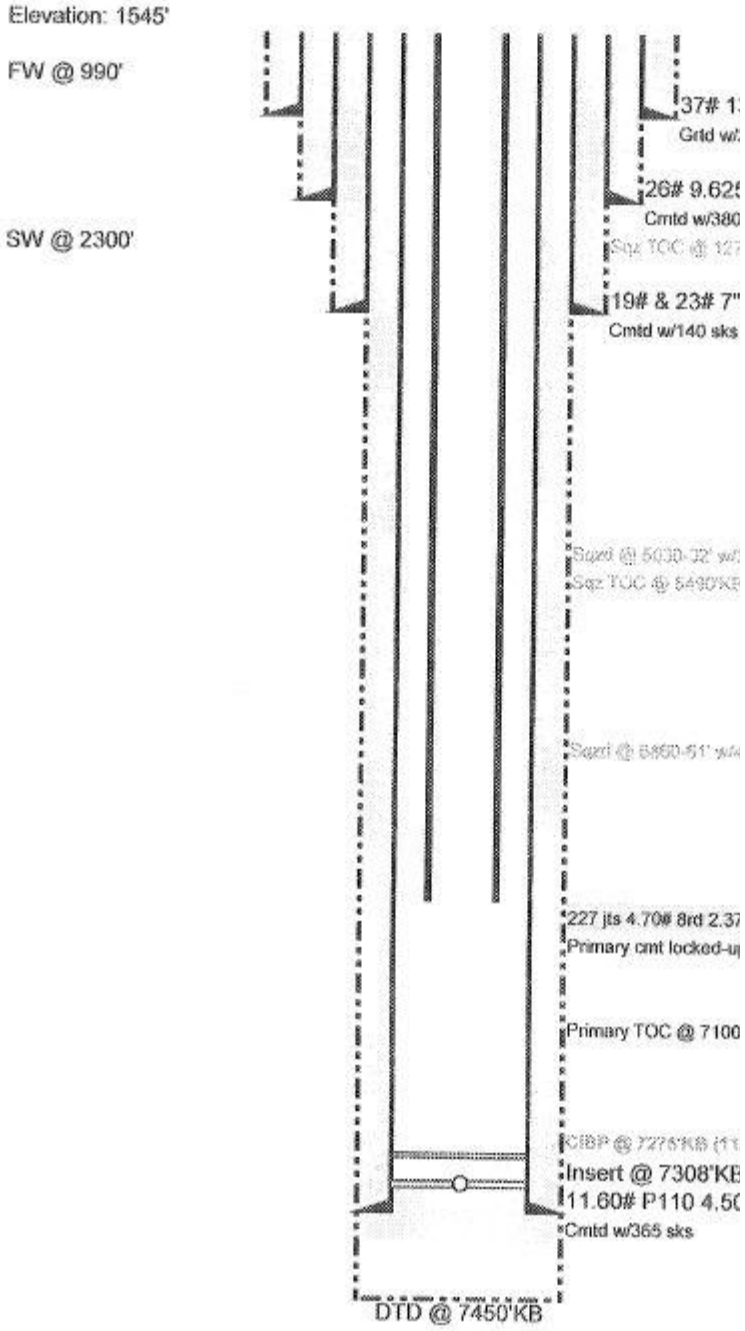
[a]Center on Global Change, Nicholas School of the Environment, [b]Division of Earth and Ocean Sciences, Nicholas School of the Environment, and [c]Biology Department, Duke University, Durham, NC 27708

