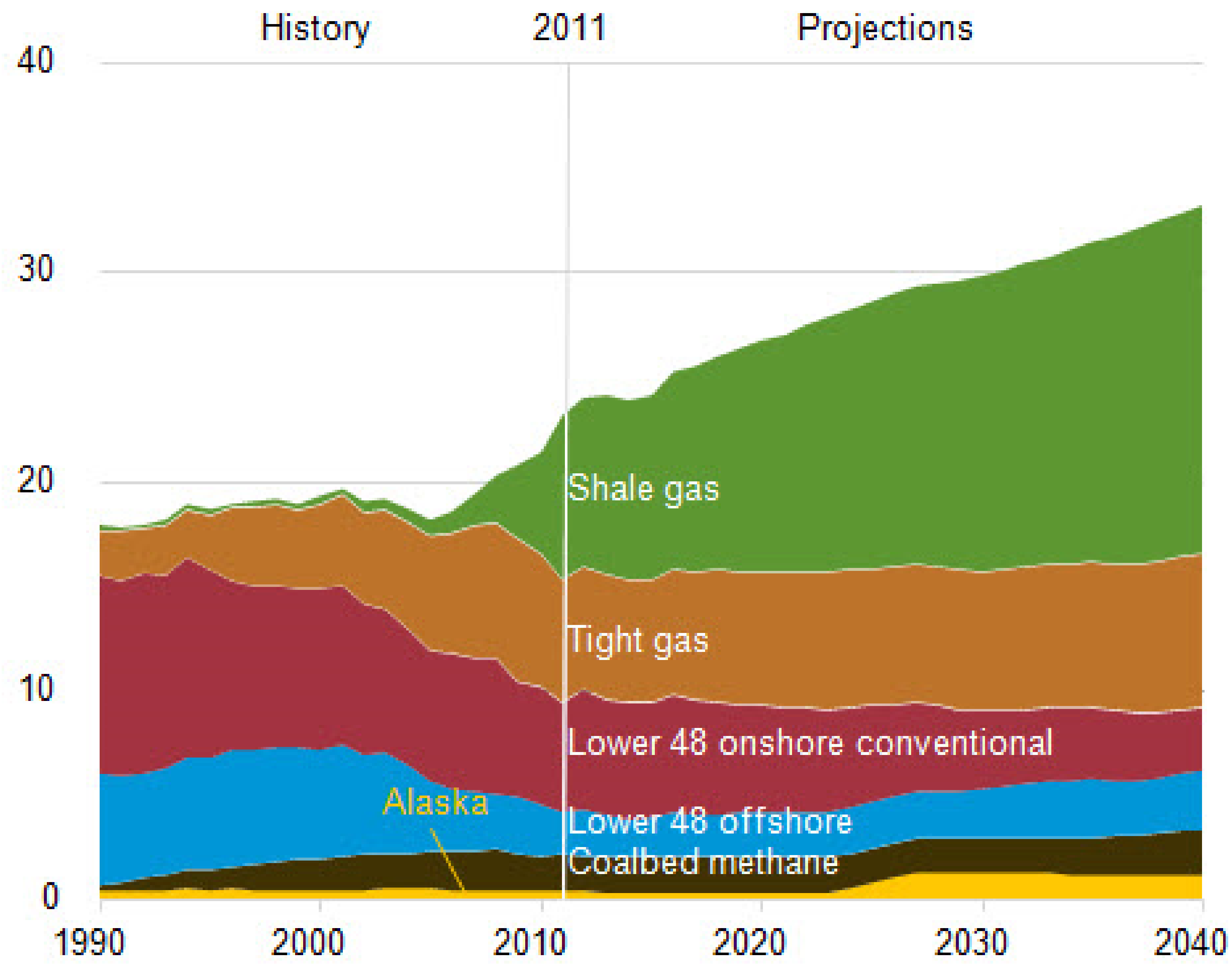
Shale gas : science and controversy

Mike Stephenson
British Geological Survey

Fact



EIA outlook


Fact?
Methane in domestic water supplies from fracking?
…or natural methane?
Do Not Drink this Water
GASLAND THEMOVIE.COM


Fact?
Cracks in a bridge from earthquakes caused by fracking
…or cracks that were already there


Fact?
2006 to 2011, CO_2 from fossil fuels declined by 7.7% due to substitution of shale gas for coal in power stations
…but more greenhouse gas emissions due to 'fugitive emissions' of methane associated with fracking?

Contestable areas in shale gas

Does shale gas use too much water?

Do shale gas wells contaminate groundwater?

Does fracking cause dangerous earthquakes?

Does shale gas cause subsidence?

Does fracking produce dangerous radioactivity?

Is shale gas lower carbon than coal?

Shale gas

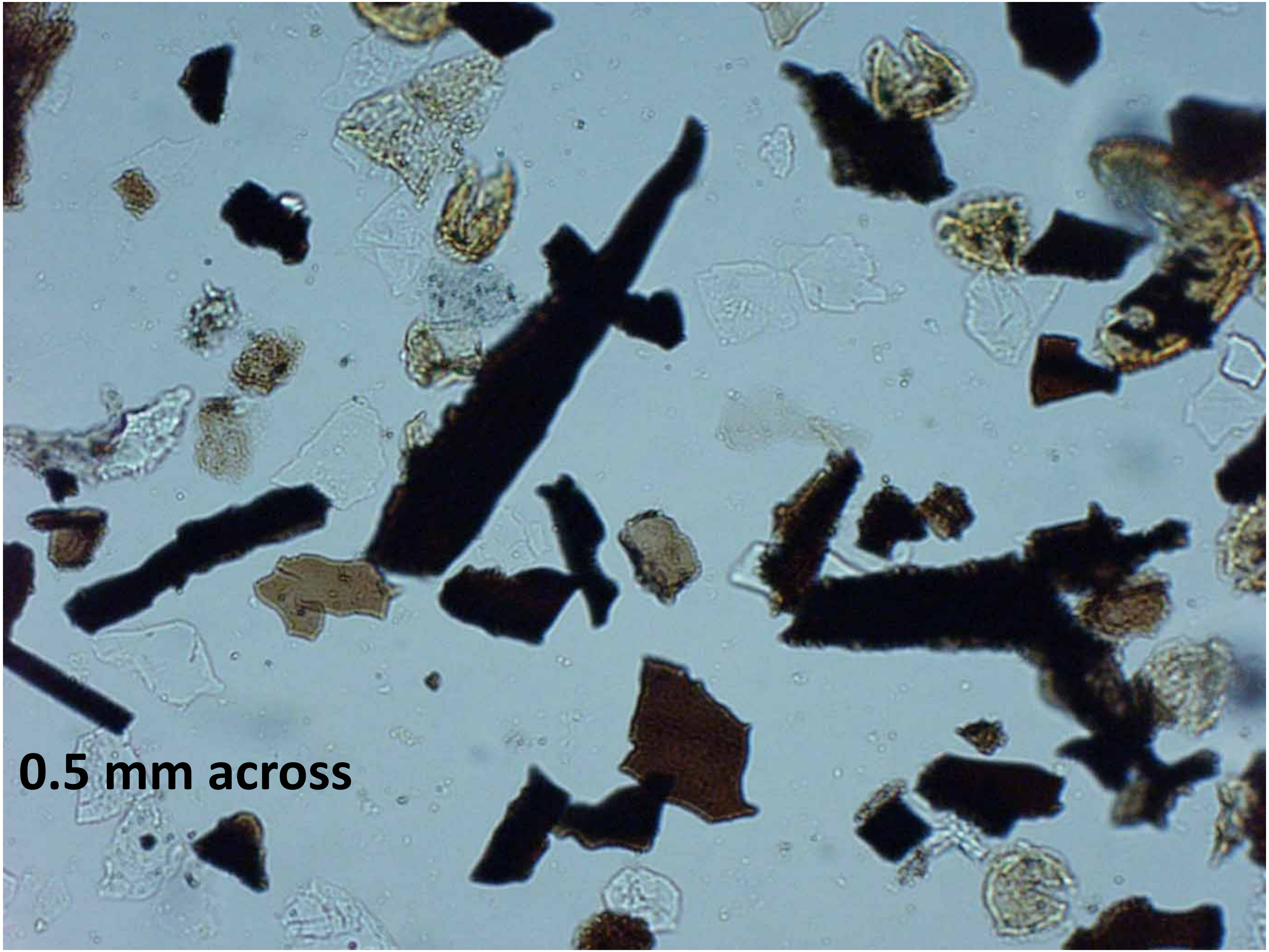
Peer reviewed science

I’m going to show you how the ‘science gauge’ can be applied to some of these contestable issues.

