Environmental Impacts of “fracking”

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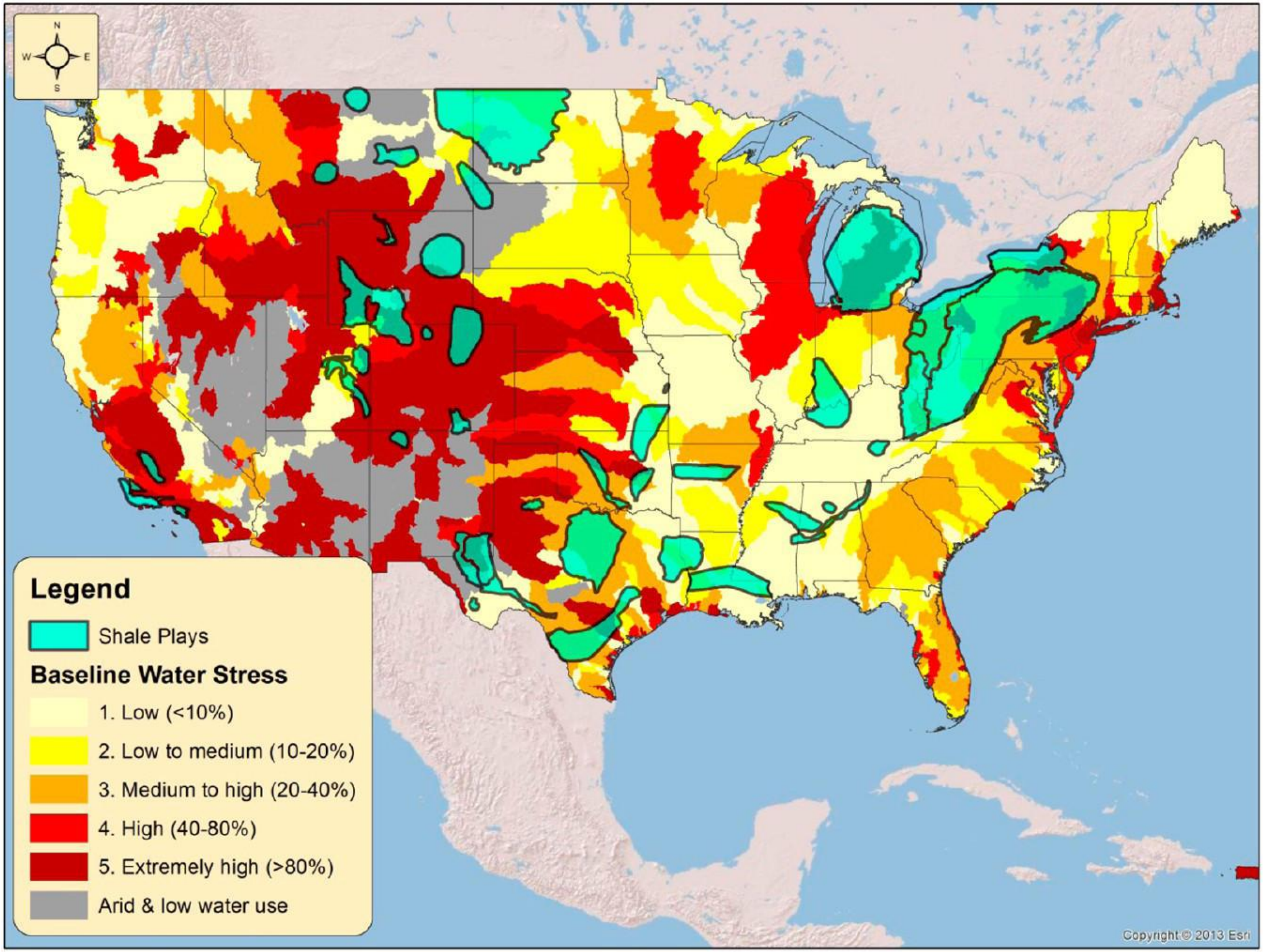
Outline

- **Water Use**
- **Water Contamination**
- **Air Pollution**
- **Greenhouse Gases**
- **Induced Seismicity**

Water Use

- 2 to 10 million gallons per well
- 44 Billion Gal/yr 2011, 2012.
- 1% of national water consumption.
- Locally 10% - 30% or more.
- EPA (data from FracFocus)
- Median reuse of water 5%


N
W
E
S
Legend
Shale Plays
Baseline Water Stress
1. Low (<10%)
2. Low to medium (10-20%)
3. Medium to high (20-40%)
4. High (40-80%)
5. Extremely high (>80%)
Arid & low water use
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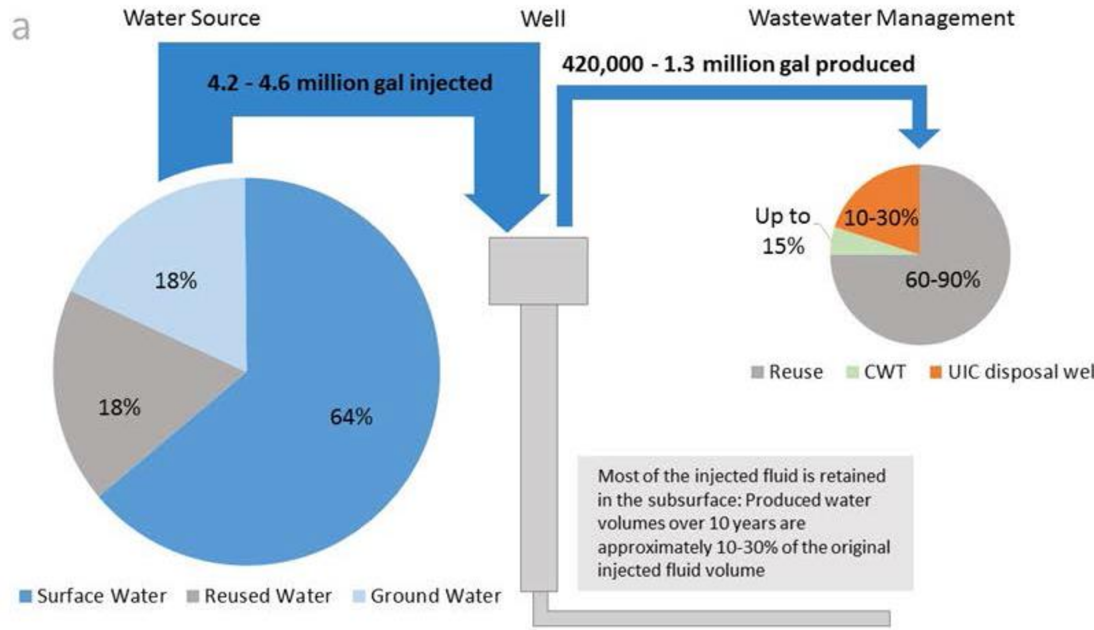
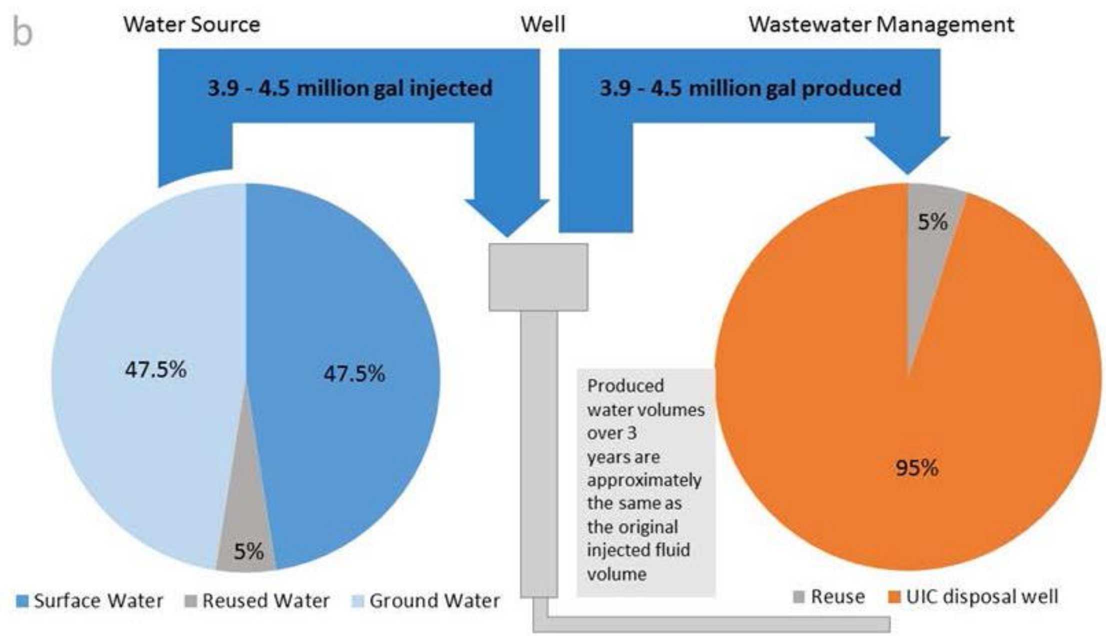
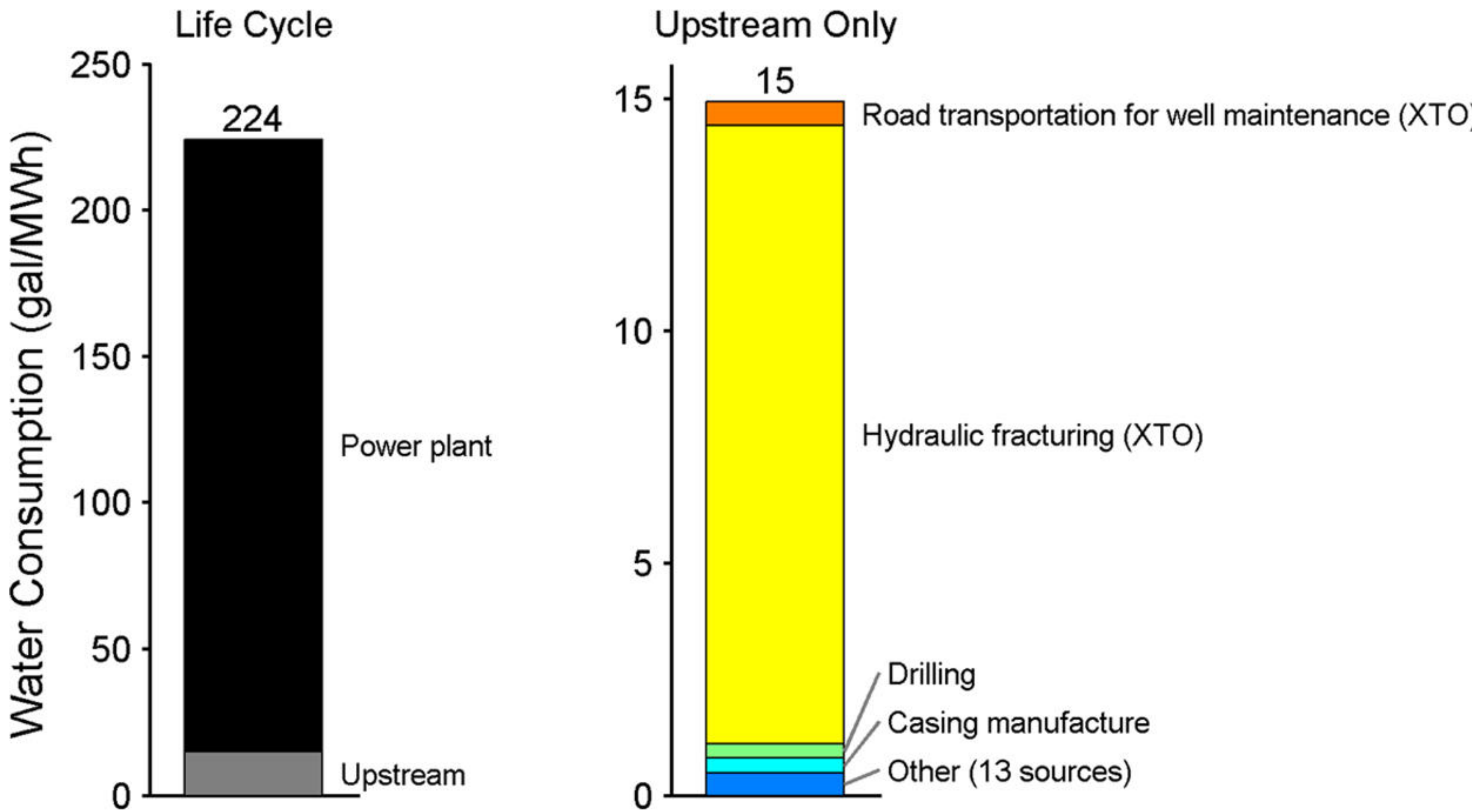
Marcellus, PA