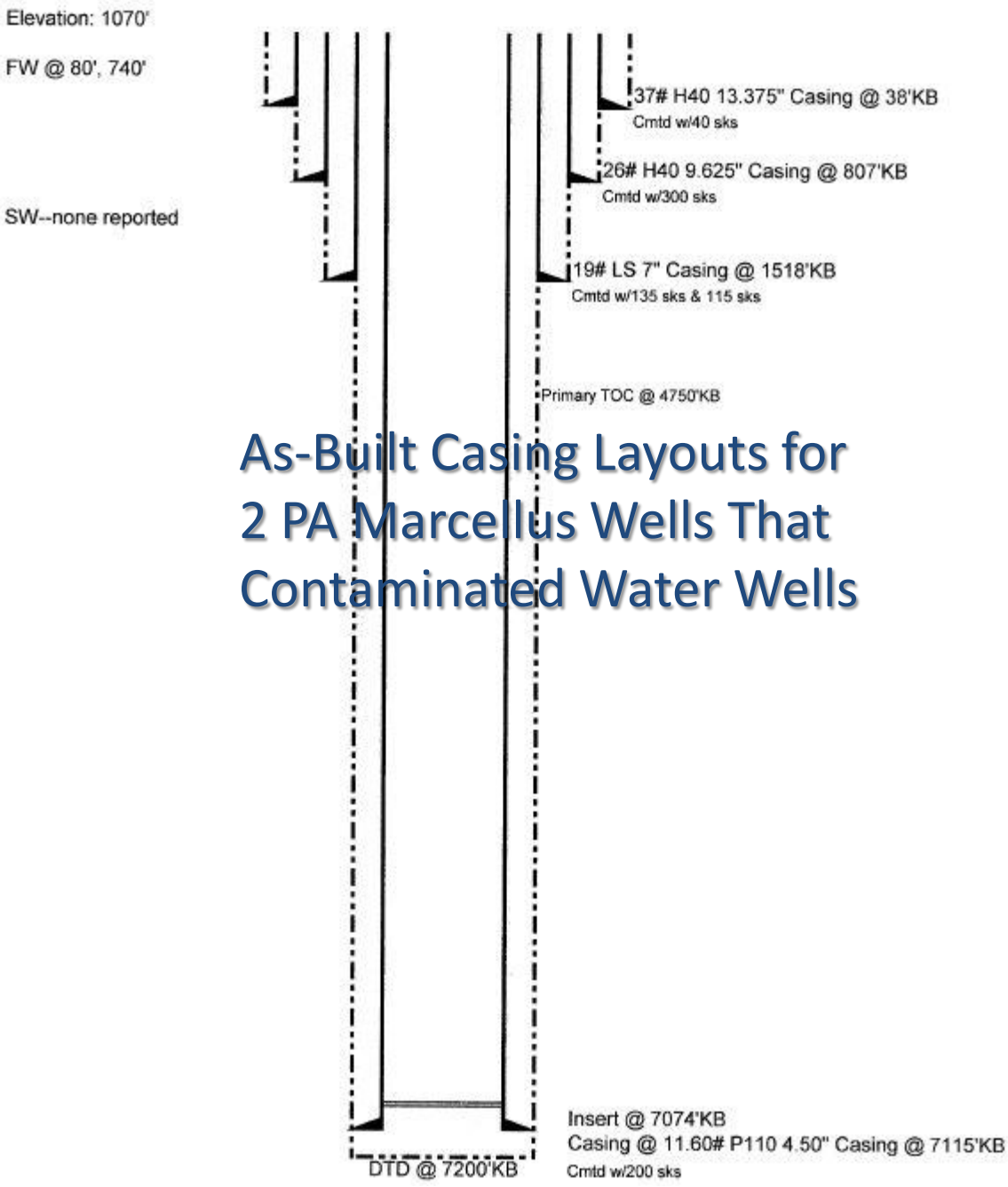
Edited* by William H. Schlesinger, Cary Institute of Ecosystem Studies, Millbrook, NY, and approved April 14, 2011 (received for review January 13, 2011)