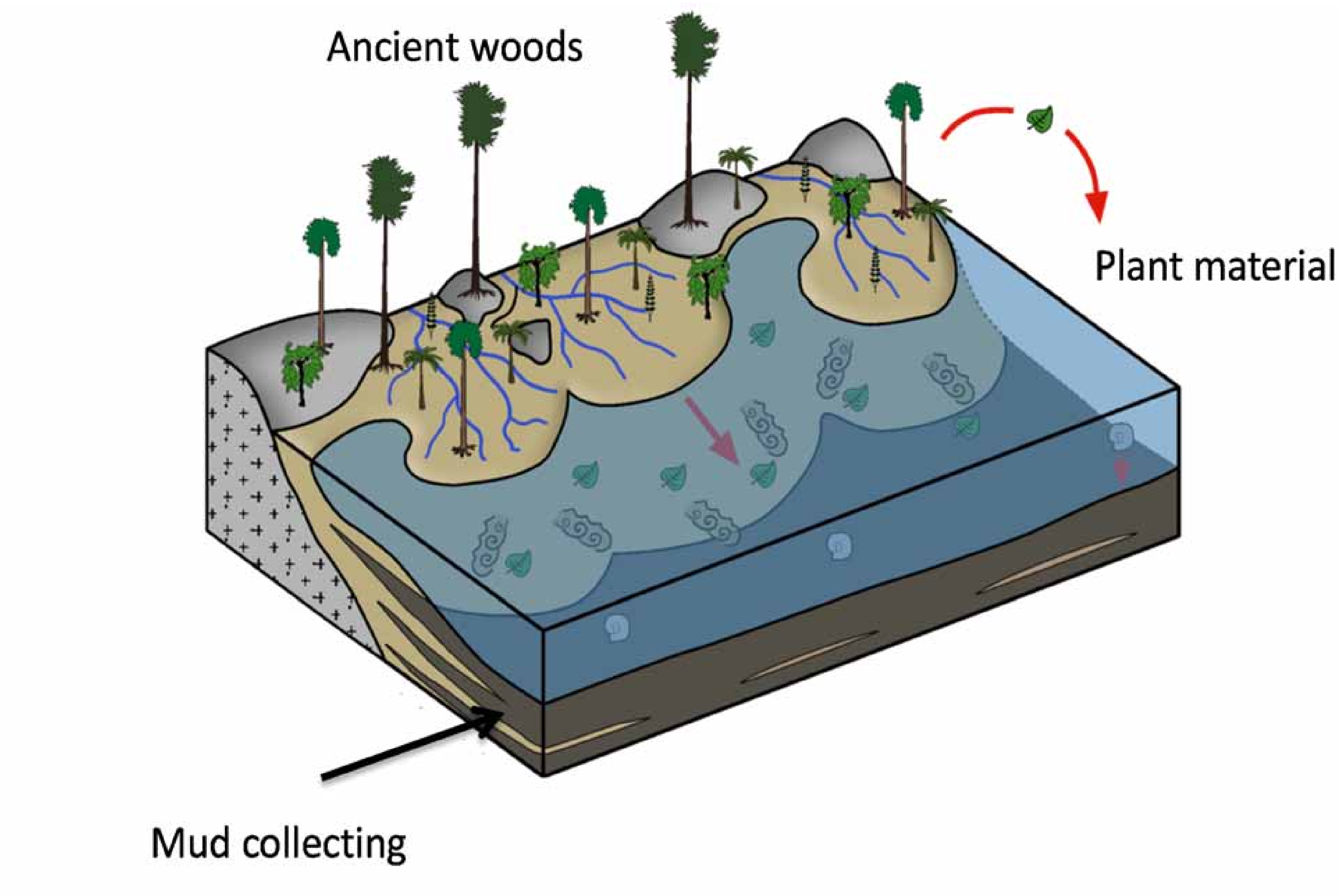
SOME SHALE AND FRACKING BASICS

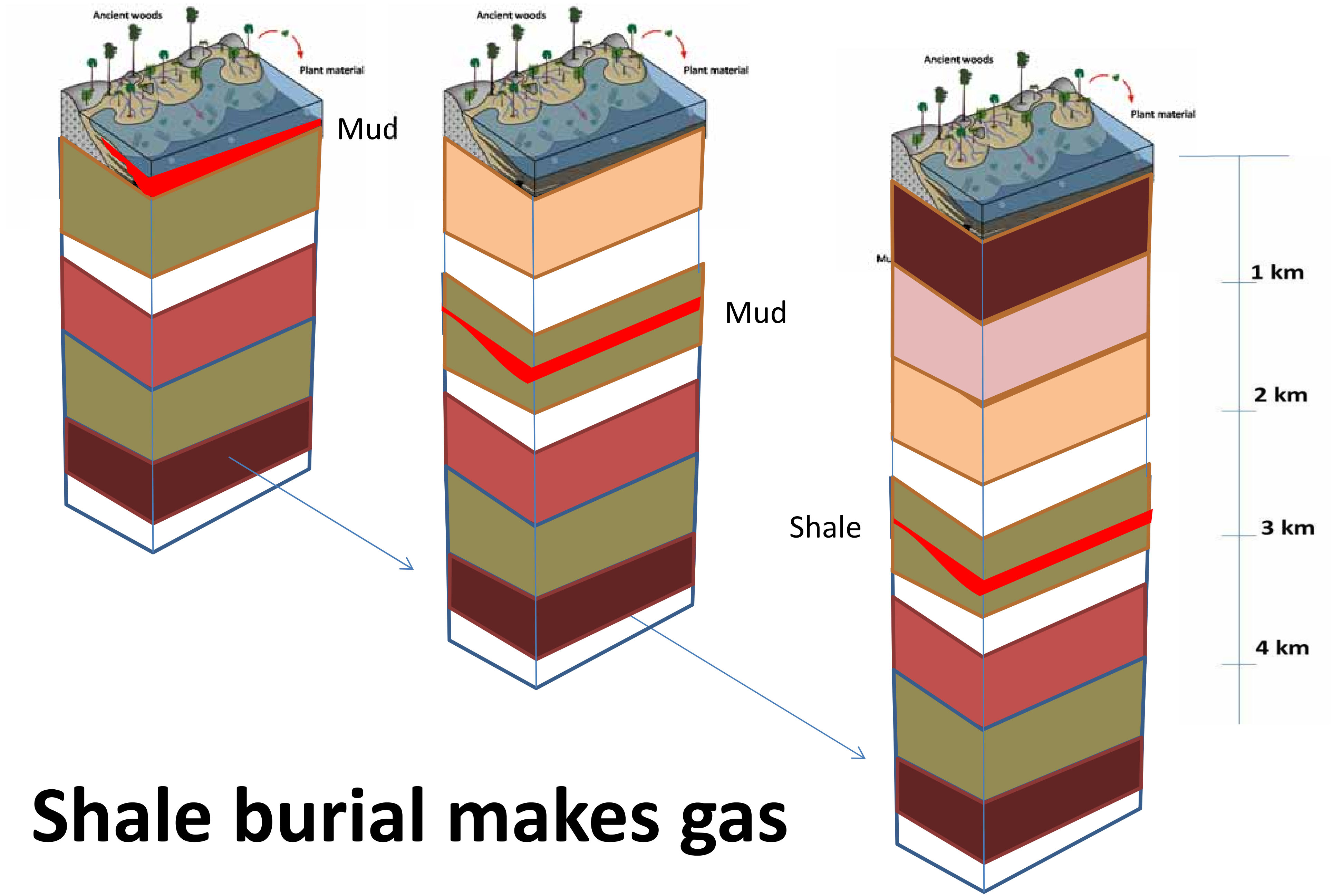
Shale

- Grey or black, soft
- Fine grained
- 70% of the world's surface rocks are sedimentary; 50% of those are shale
- Lots of organic matter (up to 10%)