Barnett, TX





Breakdown of water use for shale gas. Laurenzi and Jersey 2013

Figure 17.3 ▷ Water use for primary energy production

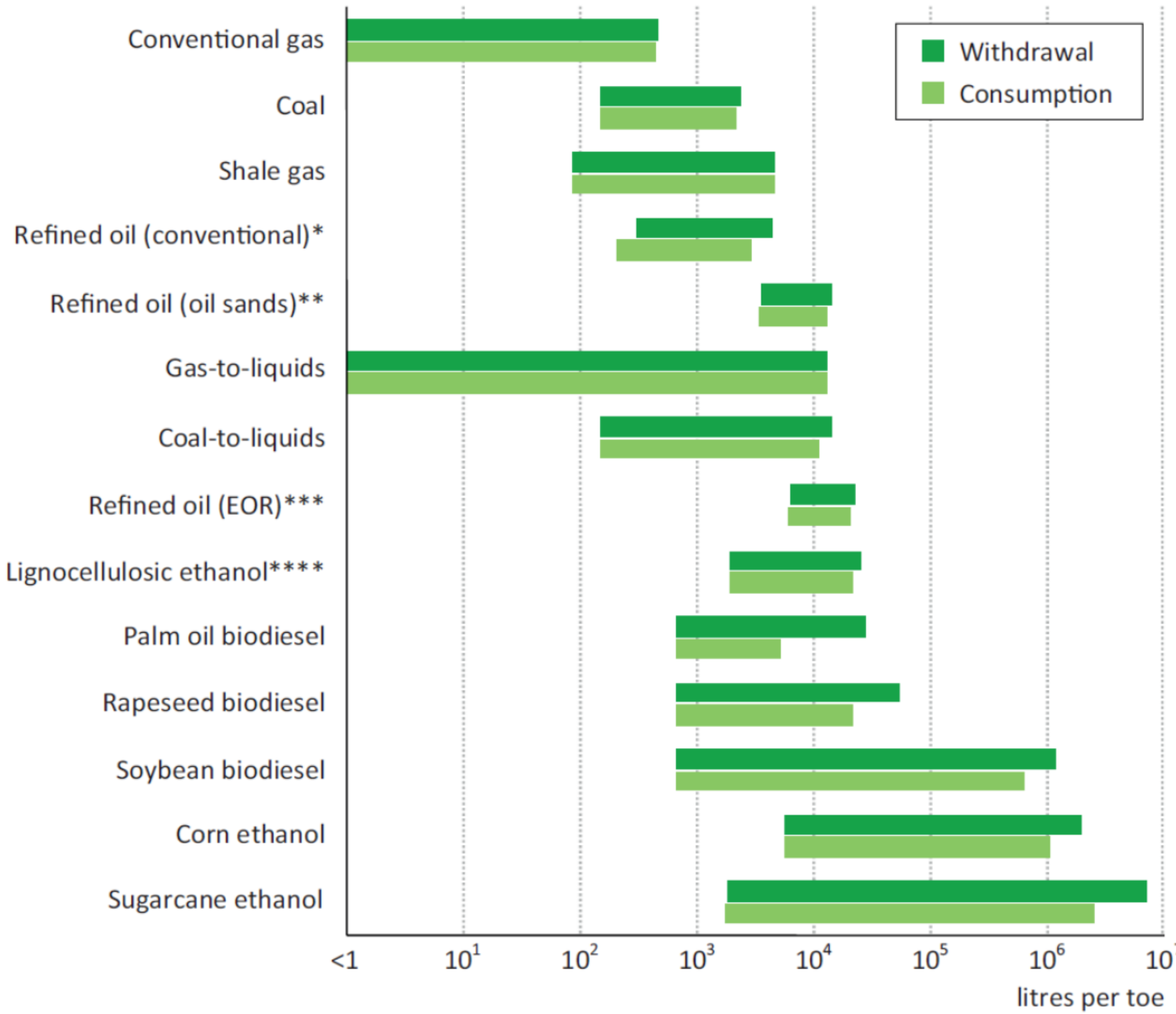
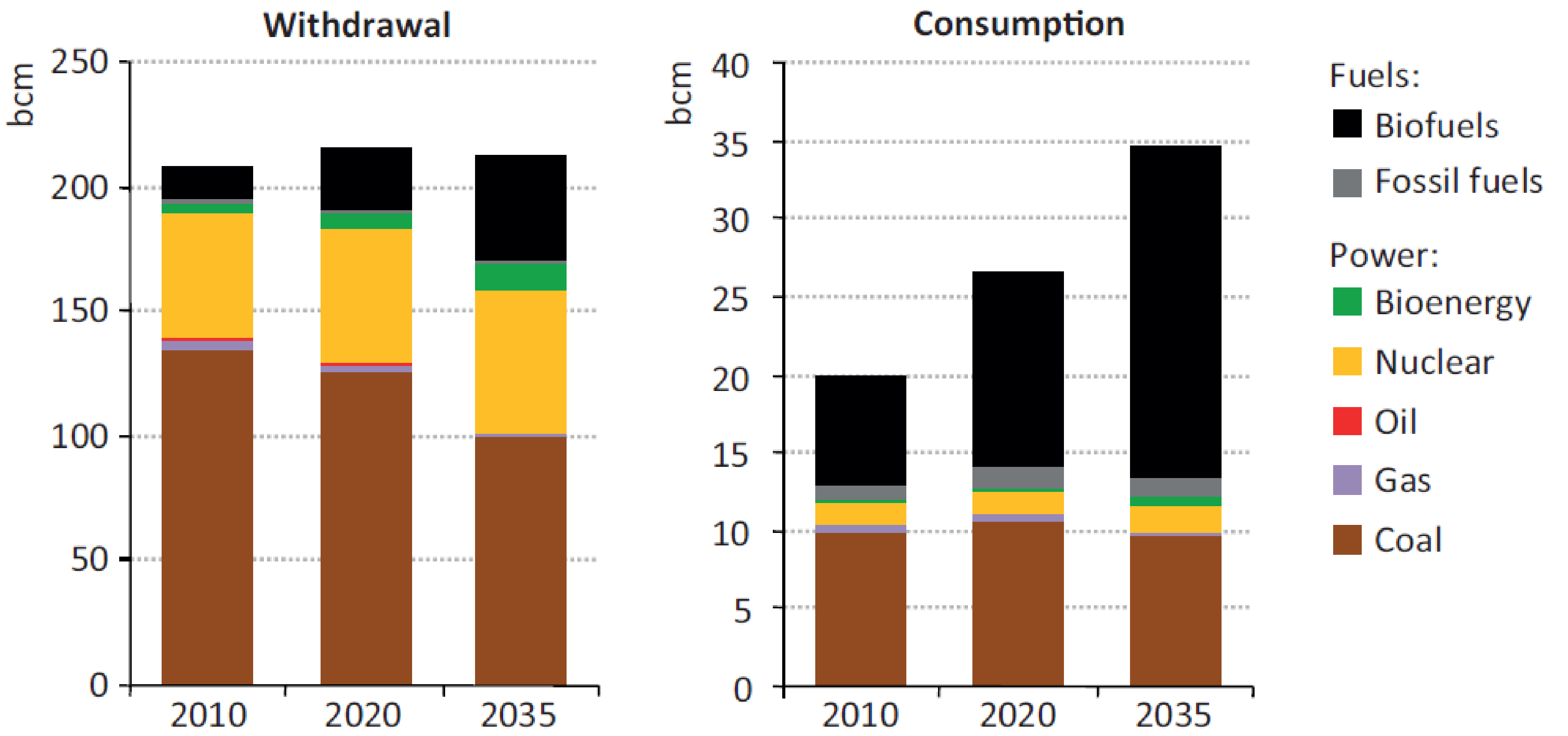