www.pnas.org/cgi/doi/10.1073/pnas.1100682108

As-Built Casing Layouts for 2 PA Marcellus Wells That Contaminated Water Wells



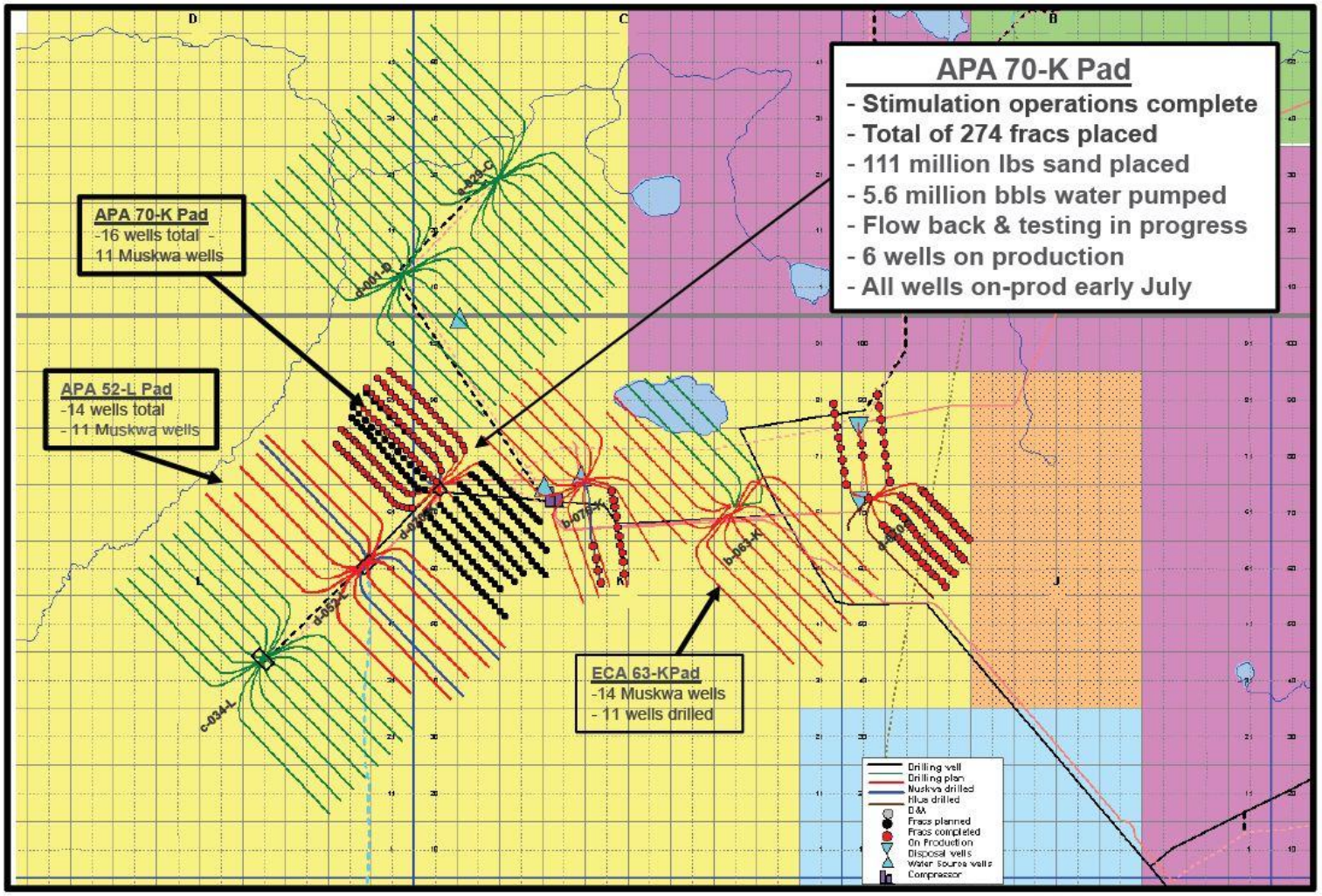


World's Largest Frac Job ?????