0.5 mm across

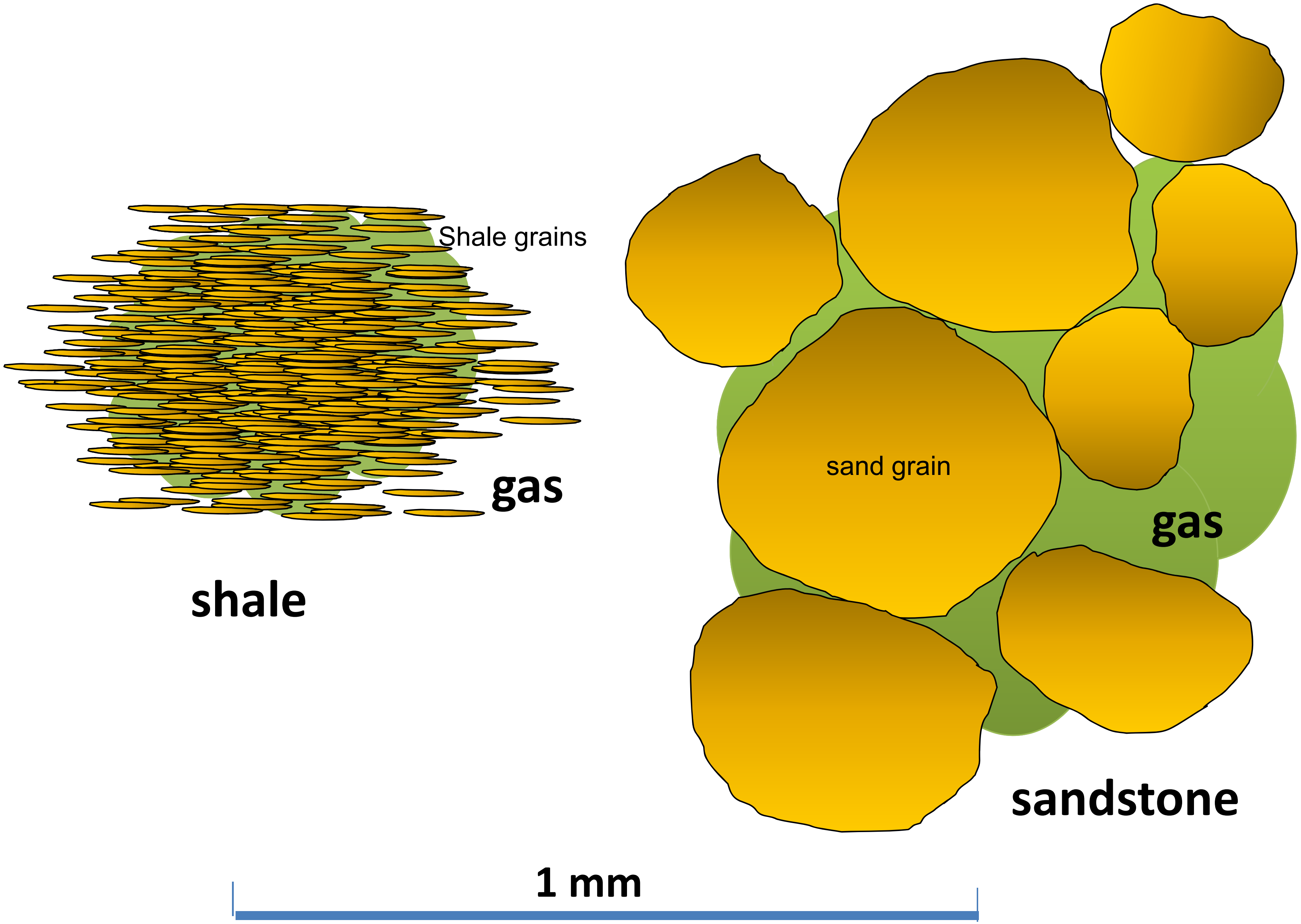
Where the organic matter comes from



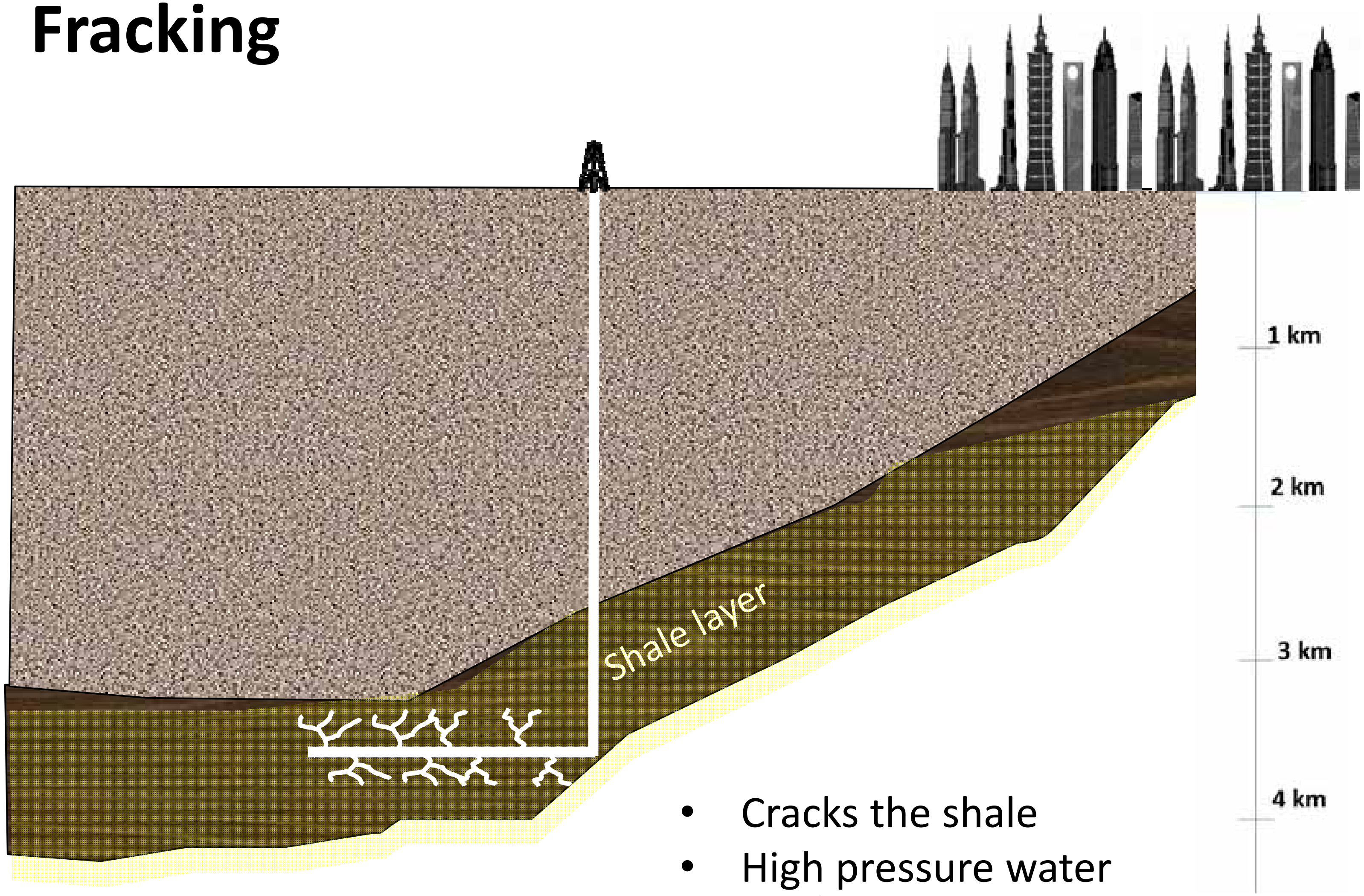


Shale burial makes gas

Gas in sandstone and shale



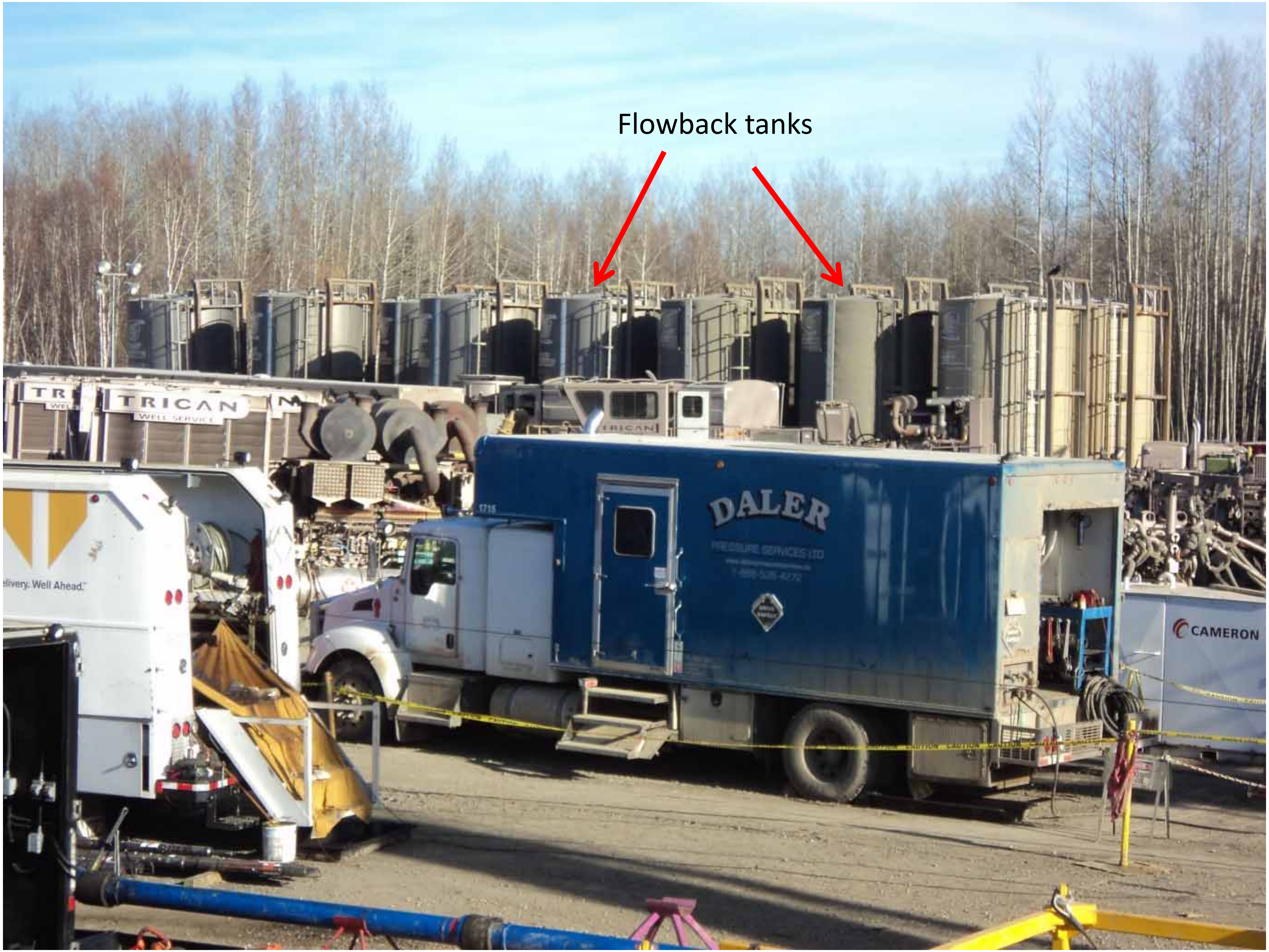
Fracking



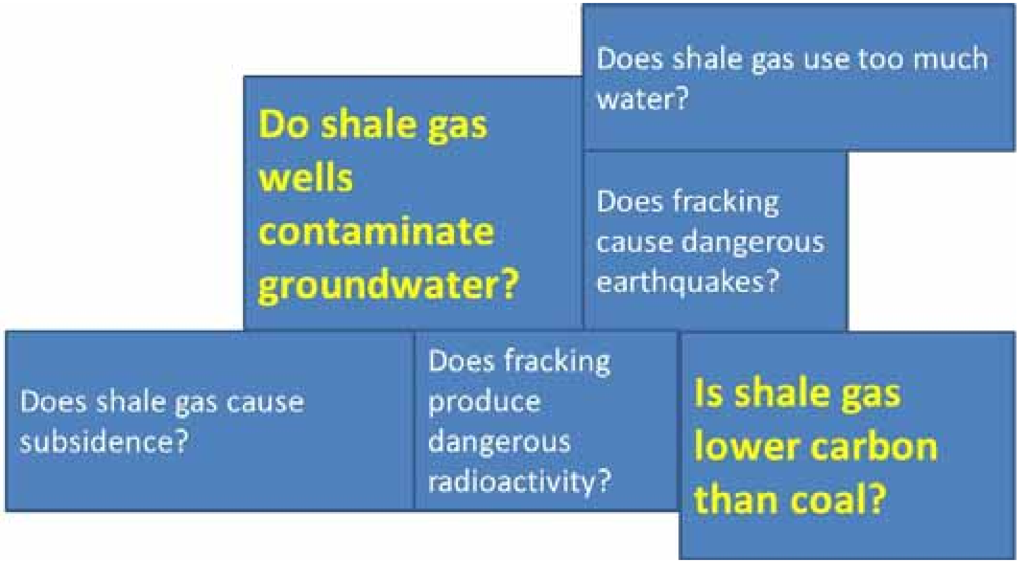
- Cracks the shale
- High pressure water or nitrogen, 350-700 bar
- Sand pumped in to hold cracks open

Fracking site in Alberta


Frack trucks


Flowback tanks
TRICAN
DALER
CAMERON
elivery. Well Ahead.

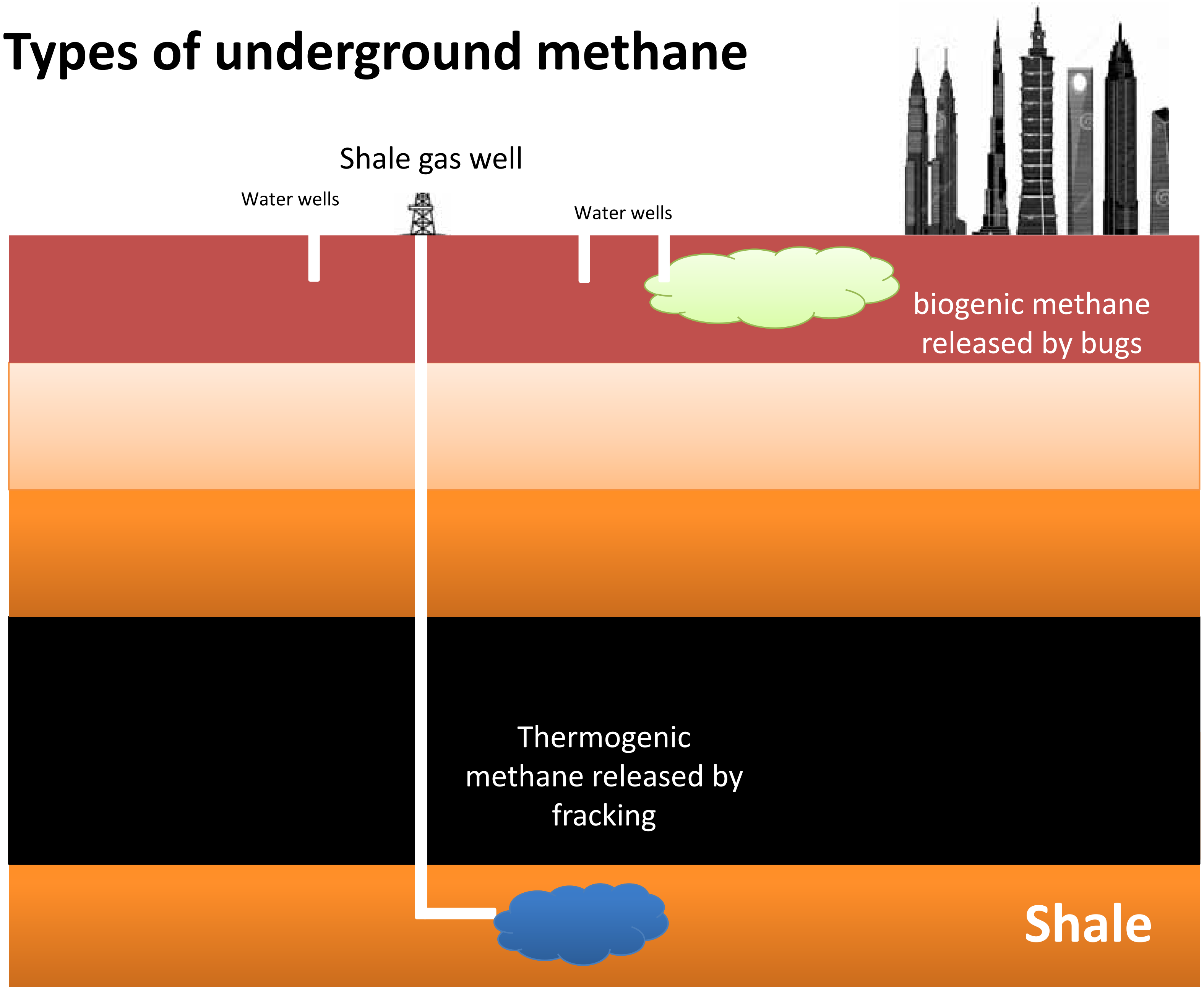
Truck carrying proppant



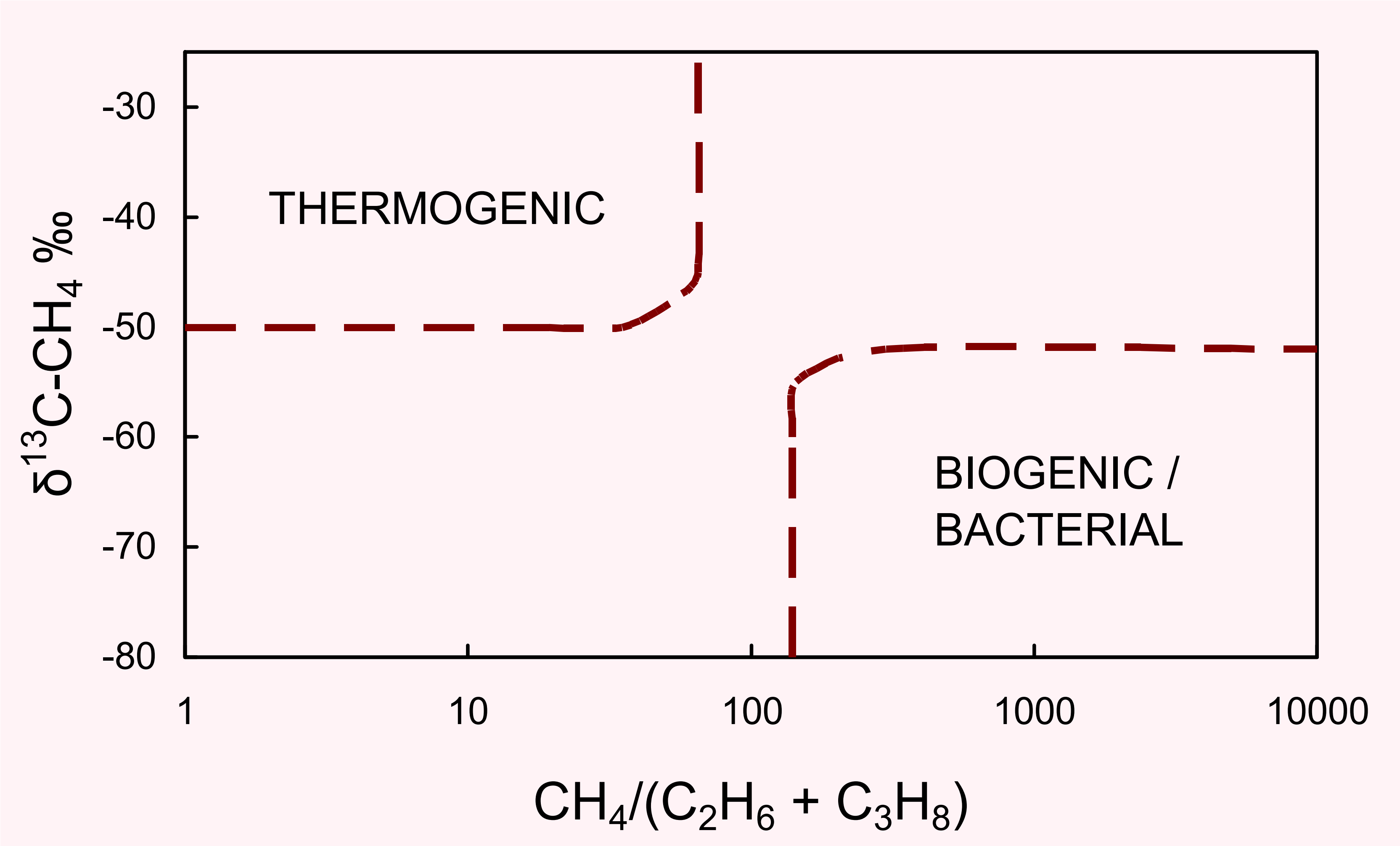
DO SHALE GAS WELLS CONTAMINATE GROUNDWATER?