Table 2 Water intensity for extraction, processing, and electricity generation of different energy sources

Energy source (data source)	Water for extraction (L/GJ, gallons/MMBTU)	Water for extraction and processing (L/GJ, gallons/MMBTU)	Water consumption intensity of electricity generation (L/MWh)[a]
Natural gas, conventional (42, 50)	0.7, 0.2	6.7, 1.9	See below
Natural gas, unconventional (47–49)	8.6, 2.4	15, 4.1	See below
Natural gas combined cycle (once through)	See above	See above	520
Natural gas combined cycle (closed loop)	See above	See above	850
Pulverized coal (once through) (47–49)	9.0, 2.5	27, 7.5	1,400
Pulverized coal (closed loop) (47–49)	9.0, 2.5	27, 7.5	1,900
Saudi Arabian crude (47)	79, 22	110, 32	NA
Oil shale (51)	200, 57	240, 67	NA
Oil sands (47)	NA	110, 31	NA
Nuclear (once through) (47–49)	14, 4	47, 13	1,700
Corn ethanol (unirrigated) (47, 48)	300, 83	430, 119	2,100
Corn ethanol (irrigated) (47, 48)	14,000, 3,800	14,000, 3,800	16,000
Solar photovoltaic (47–49)	0, 0	0, 0	10
Concentrated solar power[b] (47, 48)	NA	NA	3,100
Wind[a]	0, 0	0, 0	4

Figure 17.13 ▷ Water use for energy production in the United States in the New Policies Scenario



Water Contamination

- Can fracking fluids reach aquifers?
- Can natural gas reach aquifers?
- Can there be spills that affect surface water?

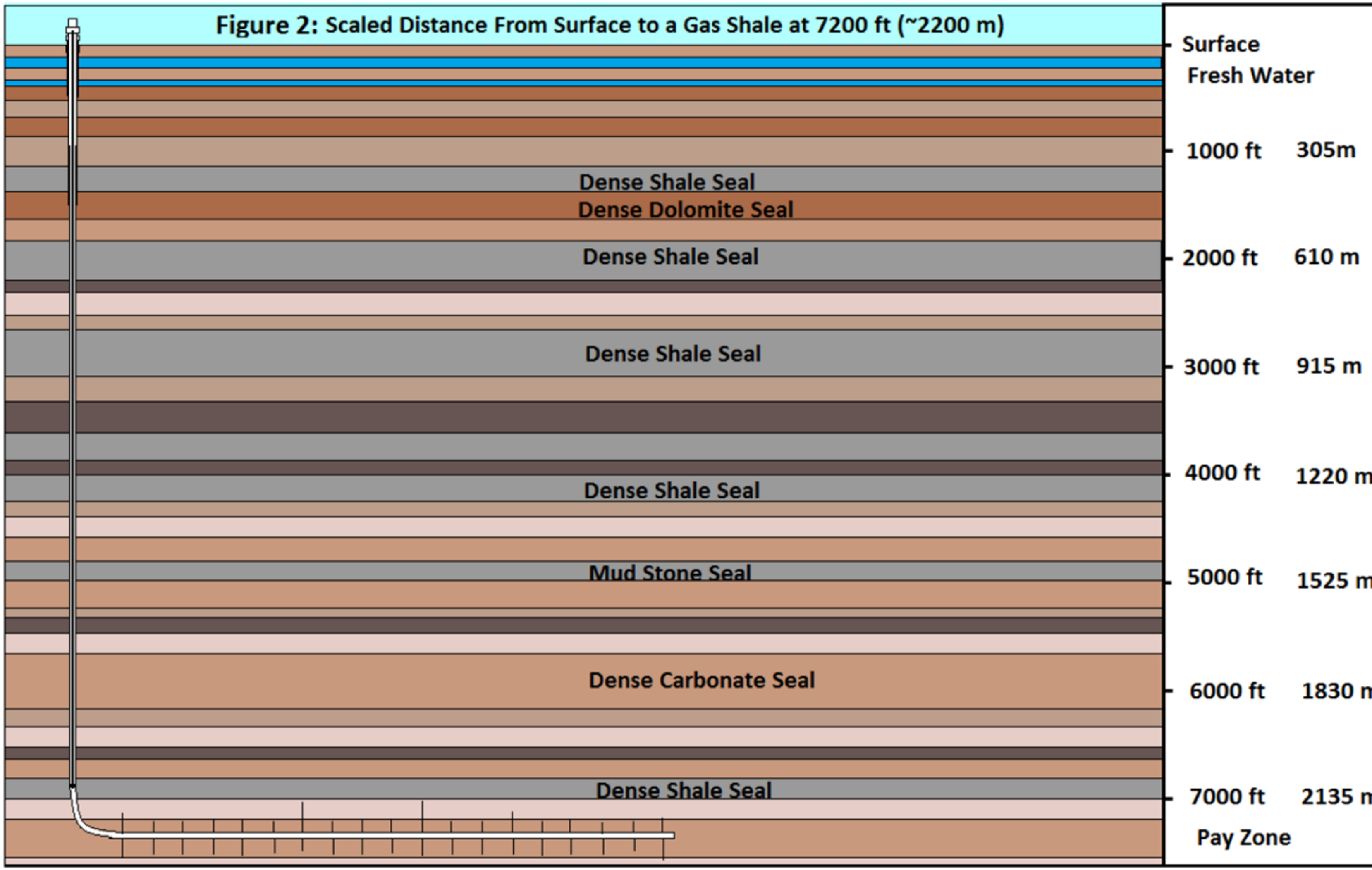
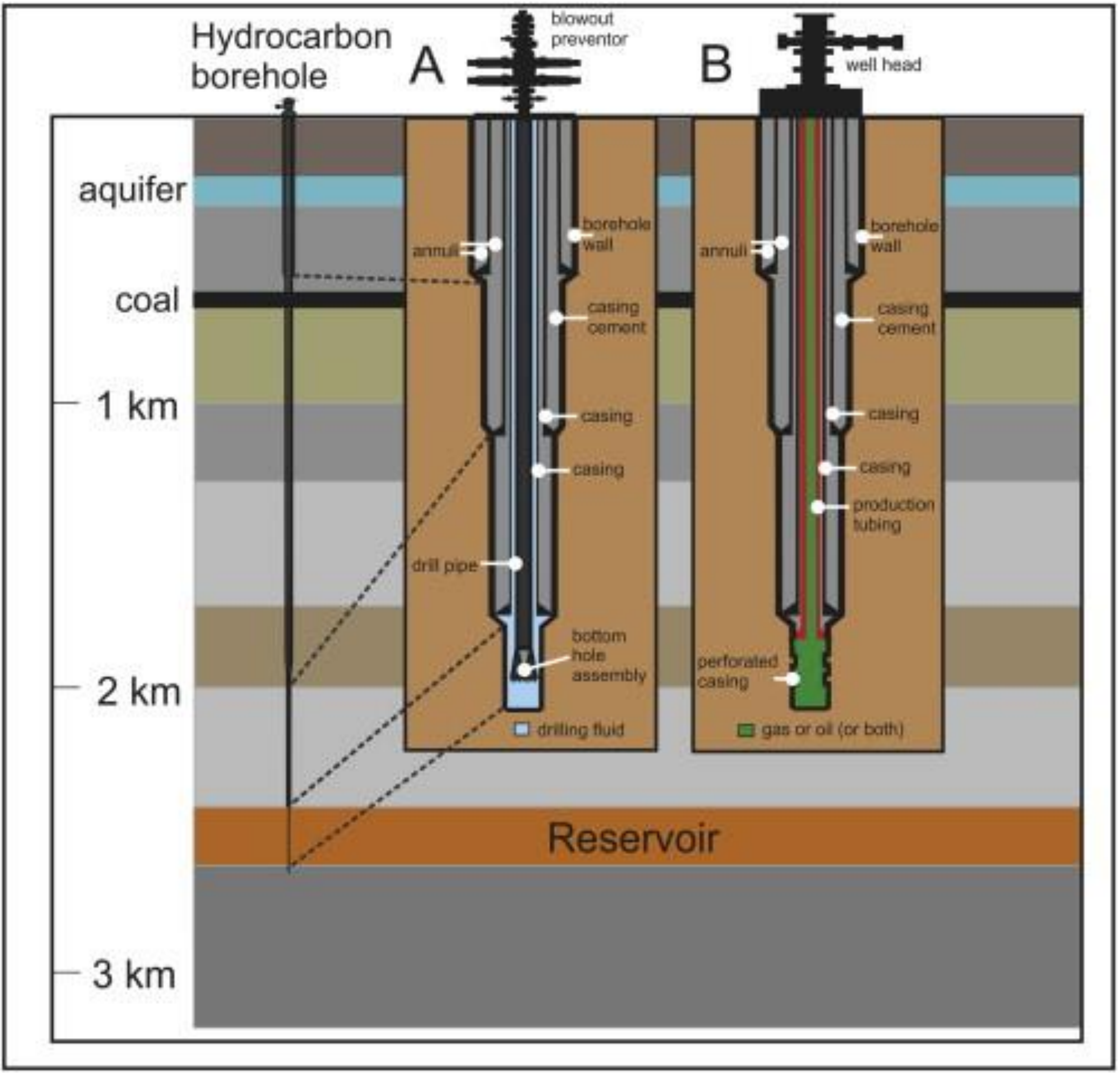
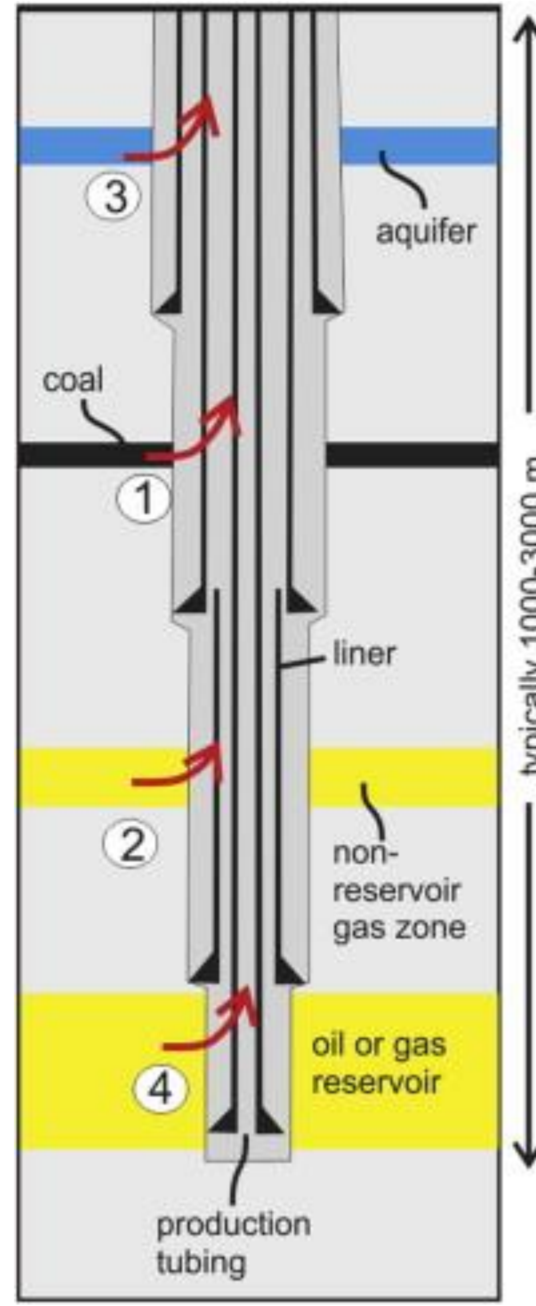