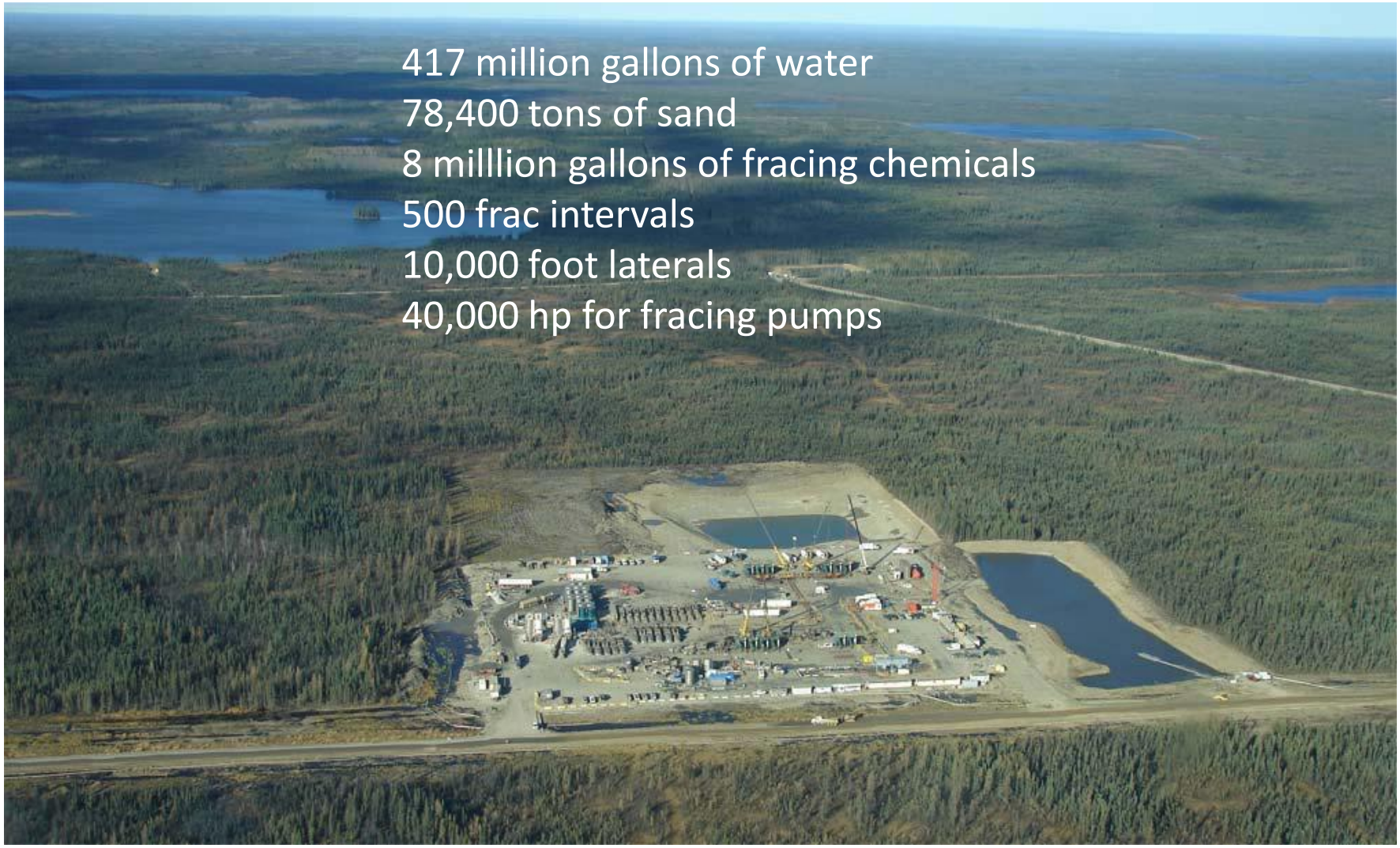
Apache CORPORATION

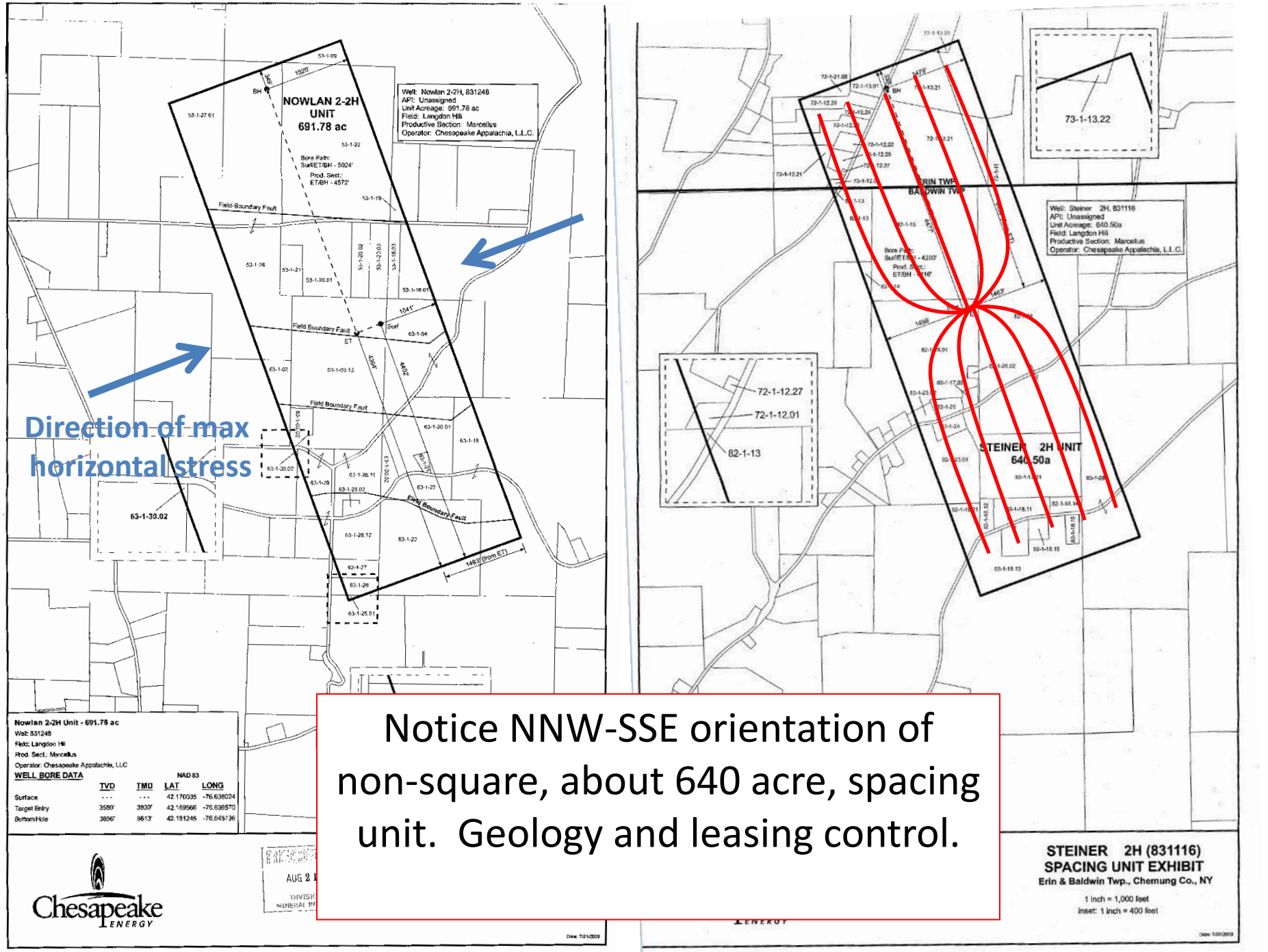
Horn River Area, NE British Columbia

Two Island Lake Operations Status



Encana Says “No!” This One Is It





Notice NNW-SSE orientation of non-square, about 640 acre, spacing unit. Geology and leasing control.