SOME BASICS

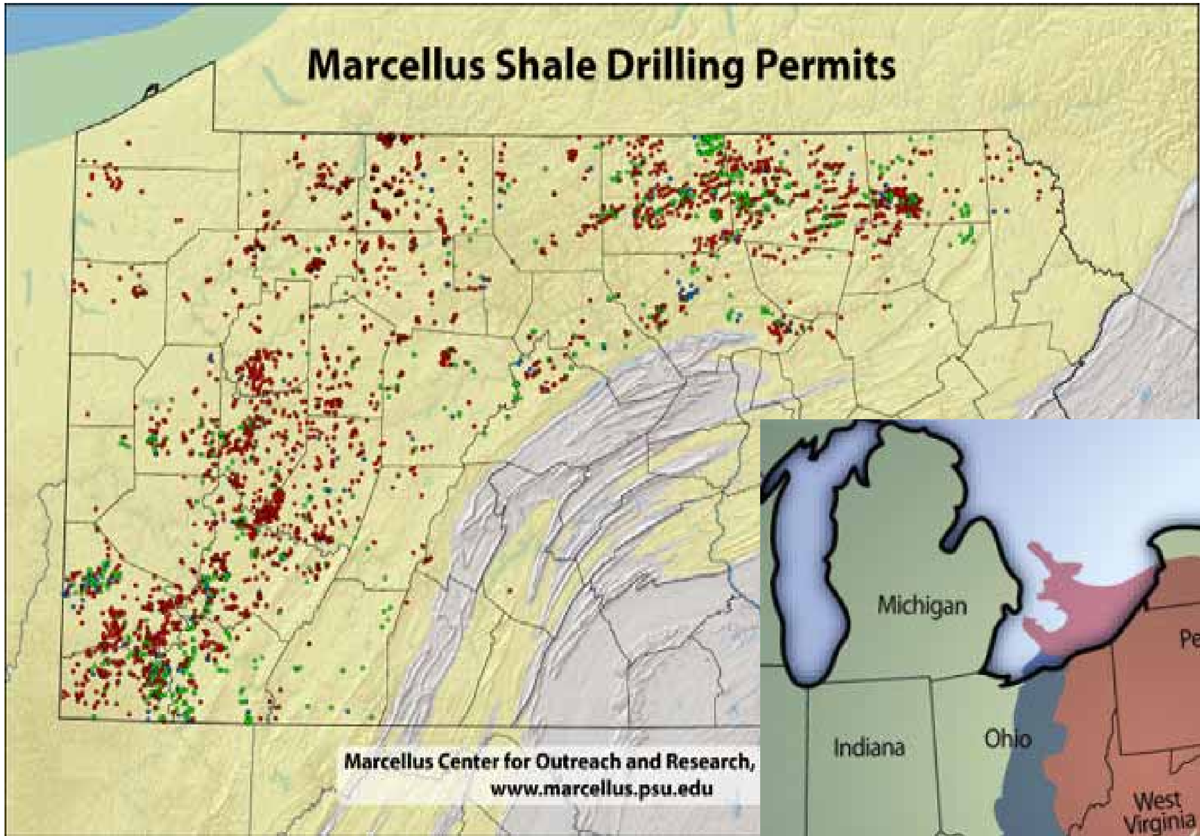
Types of underground methane

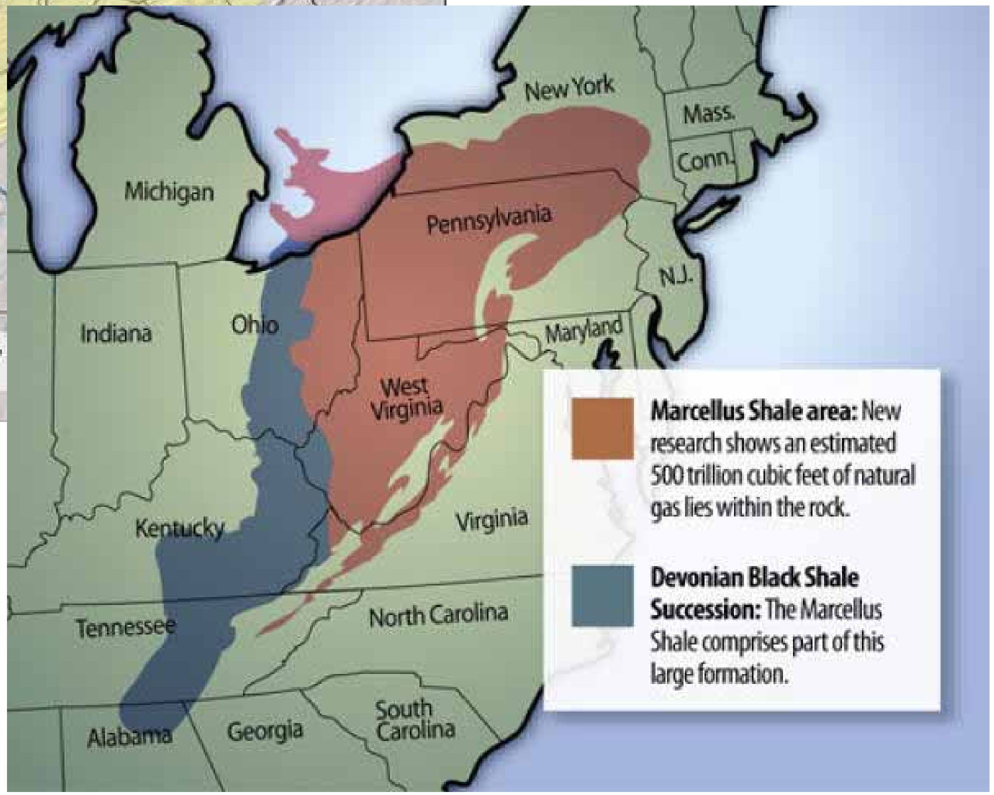


Distinguishing biogenic and thermogenic



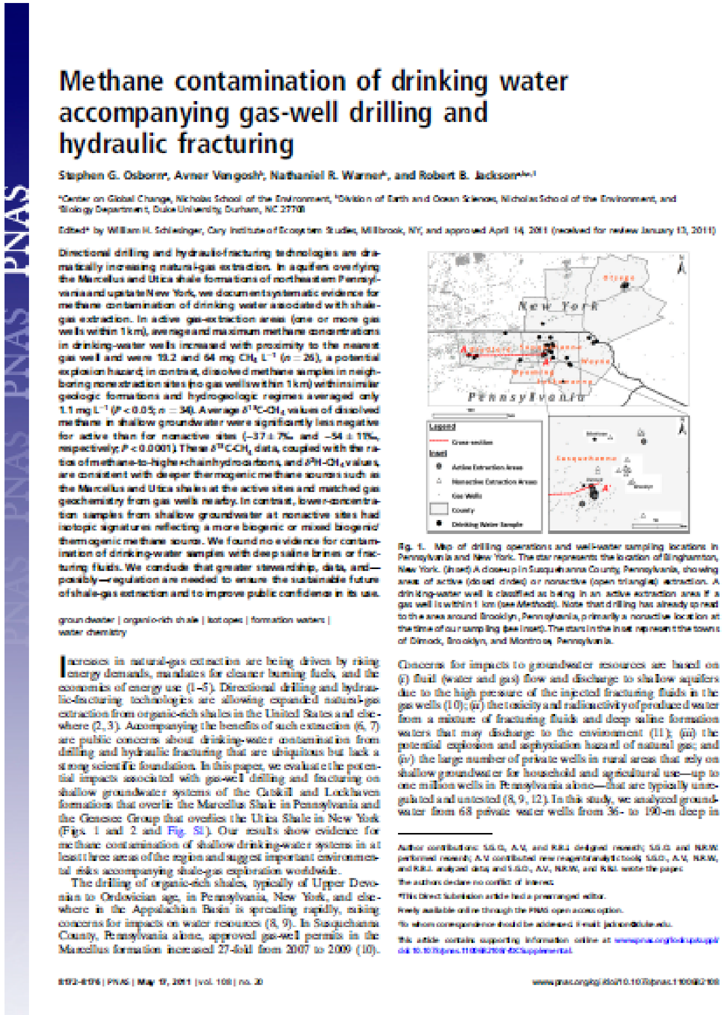
Marcellus, Pennsylvania





Contamination from fracking?

Osborn et al. 2011, Duke University


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)

- Measured methane content and $\delta^{13}C$
- Higher methane concentrations in water wells close to shale gas wells
- $\delta^{13}C$ suggests thermogenic
- Authors then say '*likely to be shale gas from the fracking*'

Thermogenic methane unrelated to fracking?

Molofsky et al. 2013

Groundwater

Evaluation of Methane Sources in Groundwater in Northeastern Pennsylvania

by Lisa J. Molofsky[1], John A. Connor[2], Albert S. Wylie[3], Tom Wagner[3], and Shahla K. Farhat[2]

Abstract

Testing of 1701 water wells in northeastern Pennsylvania shows that methane is ubiquitous in groundwater, with higher concentrations observed in valleys vs. upland areas and in association with calcium-sodium-bicarbonate, sodium-bicarbonate, and sodium-chloride rich waters—indicating that, on a regional scale, methane concentrations are best correlated to topographic and hydrogeologic features, rather than shale-gas extraction. In addition, our assessment of isotopic and molecular analyses of hydrocarbon gases in the Dimock Township suggest that gases present in local water wells are most consistent with Middle and Upper Devonian gases sampled in the annular spaces of local gas wells, as opposed to Marcellus Production gas. Combined, these findings suggest that the methane concentrations in Susquehanna County water wells can be explained without the migration of Marcellus shale gas through fractures, an observation that has important implications for understanding the nature of risks associated with shale-gas extraction.

Introduction

Significant media attention has been focused on the potential for methane impacts in drinking water wells located within areas of hydraulic fracturing activities for shale-gas development. Distinguishing among the various sources of methane gas that may affect drinking water wells requires proper assessment of background conditions. In this study, we review the results of background methane and groundwater quality surveys, in conjunction with geologic and historical information, to develop a better understanding of the potential sources of methane levels in drinking water wells in Susquehanna County in northeastern Pennsylvania.

Susquehanna County has experienced substantial gas extraction activities in the Marcellus shale since 2006. Prior to that time, there was not a significant history of oil and gas operations in this county, thereby providing a unique opportunity to evaluate the potential effects of shale-gas extraction on groundwater resources in the Appalachian basin. Other researchers have suggested that elevated methane concentrations in water wells in Susquehanna County are the result of regional impacts from shale-gas extraction activities (e.g., Osborn et al. 2011). To test this hypothesis, we have evaluated data from the sampling and testing of 1701 water wells throughout Susquehanna County to assess the prevalence and distribution of methane concentrations in groundwater. We have also evaluated isotopic and molecular analyses of hydrocarbon gases in the Dimock Township of Susquehanna County, an area of focused sampling by the Pennsylvania Department of Environmental Protection (DEP) and the U.S. Environmental Protection Agency, to determine whether reported methane concentrations above the Pennsylvania DEP action level (7000 µg/L) in local water wells exhibit signatures consistent with Marcellus production gases, or overlying Middle and Upper Devonian gases sampled in annular spaces of local gas wells.