Figure 2: Scaled Distance From Surface to a Gas Shale at 7200 ft (~2200 m)
Surface
Fresh Water
1000 ft 305m
Dense Shale Seal
Dense Dolomite Seal
Dense Shale Seal
2000 ft 610 m
Dense Shale Seal
3000 ft 915 m
4000 ft 1220 m
Dense Shale Seal
Mud Stone Seal
5000 ft 1525 m
Dense Carbonate Seal
6000 ft 1830 m
Dense Shale Seal
7000 ft 2135 m
Pay Zone



Hydrocarbon borehole
A
blowout preventor
B
well head
aquifer
coal
1 km
2 km
3 km
annuli
borehole wall
casing cement
casing
casing
drill pipe
bottom hole assembly
drilling fluid
annuli
borehole wall
casing cement
casing
casing
production tubing
perforated casing
gas or oil (or both)
Reservoir

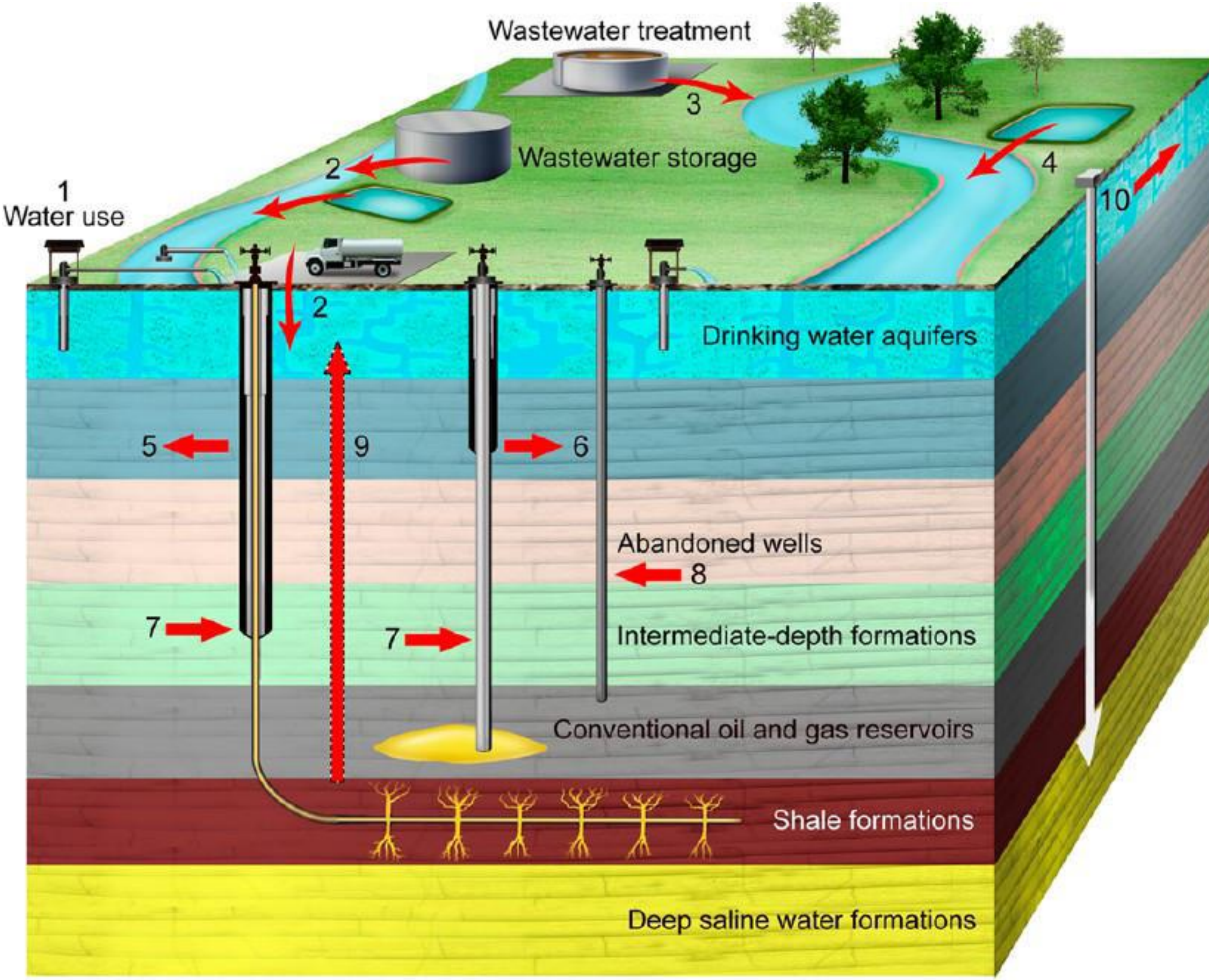


3
aquifer
coal
1
liner
2
non-reservoir gas zone
4
oil or gas reservoir
production tubing
typically 1000-3000 m

Well barrier/integrity failure

- Values from different studies are all over the map
- Anywhere from 1.9% to 75% (Davies et al. 2014)
- Estimated at ~6% of wells for Marcellus (from regulators' data)

Elevated pressures during fracking are well above the value shown to cause damage.


Wastewater treatment
3
Wastewater storage
2
4
1
Water use
10
2
Drinking water aquifers
5
9
6
Abandoned wells
8
7
7
Intermediate-depth formations
Conventional oil and gas reservoirs
Shale formations
Deep saline water formations

Spills

- Chemicals used in fracking fluid
- Mixed fracking fluid
- Flowback water
- Produced water

Contaminants: BTEX, Cl, Na, NORM, crude, among others

Sources: Trucks, holding ponds, containers, pipelines.

Spills

- Colorado: 1 spill per 100 wells
- Pennsylvania: 0.4 to 12.2 spills per 100 wells

EPA, 2015.

Very little data, not segregated by kind of spill.

We did not find evidence that these mechanisms have led to widespread, systemic impacts on drinking water resources in the United States. Of the potential mechanisms identified in this report, **we found specific instances where one or more mechanisms led to impacts on drinking water resources**, including contamination of drinking water wells. The number of identified cases, however**, was small compared to the number of hydraulically fractured wells**.

U.S. EPA 2015

Water Contamination

- Can fracking fluids reach aquifers? (most likely no)
- Can natural gas reach aquifers? (most likely yes, in some cases)
- Can there be spills that affect surface water? (yes)

Greenhouse Gases

- Shale gas: better or worse than coal?
- Is shale gas a good “bridge fuel”

Agreement:

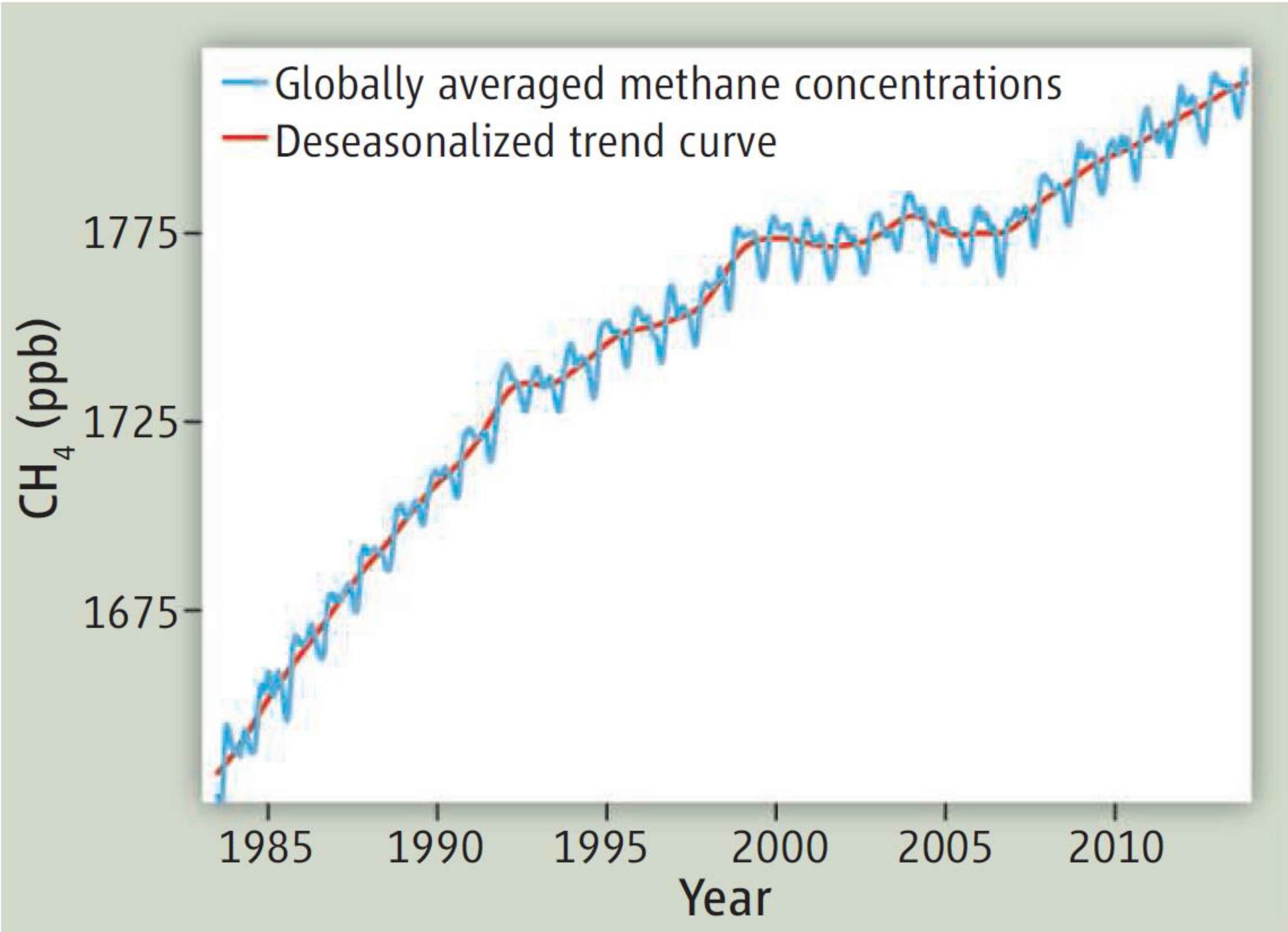
CO_2 emissions only about half that of coal