Footprint of the Best Unit, 7-Well Pad, Pennsylvania

Photos courtesy Robert Donnan

Marcellus Well Being "Finished" Outside Dimock, Pa June, 2011: Major Source of Methane Emission

Photo and FLIR Methane-Tuned Video Courtesy Frank Finan

Marcellus Well Being "Finished" Outside Dimock, Pa. June, 2011: Major Source of Methane Emission

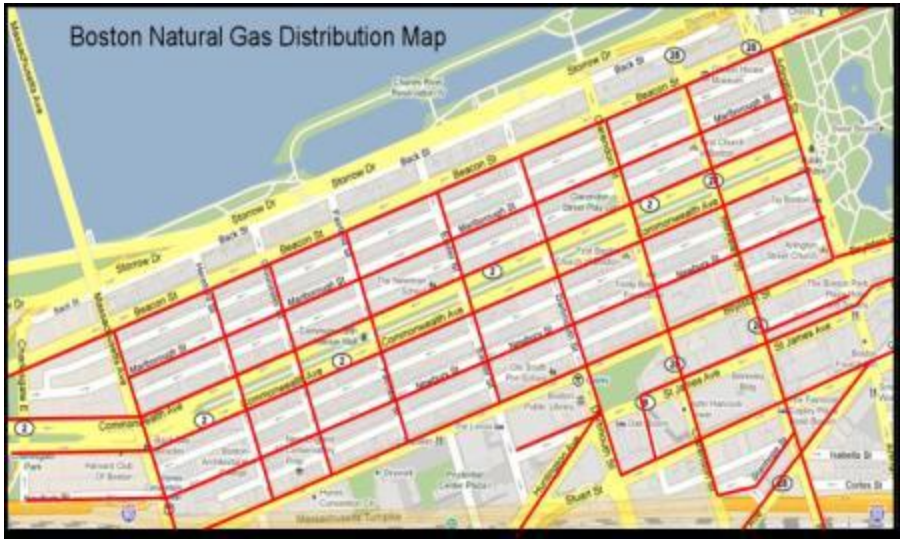
Video

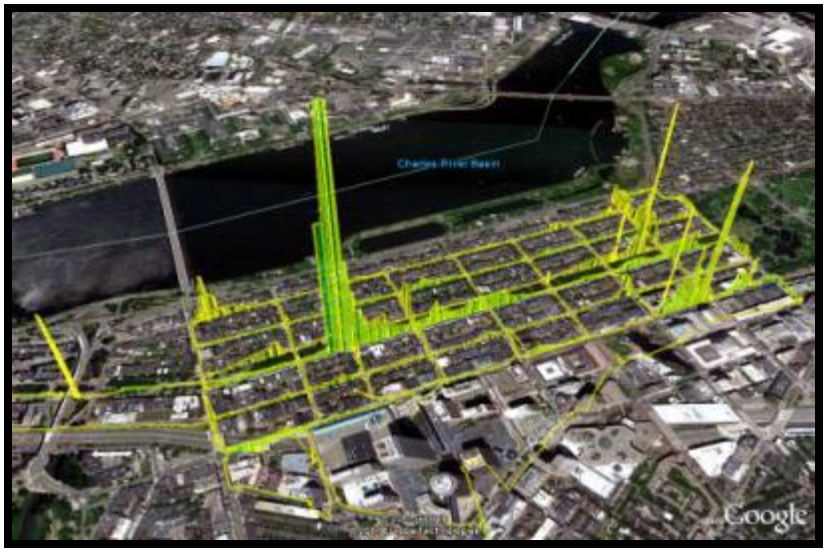
Video courtesy of Frank Finan