Our research indicates that shale-gas extraction has not resulted in regional impacts on groundwater quality in Susquehanna County, a finding which suggests that

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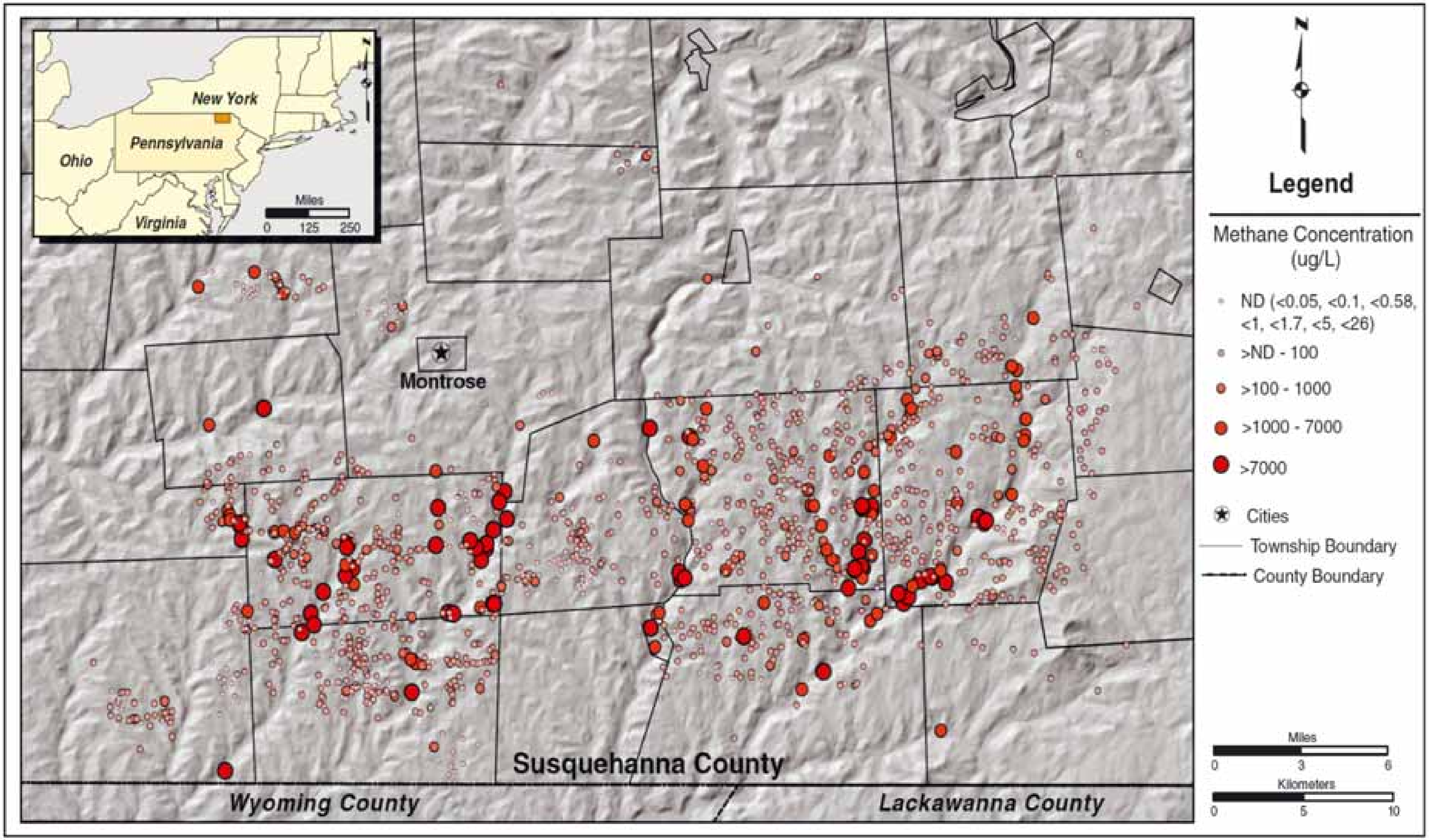
doi: 10.1111/gwat.12056

- Looked at some of the Osborn et al data
- Also at baseline water data: historical records show flammable and effervescing natural springs and water wells back to the late 1700s.

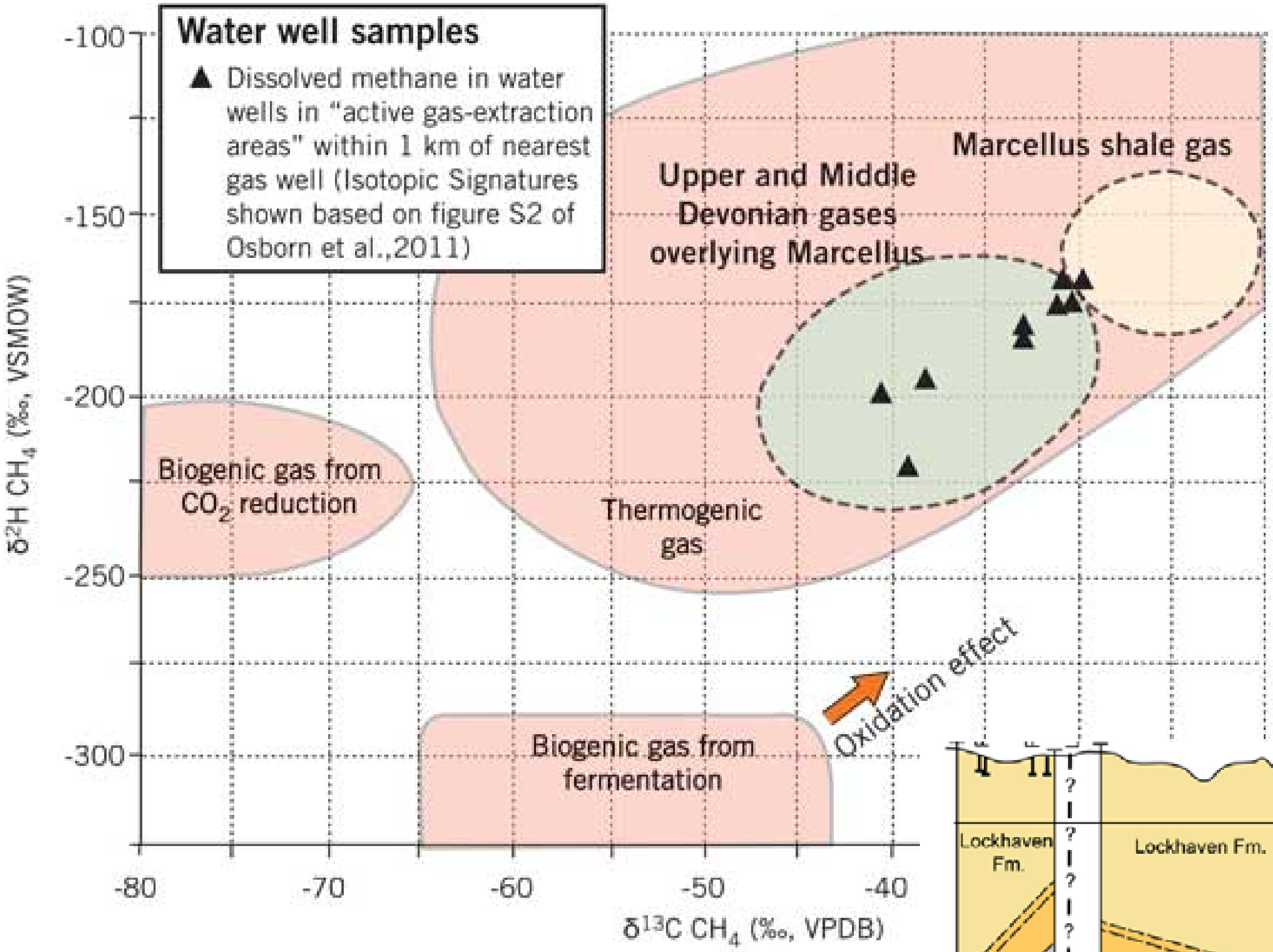
Dec 2011

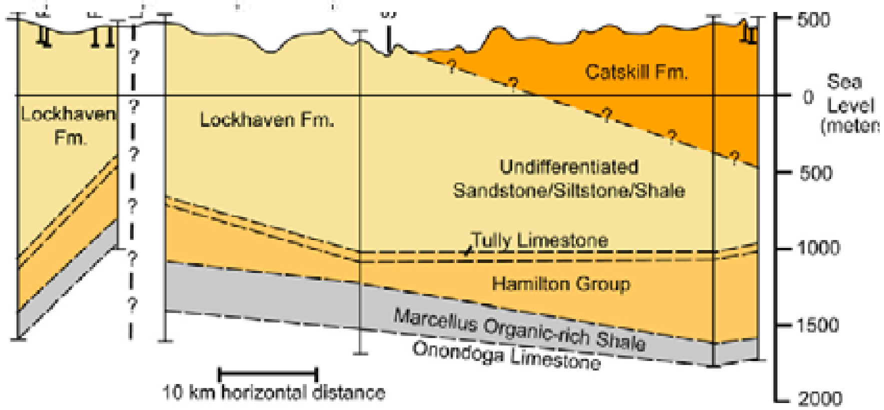
Thermogenic methane related to topography?



Molofsky et al. (2013).

Methane signature indicates layers above Marcellus





Molofsky et al. 2011

Another look at the water wells

Jackson et al. 2013


PNAS

Increased stray gas abundance in a subset of drinking water wells near Marcellus shale gas extraction

Robert B. Jackson, Avner Vengosh, Thomas H. Darrah, Nathaniel R. Warner, Adrian Down, Robert J. Poreda, Stephen G. Osborn, Kaiguang Zhao, and Jonathan D. Karr

Duke University Group

Statistically significant evidence

141 water wells studied

methane concentrations six times higher for water wells within 1 km of shale gas wells

No correlation with topography (valleys)

More recent research

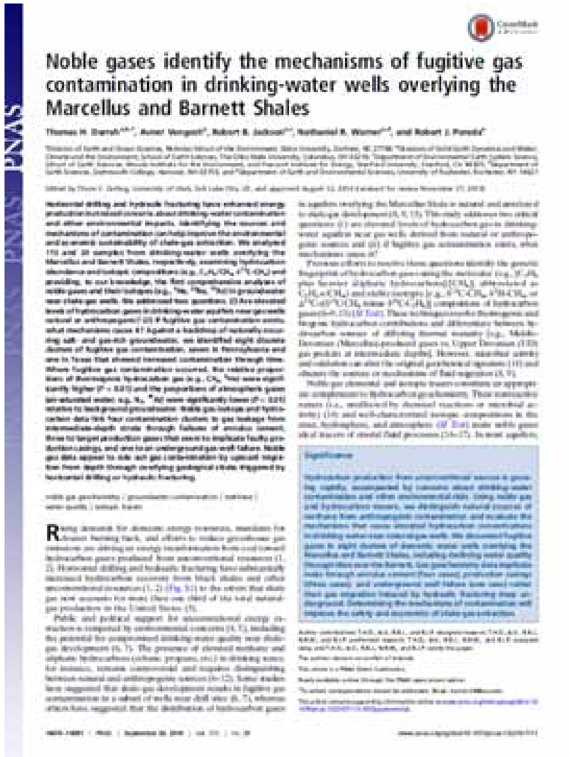
Llewellyn et al. 2015

- groundwater supply contamination incident
- additives probably derived from drilling or hydraulic fracturing fluid were present in groundwater

Evaluating a groundwater supply contamination incident attributed to Marcellus Shale gas development

Darrah et al. 2014

- Noble gas and methane
- Suggests leakage at intermediate depth due to casing and cement problems



Noble gases identify the mechanisms of fugitive gas contamination in drinking-water wells overlying the Marcellus and Barnett Shales

Darrah et al. 2015

- Noble gas, methane and other geochemistry
- Outside shale gas areas
- Diffusison of deep shale gas into shallow aquifers helped by neotectonic fracturing

The evolution of Devonian hydrocarbon gases in shallow aquifers of the northern Appalachian Basin: Insights from integrating noble gas and hydrocarbon geochemistry

Thomas H. Darrah, Robert B. Jackson, Avner Vengosh, Nathaniel R. Warner, Colin J. Whyte, Talor B. Walsh, Andrew J. Kondash, Robert J. Poreda


Contents lists available at SciVerse ScienceDirect

Applied Geochemistry

journal homepage: www.elsevier.com/locate/apgeochem

ELSEVIER

Geochemical and isotopic variations in shallow groundwater in areas of the Fayetteville Shale development, north-central Arkansas

Nathaniel R. Warner, Timothy M. Kresse, Phillip D. Hays, Adrian Down, Jonathan D. Karr, Robert B. Jackson, Avner Vengosh

ARTICLE INFO

ABSTRACT

1. Introduction

Outside Pennsylvania

Arkansas

127 drinking water wells

Fayetteville shale 4000 wells drilled since 2004

very low concentrations of methane

biogenic, not thermogenic

Shale gas wells do leak but only a small number…
And mostly in Pennsylvania….
Water contamination most likely from leaky wells - not fracking

Modelling studies…

2015

Reagan et al. 2015

Production will reduce chance of stray gas

- reduction of free gas
- lowering of reservoir pressure

2015

Nowamooz et al. 2015

- Modelling hypothetical decommissioned shale gas well
- For the poorest cementation scenario, maximum stray gas within 1 year after well closure.