Disagreement:

Methane emissions can offset those gains

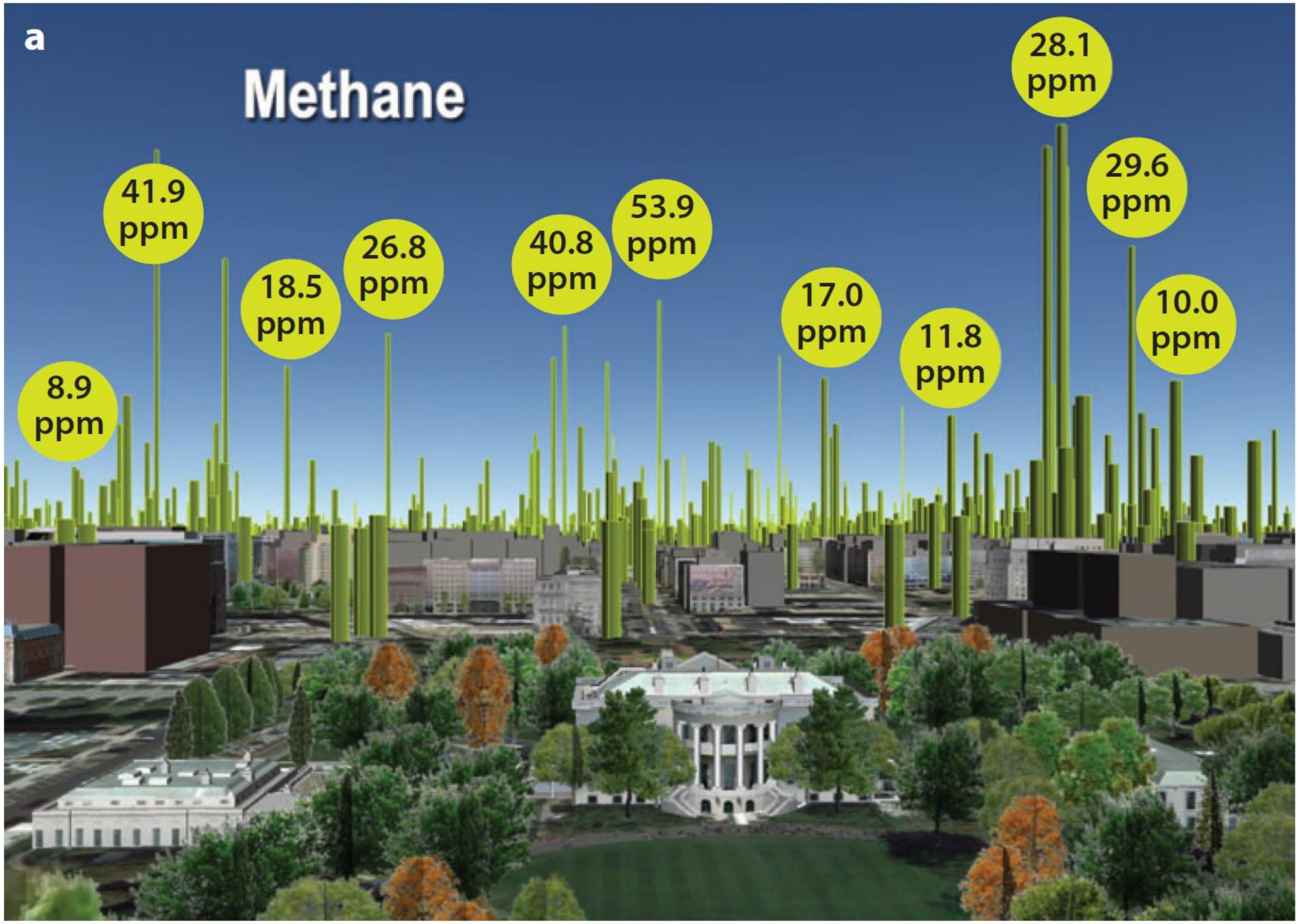
Reasons for disagreement

- Quantity of methane leaked
- Primary use of the fuel
- GWP and time horizon

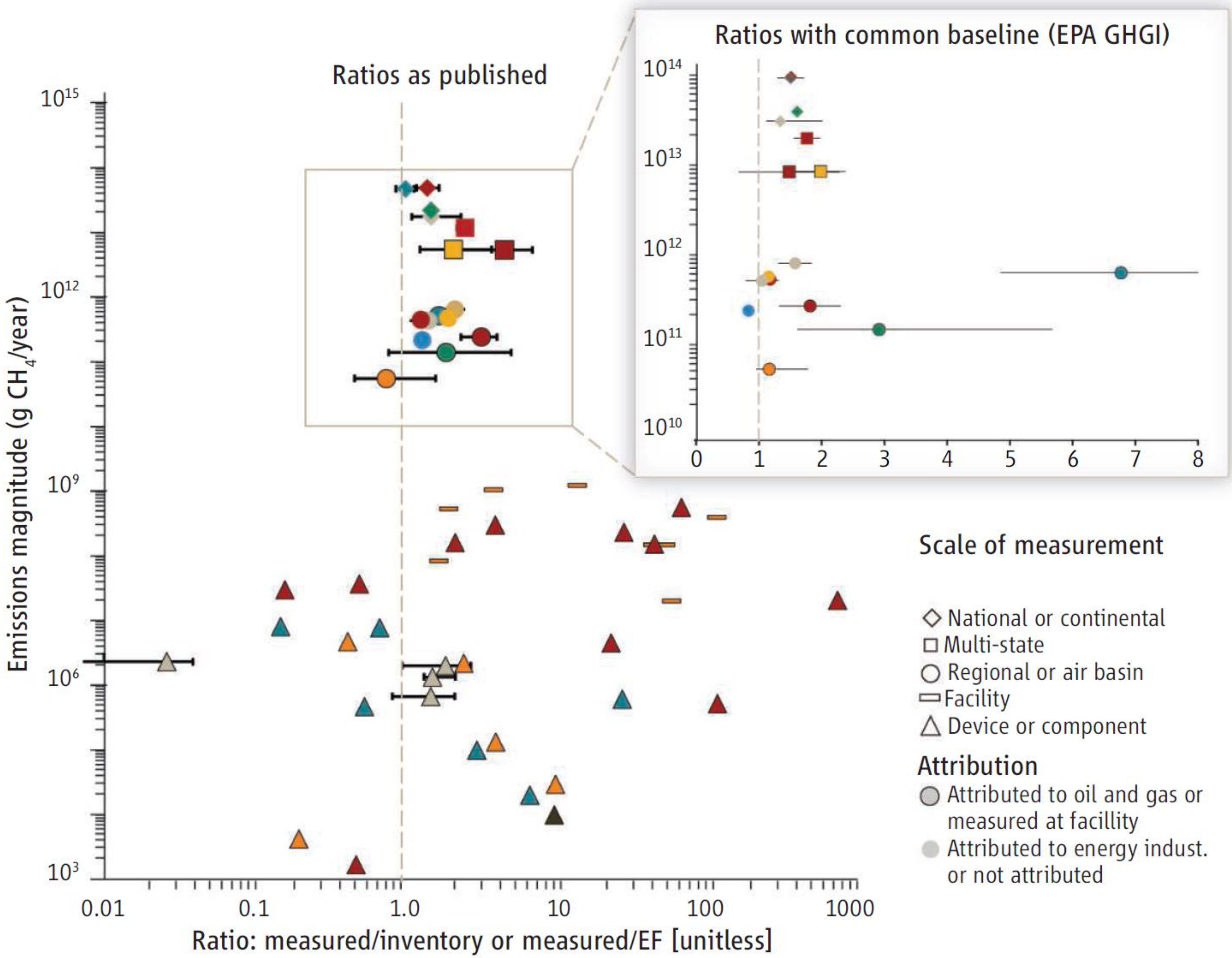


Globally averaged methane concentrations
Deseasonalized trend curve
1775
1725
1675
CH_4 (ppb)
1985
1990
1995
2000
2005
2010
Year