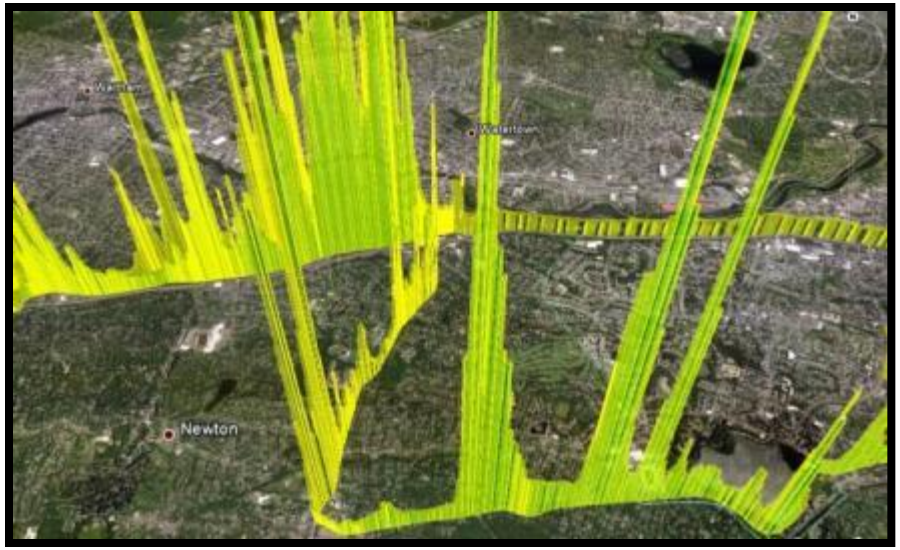
Ancillary Infrastructure Is Major Source of Methane Emission

Courtesy of Calvin Tillman.

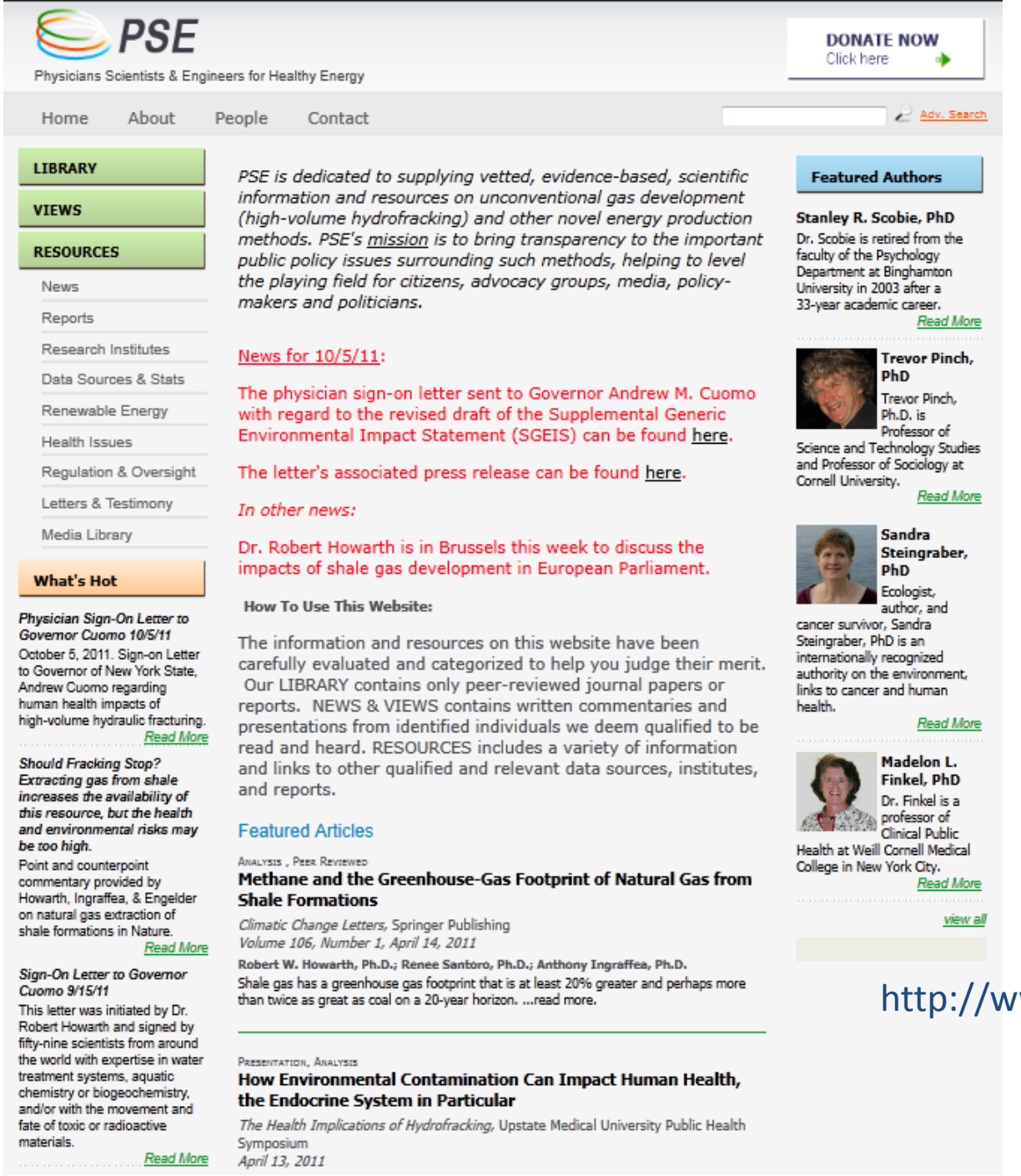
Natural Gas Leaks in and Around Boston: Pipelines A Major Source of Methane Emission







Courtesy of Prof. Nathan Phillips, Boston University



Where Can You Find Reliable Information?

http://www.psehealthyenergy.org/

Where Can You Find Reliable Information?