2015

Birdsell et al. 2015

- Much previous modelling studies neglected imbibition and production
- overestimated the likelihood and quantity of stray HF

2014

Groundwater

Constraints on Upward Migration of Hydraulic Fracturing Fluid and Brine

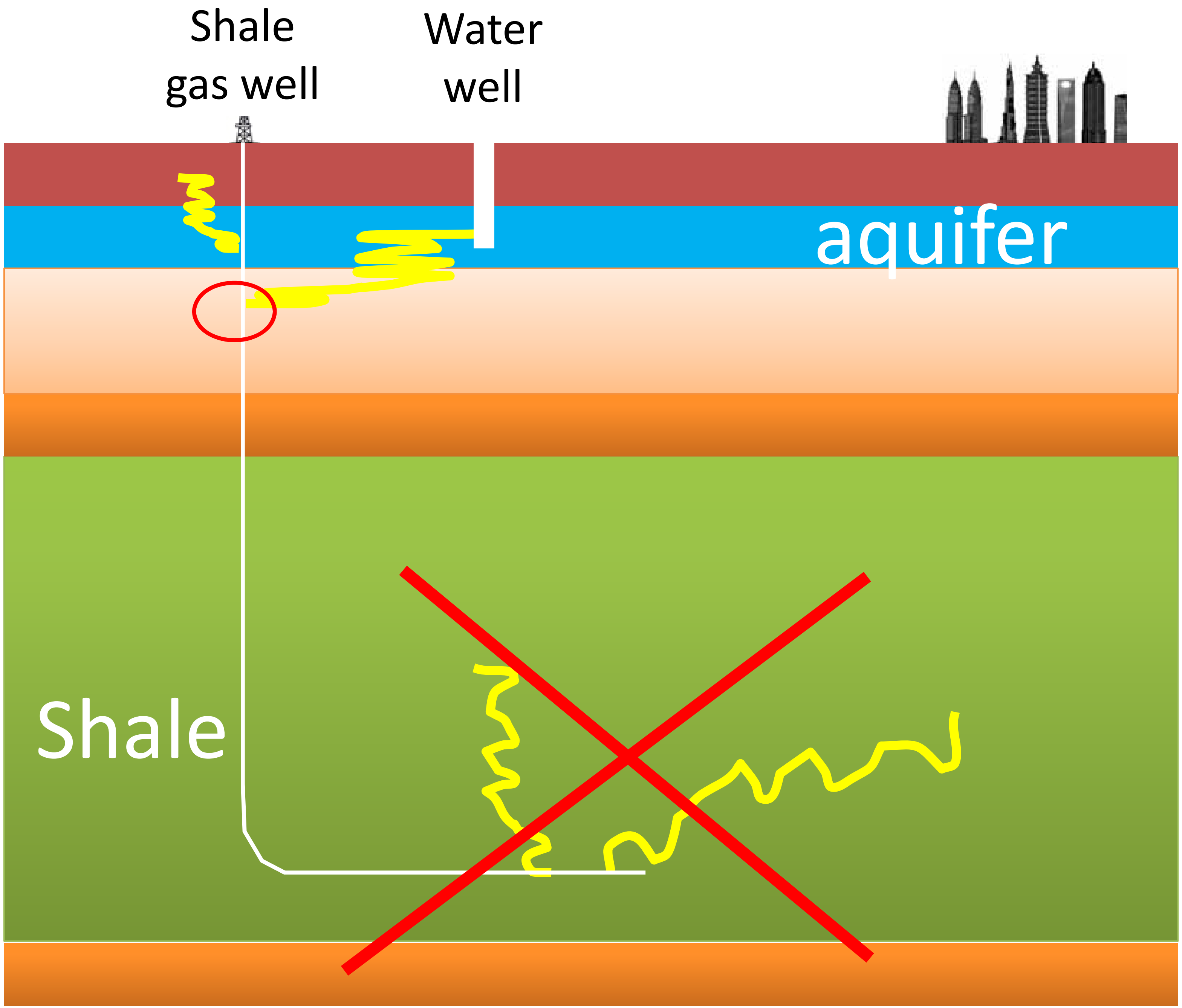
Flewwlling & Sharma 2014

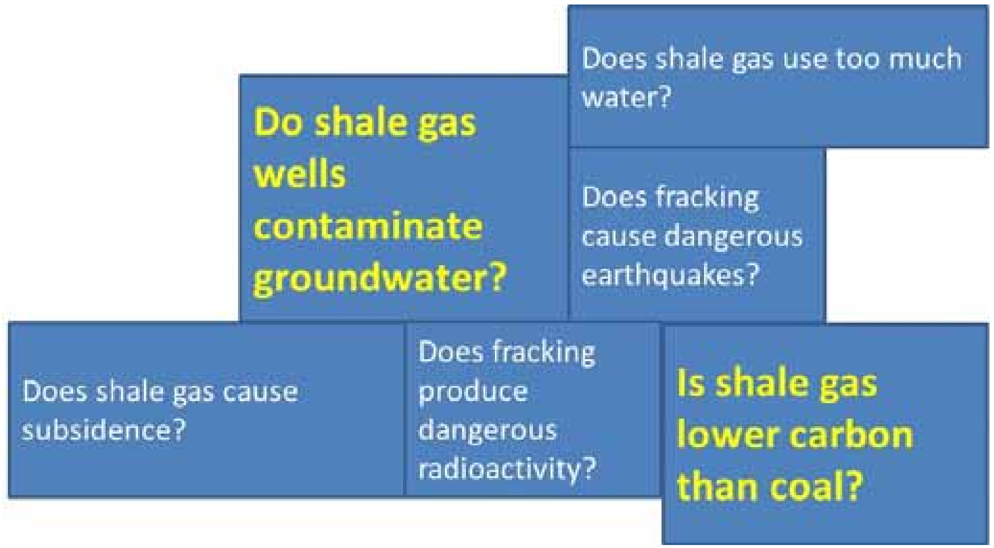
- Where there is an upward gradient, permeability is low, upward flow rates are low, and mean travel times are long (often >1000000 years).

2014

Cai & Ofterdinger 2014

- Bowland Shale discrete fracture model
- Crack size affects likelihood of upward migration

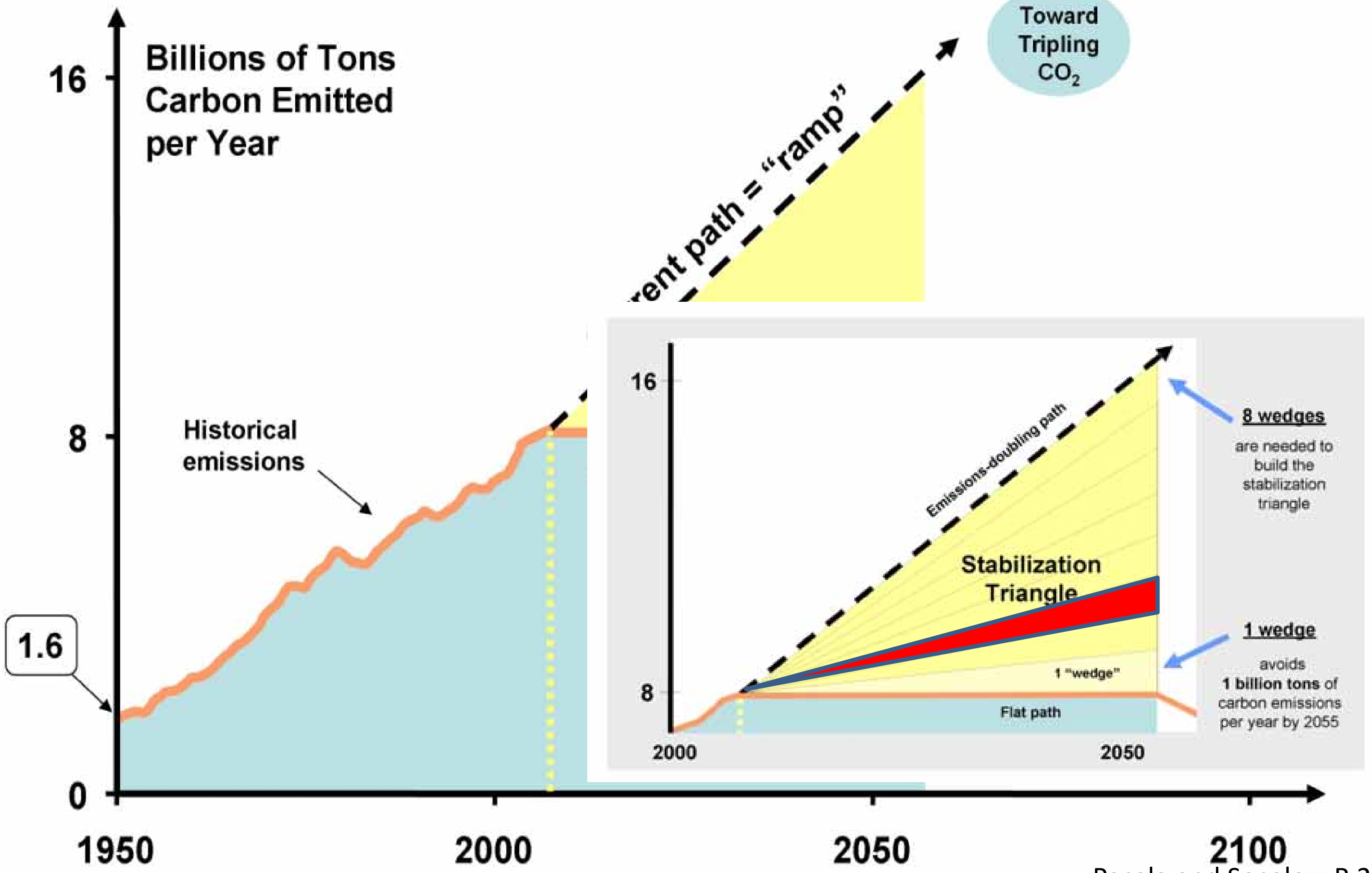

Shale
gas well
Water
well
aquifer
Shale



IS SHALE GAS 'LOWER CARBON' THAN COAL?