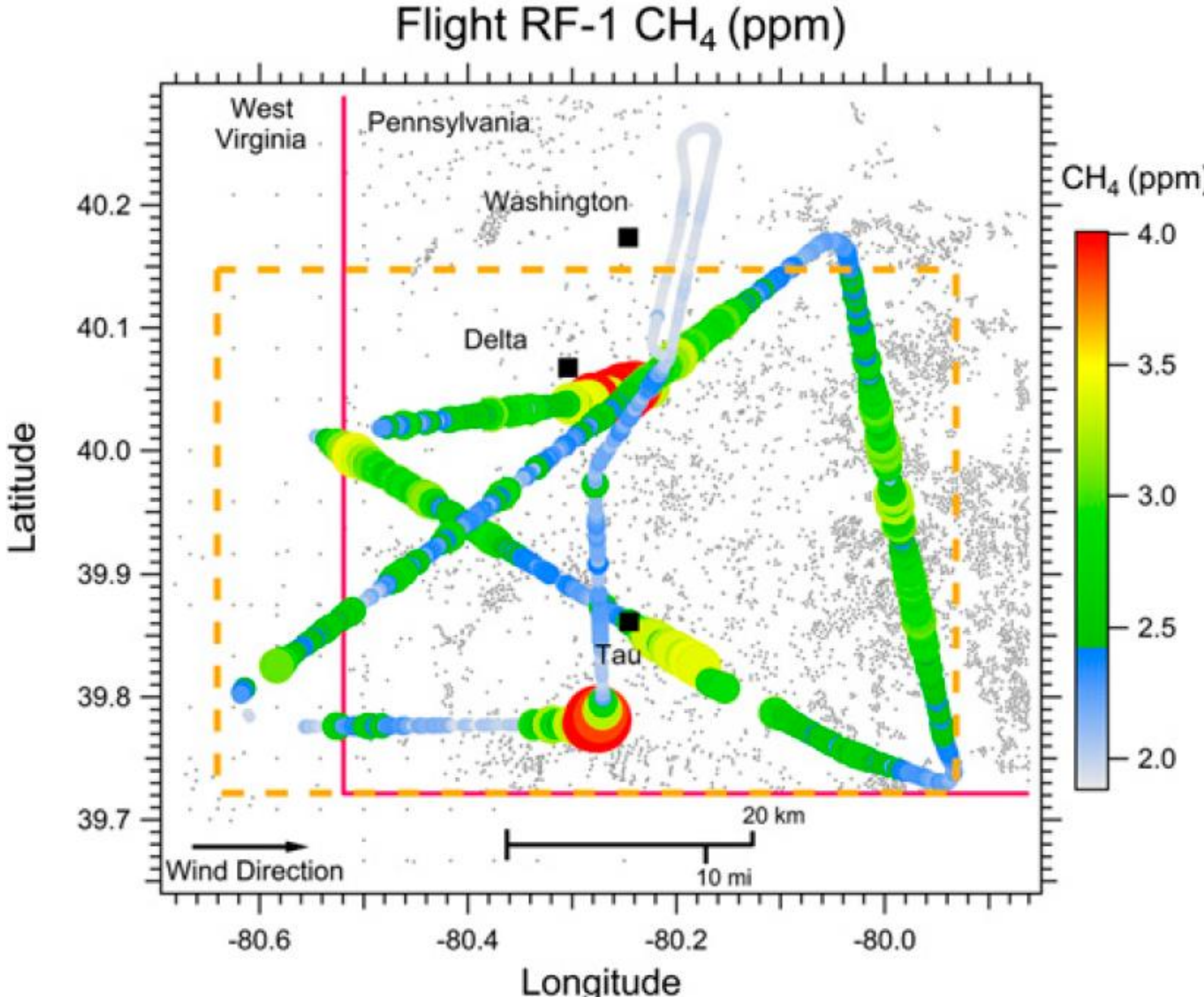
Leaks in distribution systems



Jackson et al., 2014

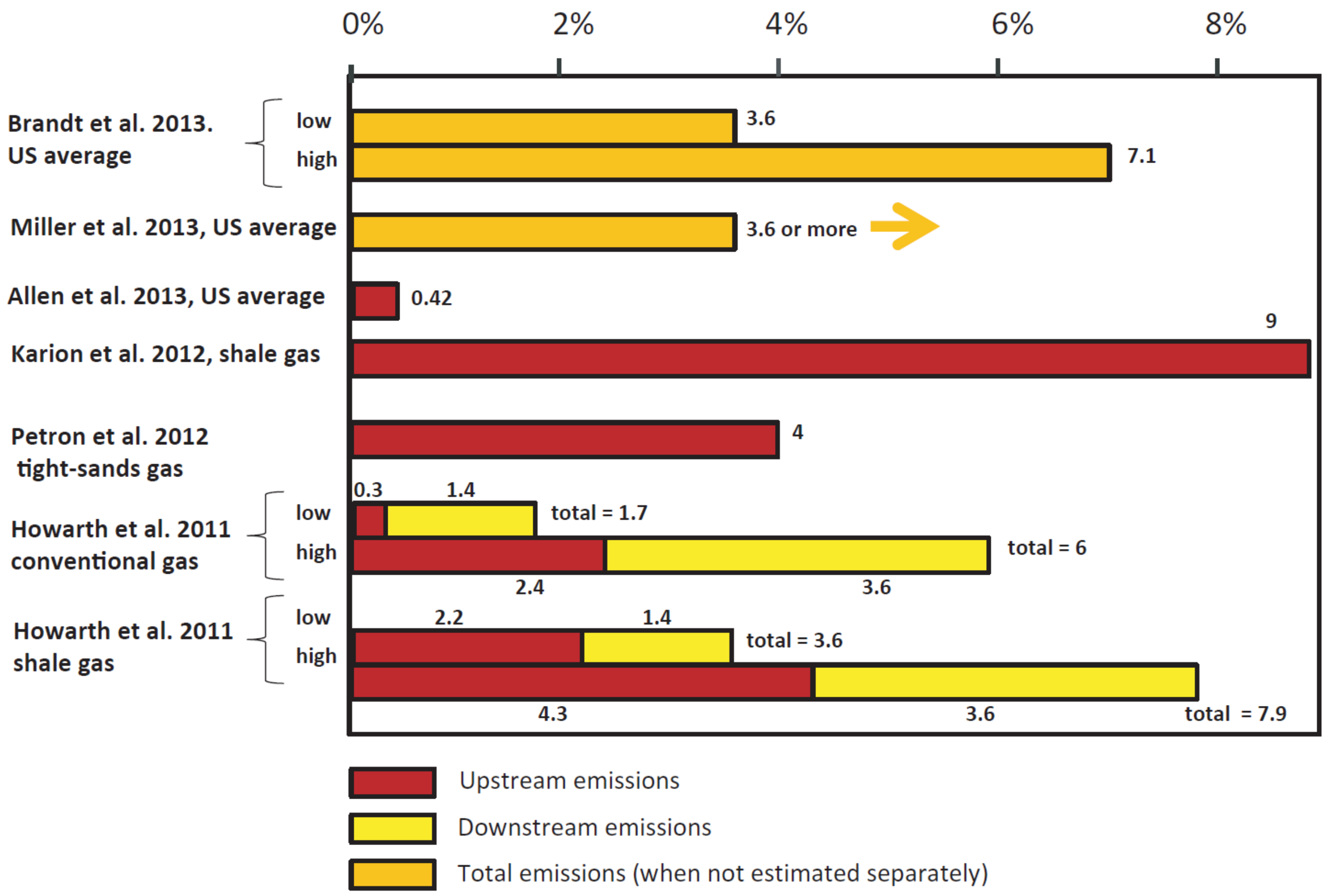


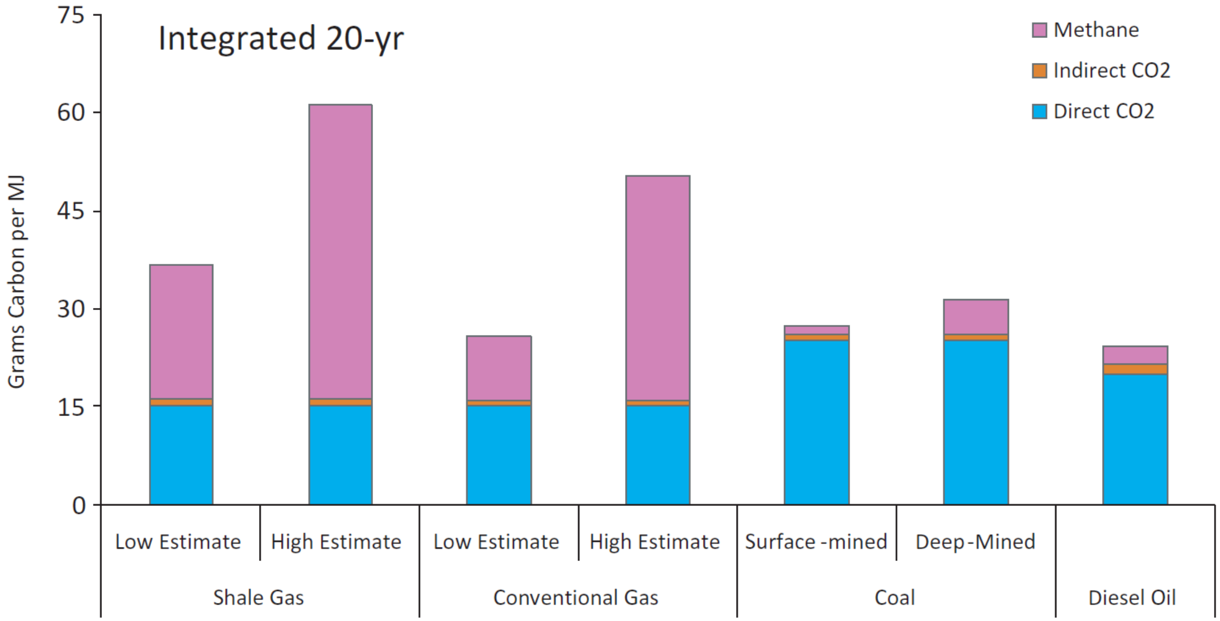
Brandt et al., 2014

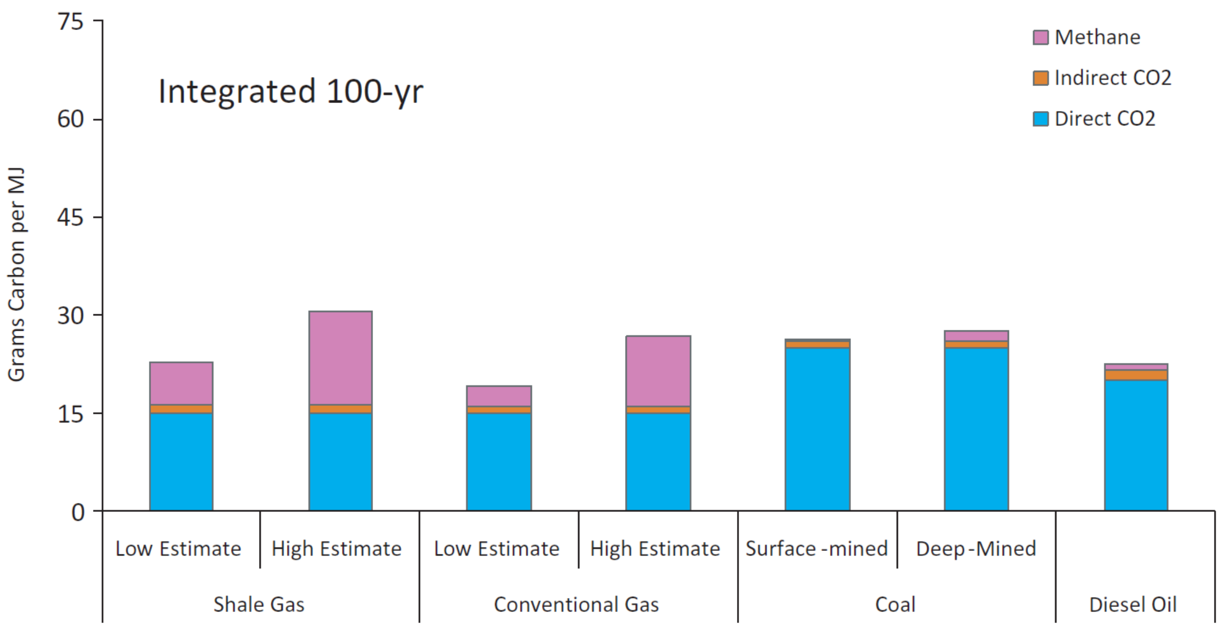


Caulton et al, 2014

How much methane leaks out?



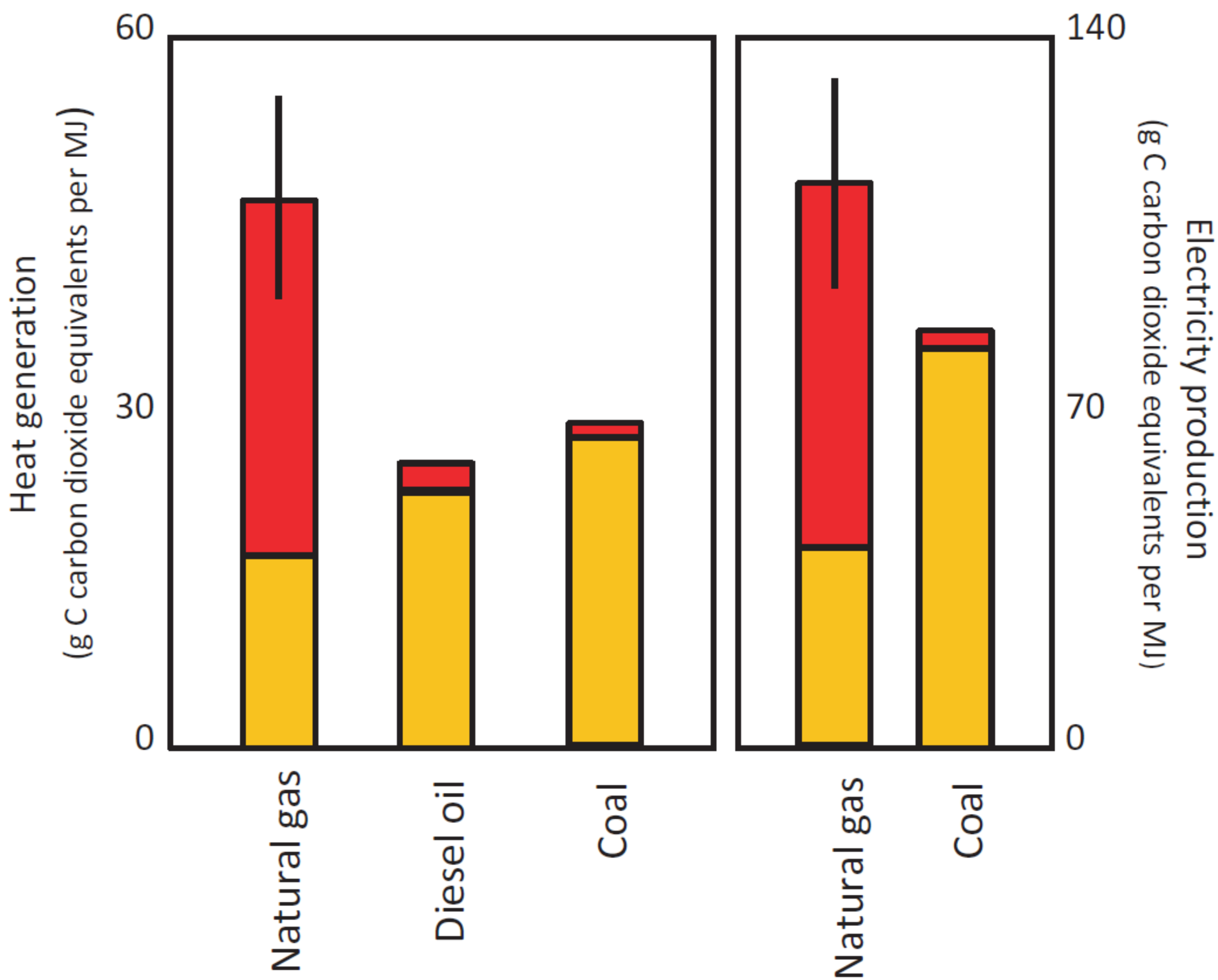




Howarth et al., 2011
Howarth, 2014

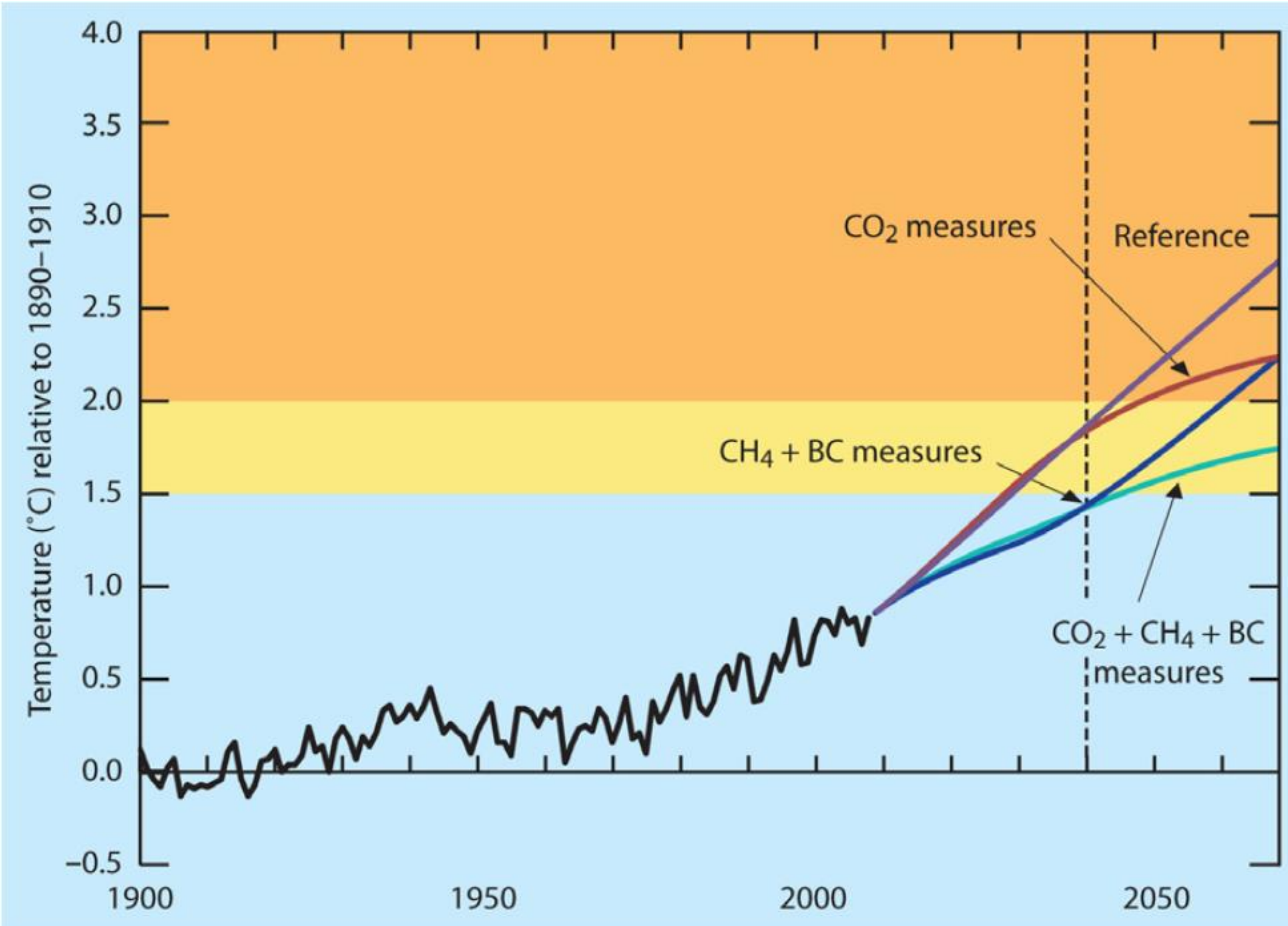
Publication	Timescale considered	20-year GWP	100-year GWP
IPCC [35]	**20 and 100 years**	**56**	**21**
Hayhoe et al. [2]	0–100 years	NA	NA
Lelieveld et al. [3]	20 and 100 years	56	21
Jamarillo et al. [4]	100 years	–	21
IPCC [36]	**20 and 100 years**	**72**	**25**
Shindell et al. [37]	**20 and 100 years**	**105**	**33**
Howarth et al. [8]	20 and 100 years	105	33
Hughes [20]	20 and 100 years	105	33
Venkatesh et al. [12]	100 years	–	25
Jiang et al. [13]	100 years	–	25
Wigley [38]	0–100 years	NA	NA
Stephenson et al. [14]	100 years	–	25
Hultman et al. [15]	20 and 100 years	72, 105	25, 44
Skone et al. [39]	100 years	–	25
Burnham et al. [16]	100 years	–	25
Cathles et al. [17]	100 years	–	25
Alvarez et al. [40]	0–100 years	NA	NA
IPCC [34]	**10, 20, and 100 years**	**86**	**34**
Brandt et al. [29]	100 years	–	25