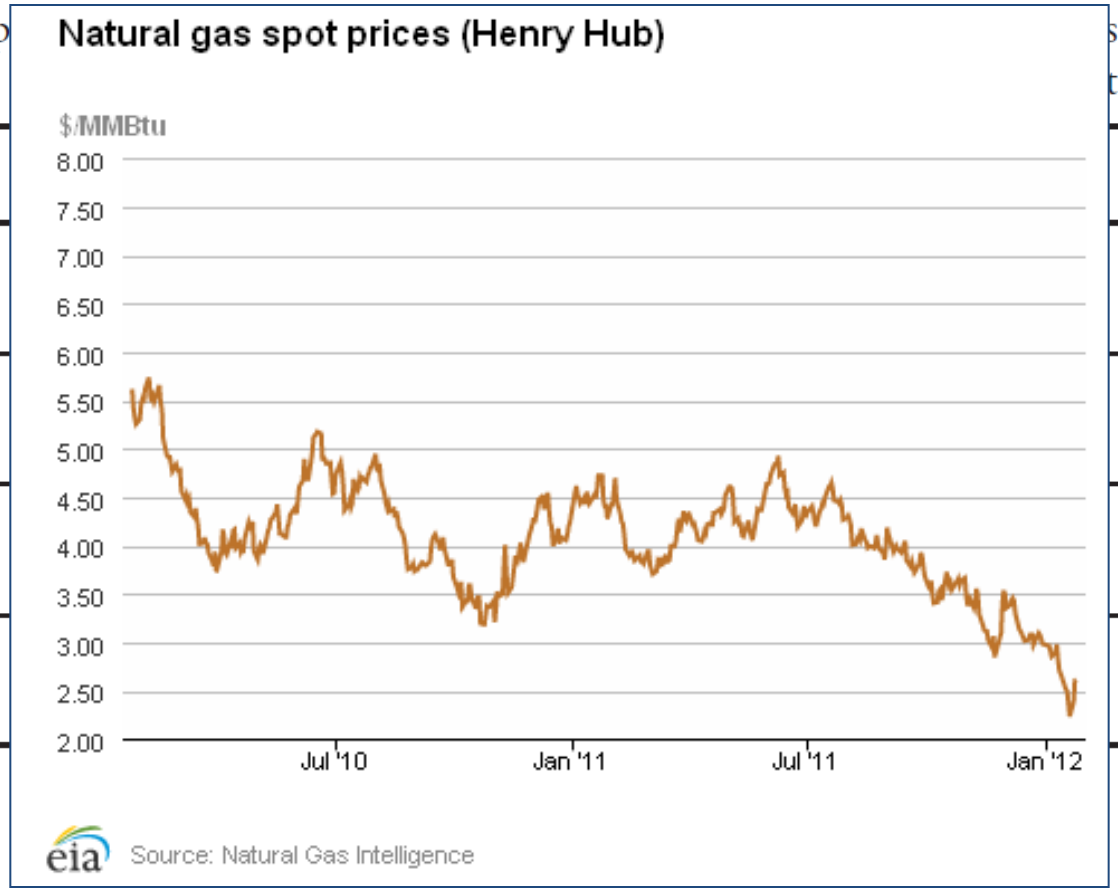
http://www.earthworksaction.org/oil_and_gas.cfm

MIT Study On Economics of Shale Gas

TABLE 1

Initial p … s in major U.S. shale plays … tes

	Marcellus	Woodford
Mean	3,500 **4.00**	2,676 **5.67**
Median	n/a **n/a**	2,520 **5.97**
P20	5,500 **2.87**	4,200 **3.95**
P80	1,500 **8.09**	1,000 **13.71**



Jacoby *et al.,* Economics of Energy & Environmental Policy, Vol. 1, No. 1, pp. 37-51, 2011