SOME BASICS

Context



Pacala and Socolow R 2004

If 1400 natural gas power stations were substituted for an equal number of coal-fired power stations then this would save one wedge of CO2 emissions

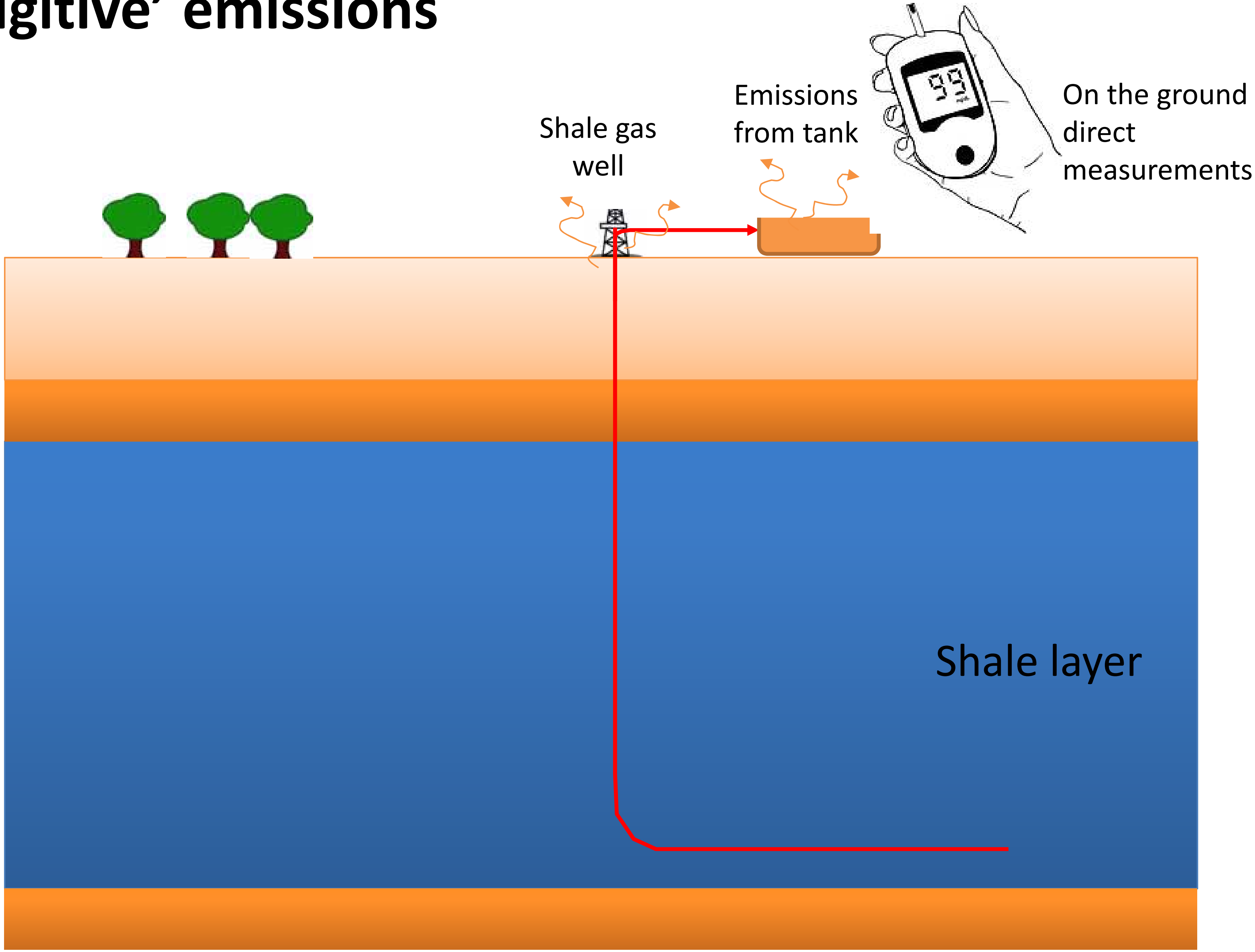
Fuel	Pounds of CO_2 emitted per million BTU of energy
Coal (anthracite)	228.6
Coal (bituminous)	205.7
Coal (lignite)	215.4
Coal (subbituminous)	214.3
Diesel fuel & heating oil	161.3
Gasoline	157.2
Propane	139
Natural gas	117

Source **US EIA**

Open flowback tanks

But what about methane?

‘Fugitive’ emissions



Climatic Change (2011) 106:679–690
DOI 10.1007/s10584-011-0061-5

LETTER

Methane and the greenhouse-gas footprint of natural gas from shale formations

A letter

Robert W. Howarth · Renee Santoro · Anthony Ingraffea

Received: 12 November 2010 / Accepted: 13 March 2011 / Published online: 12 April 2011

Abstract We evaluate the greenhouse gas footprint of natural gas obtained by high-volume hydraulic fracturing from shale formations, focusing on methane emissions. Natural gas is composed largely of methane, and 3.6% to 7.9% of the methane from shale-gas production escapes to the atmosphere in venting and leaks over the life-time of a well. These methane emissions are at least 30% more than and perhaps more than twice as great as those from conventional gas. The higher emissions from shale gas occur at the time wells are hydraulically fractured—as methane escapes from flow-back return fluids—and during drill out following the fracturing. Methane is a powerful greenhouse gas, with a global warming potential that is far greater than that of carbon dioxide, particularly over the time horizon of the first few decades following emission. Methane contributes substantially to the greenhouse gas footprint of shale gas on shorter time scales, dominating it on a 20-year time horizon. The footprint for shale gas is greater than that for conventional gas or oil when viewed on any time horizon, but particularly so over 20 years. Compared to coal, the footprint of shale gas is at least 20% greater and perhaps more than twice as great on the 20-year horizon and is comparable when compared over 100 years.

Keywords Methane · Greenhouse gases · Global warming · Natural gas · Shale gas · Unconventional gas · Fugitive emissions · Lifecycle analysis · LCA · Bridge fuel · Transitional fuel · Global warming potential · GWP

Electronic supplementary material The online version of this article (doi:10.1007/s10584-011-0061-5) contains supplementary material, which is available to authorized users.

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Springer

Howarth et al. 2011 (Cornell Uni)

direct measurements

3 to 8% of the total methane production escapes to the atmosphere through the lifetime of *every shale gas well*

This is enough leaking gas to really make a difference

Is shale gas is worse than coal?

Cathles et al. 2012 (Cornell Uni) rebuttal

High leakage rates of Howarth unrepresentative?

(ten tests of wells drilled into the Haynesville shale)

Source (mainly scientific papers and reports)	Shale layer	Volume of Gas released during flowback (thousands of cubic metres per well)
Jiang	Marcellus	603
Howarth	Haynesville	6800
Howarth	Barnett	370
EPA	Various	260
O'Sullivan and Paltsev	Haynesville	1180
O'Sullivan and Paltsev	Barnett	273
O'Sullivan and Paltsev	Fayetteville	296
O'Sullivan and Paltsev	Marcellus	405
O'Sullivan and Paltsev	Woodford	487

from McKay and Stone (2013).

Measurements of methane emissions at natural gas production sites in the United States

Allen et al. 2014 (Uni Texas)

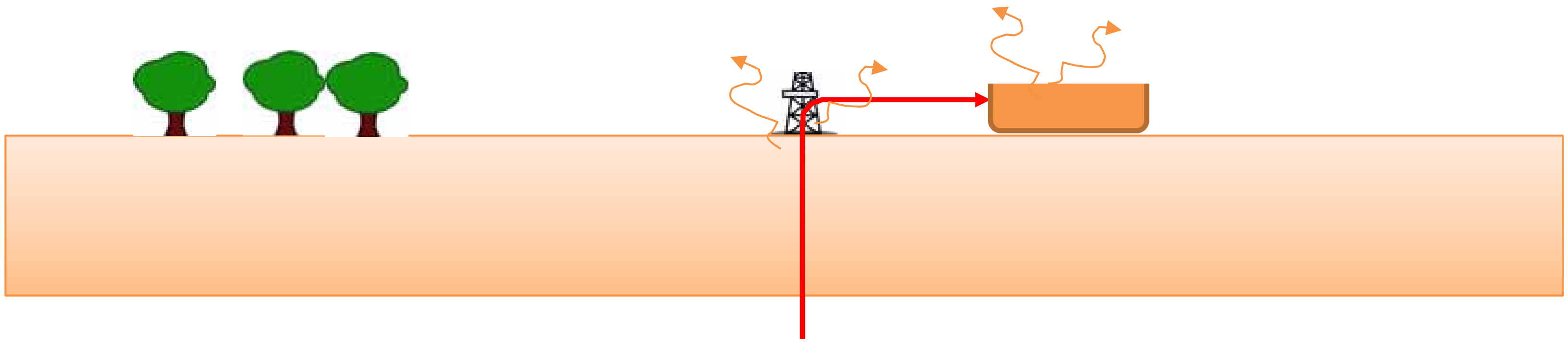
Direct measurement of 190 shale gas sites all over the US

leakage rate is about half of one percent of gas production,

much less than the 3 to 8% estimated by Howarth

Howarth et al
3 to 8%

Allen et al
<0.5%



Energy Science & Engineering

Open Access

RESEARCH ARTICLE

University of Texas study underestimates national methane emissions at natural gas production sites due to instrument sensor failure

Touché Howard

Indaco Air Quality Services, Inc., Durham, North Carolina

Keywords
Greenhouse gases, methane, natural gas

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Energy Science and Engineering 2015; 3(5):443–455

doi: 10.1002/ese3.81

Abstract

The University of Texas reported on a campaign to measure methane (CH_4) emissions from United States natural gas (NG) production sites as part of an improved national inventory. Unfortunately, their study appears to have systematically underestimated emissions. They used the Bacharach Hi-Flow® Sampler (BHFS) which in previous studies has been shown to exhibit sensor failures leading to underreporting of NG emissions. The data reported by the University of Texas study suggest their measurements exhibit this sensor failure, as shown by the paucity of high-emitting observations when the wellhead gas composition was less than 91% CH_4, where sensor failures are most likely; during follow-up testing, the BHFS used in that study indeed exhibited sensor failure consistent with under-reporting of these high emitters. Tracer ratio measurements made by the University of Texas at a subset of sites with low CH_4 content further indicate that the BHFS measurements at these sites were too low by factors of three to five. Over 98% of the CH_4 inventory calculated from their own data and 41% of their compiled national inventory may be affected by this measurement failure. Their data also indicate that this sensor failure could occur at NG compositions as high as 97% CH_4, possibly affecting other BHFS measurement programs throughout the entire NG supply chain, including at transmission sites where the BHFS is used to report greenhouse gas emissions to the United States Environmental Protection Agency Greenhouse Gas Reporting Program (USEPA GHGRP, U.S. 40 CFR Part 98, Subpart W). The presence of such an obvious problem in this high profile, landmark study highlights the need for increased quality assurance in all greenhouse gas measurement programs.

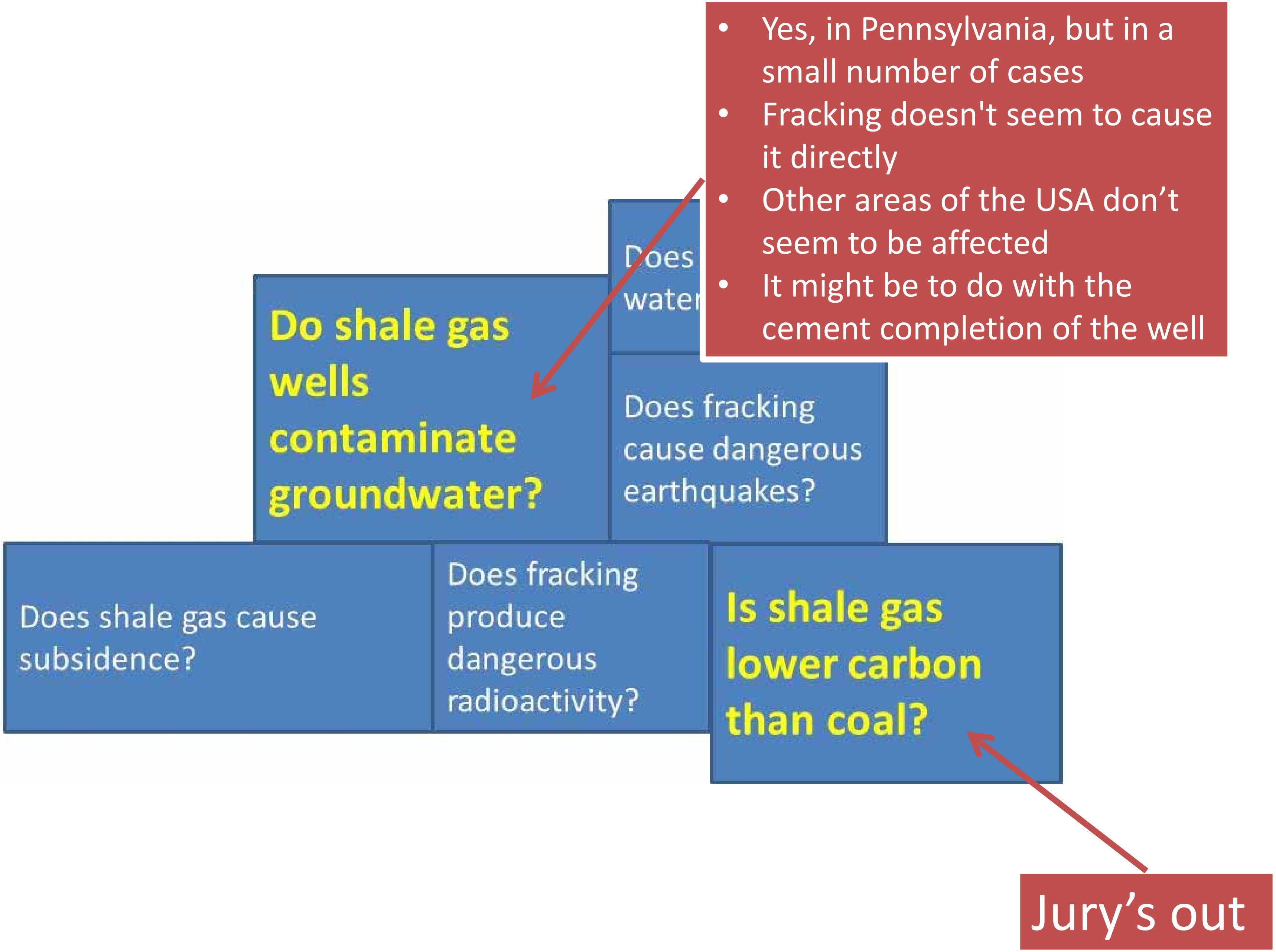
Introduction

The climatic benefits of switching from coal to natural gas (NG) depend on the magnitude of fugitive emissions of methane (CH_4) from NG production, processing, transmission, and distribution [12, 13, 27]. This is of particular concern as the United States increasingly exploits NG from shale formations: a sudden increase in CH_4 emissions due to increased NG production could trigger climate "tipping points" due to the high short-term global warming potential of CH_4 (86× carbon dioxide on a 20-year time scale) [19]. The United States Environmental Protection Agency (USEPA) estimates CH_4 emissions from the NG supply chain by scaling up individual ground-level measurements, mostly collected by reporting from industry [26]. However, some recent studies have questioned whether these "bottom-up" inventories are too low, since airborne measurements indicate that CH_4 emissions from NG production regions are higher than the inventories indicate [5, 14, 17, 20, 21].