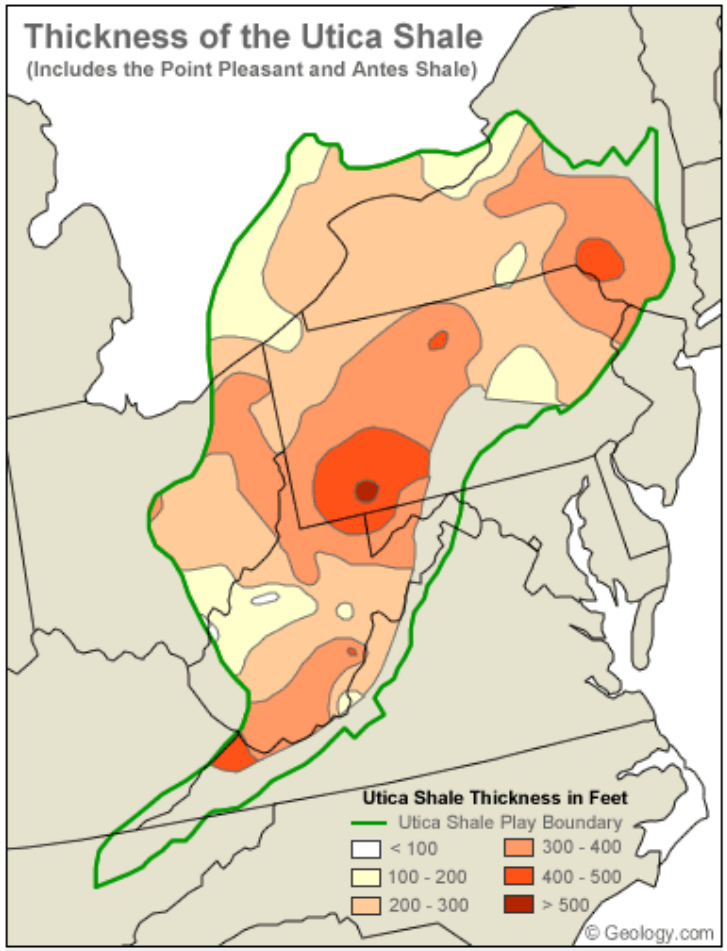


Figure 6: Thickness map of rocks present between the top of the Trenton/Black River Groups and the top of the Utica Shale. In some areas the Point Pleasant Shale and the Antes Shale are included in this thickness.

This map was compiled by Geology.com using data provided by the Energy Information Administration [1] and the U.S. Department of Energy [4].

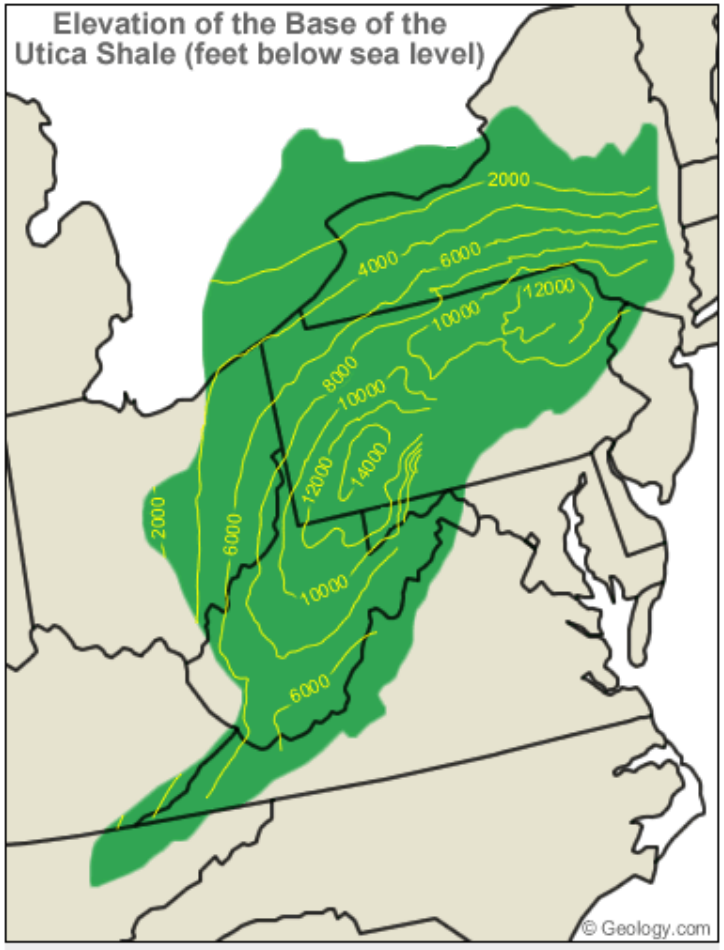


Figure 2: Approximate elevation for the base of the Utica Shale (top of the Trenton). Elevations shown on the map are feet below sea level.

This map was compiled by Geology.com using data provided by the Energy Information Administration [1], the United States Geological Survey [2] and the Pennsylvania Geological Survey [3].