In order to help determine the climate consequences of expanded NG production and use, and to address the apparent discrepancy in top-down and bottom-up measurements, the University of Texas (UT) at Austin and the

Touché Howard (2015)

- Allen et al. 2014 underestimated emissions
- They used the Bacharach Hi- Flow® Sampler which in previous studies has been shown to exhibit sensor failures
- The BHFS measurements at these sites were too low by factors of three to five



Yes, in Pennsylvania, but in a small number of cases
Fracking doesn't seem to cause it directly
Other areas of the USA don't seem to be affected
It might be to do with the cement completion of the well
Does
water
Do shale gas wells contaminate groundwater?
Does fracking cause dangerous earthquakes?
Does shale gas cause subsidence?
Does fracking produce dangerous radioactivity?
Is shale gas lower carbon than coal?
Jury's out

Post truth

MARCH FOR SCIENCE

‘Science communicated in popular media leaves the public confused’

In the ‘post-truth’ world, scientists risk further marginalization in a society that ‘…*is increasingly weighing evidence and making decisions without them*’.

WORLD VIEW *A personal take on events*

Give the public the tools to trust scientists

Anita Makri *argues that the form of science communicated in popular media leaves the public vulnerable to false certainty.*

What is truth? How do we find it and does it still carry weight in public debate? Given recent political events, these are important and urgent questions. But of the two industries I work in that are concerned with truth — science and journalism — only the latter has seriously engaged and looked for answers. Scientists need to catch up, or they risk further marginalization in a society that is increasingly weighing evidence and making decisions without them.

Whereas journalists are debating facts and falsehood, their own role and possible ways to react, scientists seem to see themselves as victims of, rather than active players in, the new political scene. Most debate centres on how the new political order threatens scientific knowledge and research funding, or downgrades climate-change policy.

All are important, but what's overlooked by many is how science is losing its relevance as a source of truth. To reclaim this relevance, scientists, communicators, institutions and funders must work to change the way that socially relevant science is presented to the public. This is not about better media training for researchers. It demands a rethink about the kind of science that we want to communicate to broader society. This message may sound familiar but the new focus on post-truth shows there is now a tangible danger that must be addressed.

Much of the science that the public knows about and admires imparts a sense of wonder and fun about the world, or answers big existential questions. It's in the popularization of physics through the television programmes of physicist Brian Cox and in articles about new fossils and quirky animal behaviour on the websites of newspapers. It is sellable and familiar science: rooted in hypothesis testing, experiments and discovery.

Although this science has its place, it leaves the public (not to mention policymakers) with a different, outdated view to that of scientists of what constitutes science. People expect science to offer authoritative conclusions that correspond to the deterministic model. When there's incomplete information, imperfect knowledge or changing advice — all part and parcel of science — its authority seems to be undermined. We see this in the public debate over food and health: first, fat was bad and now it's sugar. A popular conclusion of that shifting scientific ground is that experts don't know what they're talking about.

But the questions that people face in their lives typically rely on incremental science, a kind that accumulates evidence about complex systems with numerous variables and fuzzy social parameters. It feeds into policy and decisions about how to handle environmental pollution, vaccine safety, emerging infections, drug risks, food choices or the impacts of climate change.

This kind of socially relevant science and discussion of uncertainty does feature in the media, but it is more typical of articles that discuss the politics and the controversies around it, perhaps under the label of environment or health. This is not about manipulating or persuading the public to accept decisions, but rather providing them with the tools with which to make sense of the evidence, put the uncertainties in perspective and judge for themselves what contribution scientific information makes to truth. Without that capacity, emotions and beliefs that pander to false certainties become more credible.

It's more difficult to talk about science that's inconclusive, ambivalent, incremental and even political — it requires a shift in thinking and it does carry risks. If not communicated carefully, the idea that scientists sometimes ‘don't know’ can open the door to those who want to contest evidence.

Still, if the public is better equipped to navigate this science, it would restore trust and improve understanding of different verdicts, and perhaps help people to see through some of the fake news that circulates on scientific matters. Lifting the lid on these realities about socially relevant science is mostly about changing the content and framing of what's being communicated. And it could be encouraged by targeting various points of contact between science and the public. Public-engagement programmes of research, educational or cultural institutions are an obvious option. Closer links between educators, communicators and scientists can also strengthen how socially relevant science is represented in articles and curricula. Wider trends aren't incentivizing this sort of science story. So the push will need to come from science first. For example, science academies could offer more grants to support more-sophisticated journalism.

SCIENTISTS MUST WORK **TO CHANGE** THE WAY THAT SOCIALLY RELEVANT SCIENCE IS **PRESENTED TO THE PUBLIC.**

Scientists can influence what's being presented by articulating how this kind of science works when they talk to journalists, or when they advise on policy and communication projects. It's difficult to do, because it challenges the position of science as a singular guide to decision making, and because it involves owning up to not having all of the answers all the time while still maintaining a sense of authority. But done carefully, transparency will help more than harm. It will aid the restoration of trust, and clarify the role of science as a guide.

Current debates about truth are far from trivial. More scientists and communicators of science need to get involved, update practices and reposition themselves in a way that gets with the times and shows that science matters — while it still does. ■

Anita Makri *is a freelance writer, editor and producer, on the advisory board of the Global Health Film Initiative and a mentor with the New York Academy of Sciences.*
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Makri, A. 2017, Nature

‘Sense of wonder science’

‘…imparts a sense of wonder and fun about the world, or answers big existential questions. It’s in the popularization of physics through the television programmes of physicist Brian Cox and in articles about new fossils and quirky animal behaviour on the websites of newspapers. It is sellable and familiar science…’.

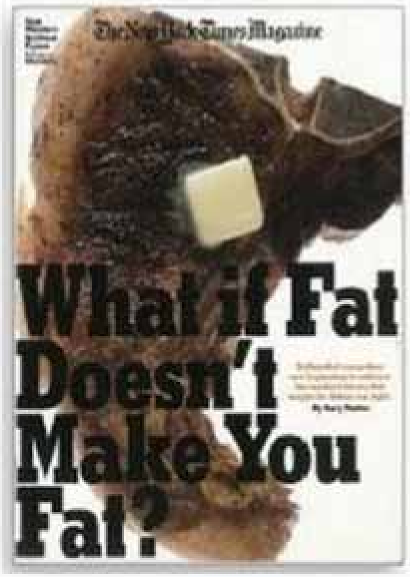
‘…sellable and familiar…’

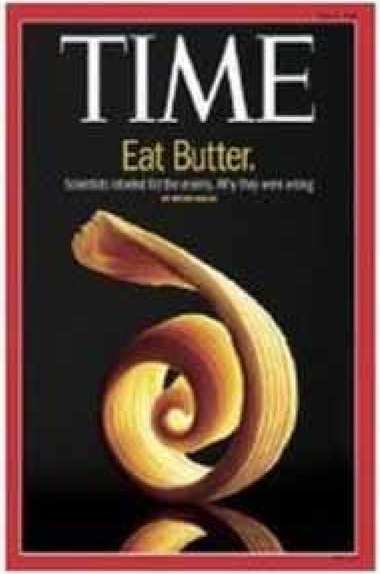
‘…first, fat was bad and now it’s sugar…’

Does
‘sense of wonder science’
makes it **<u>harder</u>** for applied scientists who work in the area of socially-relevant ‘incremental’ science

‘*It’s more difficult to talk about science that’s inconclusive, ambivalent, incremental and even political*

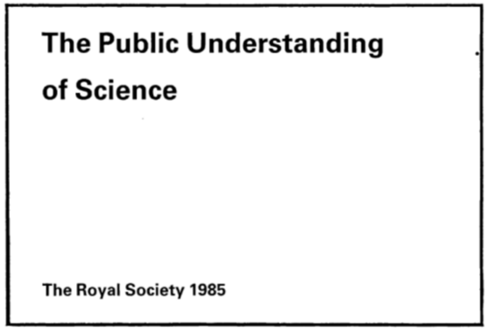
If not communicated carefully, the idea that scientists sometimes ‘don’t know’ can open the door to those who want to contest evidence.’

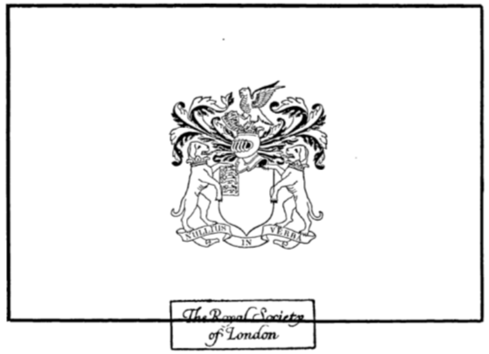




The ‘deficit model’ of science communication

Royal Society 1985 – ‘The Public Understanding of Science’





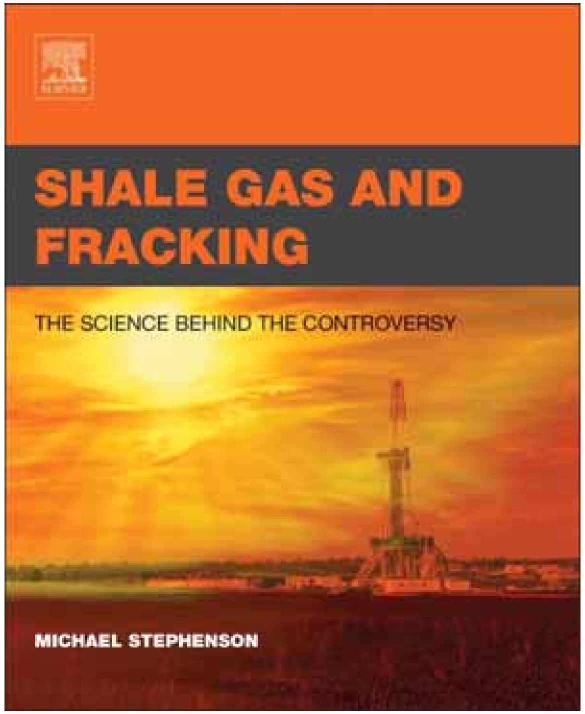
the public doesn’t believe or care much about science because they aren’t being told about it efficiently enough

Social scientists who study communication, believe that scientists worry far too much about the words they use and the diagrams they show, and too little about finding out about how their public or ‘publics’ think or feel.

Social scientist Ruth Dixon says that academics need ‘…*to question, with some humility, their own ‘deficit model’ of the public understanding of politics*’, and try to empathise a bit with our chosen public.

Conclusions

- Science can be applied to the contestable issues in shale gas
- Science is important to society and not just big telescopes and synchrotrons!
- But when we talk about it to the public we should use our (emotional) intelligence!



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