Howarth, 2014

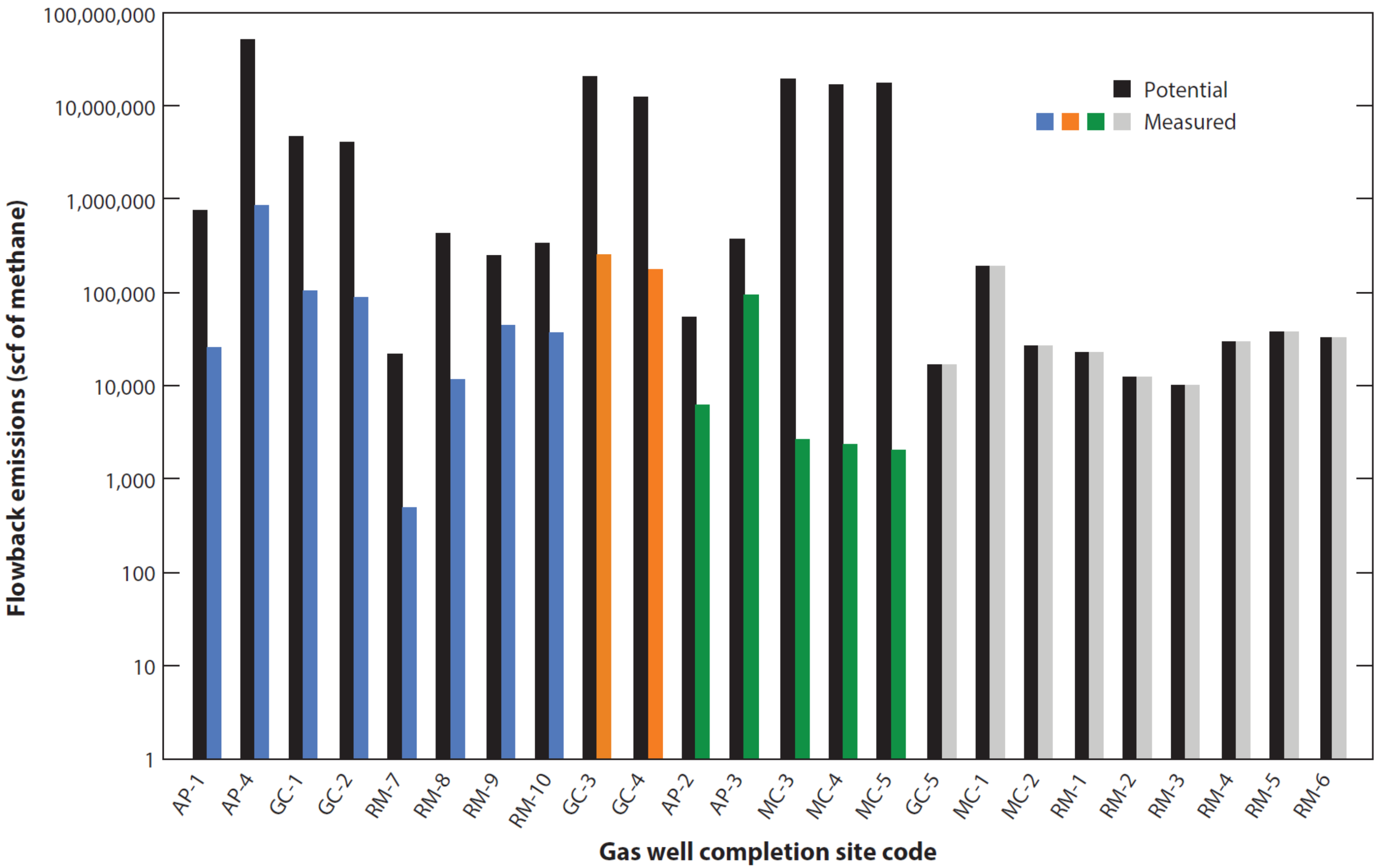


Howarth, 2014

Why 20 years instead of 100?



Green completions



Air Pollution

- Where do emissions come from?
- Is it better or worse than coal?

Glossary

BTEX

Ozone Precursors

NOx

H_2S

VOCs

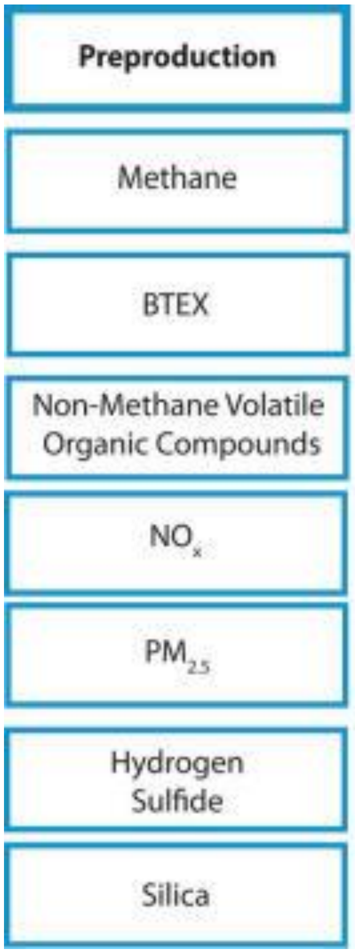
PM

Respirable Silica

Mercury

SO_x

Preproduction	Production	Transmission, Storage and Distribution	Use	Well Production End-of-Life
Methane	Methane	Methane	Methane	Methane
BTEX	BTEX		CO_2	
Non-Methane Volatile Organic Compounds	Non-Methane Volatile Organic Compounds		NO_x	
NO_x				
$PM_{2.5}$				
Hydrogen Sulfide				
Silica				



Diesel exhaust from machinery that clear well pads and creates access routes.

Diesel exhaust from mixing and pumping equipment.

Diesel engines emit PM2.5, NOx and NMVOCs
Truck traffic also produces PM10.

Chemicals in the fluid and flowback contain volatile compounds. Stored in open pits and containers.

Respirable Silica found to be 10x higher than limits on 33% of studied sites (N=111).

Flaring.

Note: this image is showing heat, not light


71% captured and sold
16% flared without capture or sold
13% flared due to existing takeaway challenges

Flaring:

- Initial production before gas wells connected to pipelines.
- In the Bakken, ~30% of natural gas is flared indefinitely (36% in Dec 2013).
- Goal is 15% in 1Q 2016

- Contributes to fine particle formation.
- Produces Ozone precursors, including formaldehyde if combustion is incomplete.
- Emits BTEX compunds.

- Initial flaring is due to be eliminated with new EPA rules for "green completions"

Compressors (wellhead and compressor stations)
Well-pad equipment leaks
Flaring emissions.

In PA: 91−97% of VOCs, 59−68% of NOx, 64−84% of PM2.5, and 40−64% of SOx emissions

Data Paucity

- Health effects studies are scarce
- O_3 often monitored only in urban areas
- Chemistry of emissions not fully understood
- Pre-drilling baselines not established
- Big differences in "bottom-up" vs "top-down" studies

Burning Coal vs Natural Gas for Electricity

Coal problems:

SO_2: leading source, public health, acid rain.

NOx: Ozone, chronic respiratory diseases.

PM: Bronchitis, asthma, premature death, haze.

Mercury: Highly toxic, >50% of emissions, brain damage, heart problems

Burning Coal vs Natural Gas for Electricity

The air-quality benefits of switching from coal to natural gas are **extensive** for pollutants such as mercury and sulfur dioxide (SO2). These benefits may be less so for nitrogen oxides (NOx)… unless combined-cycle technology is used.

Moore et al. 2014

Particulate matter is also greatly reduced.
“Clean Coal” technologies can reduce SO2 by ~50% NOx by ~70% and PM by ~99%

Air Pollution

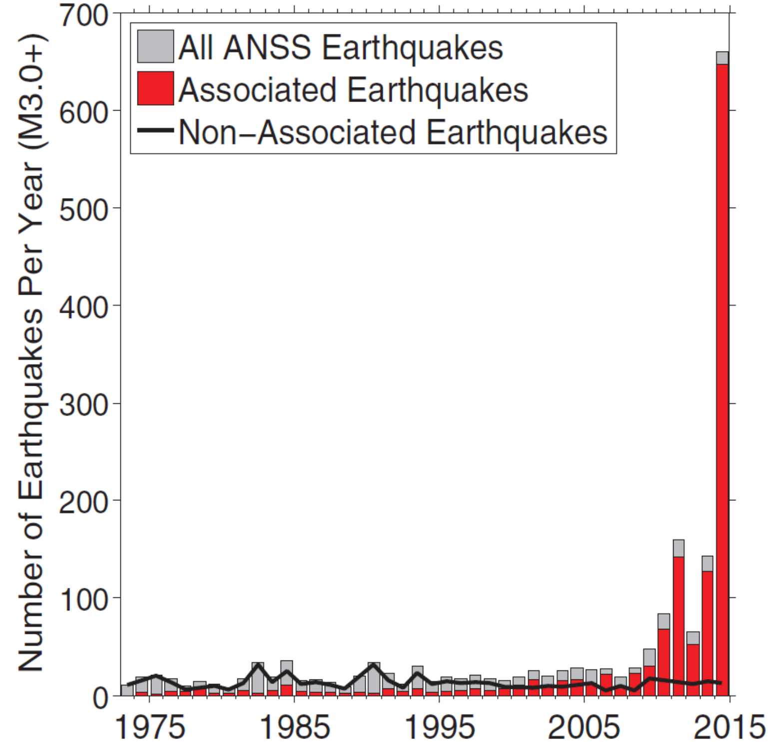
- Where do emissions come from?
- Is it better or worse than coal?

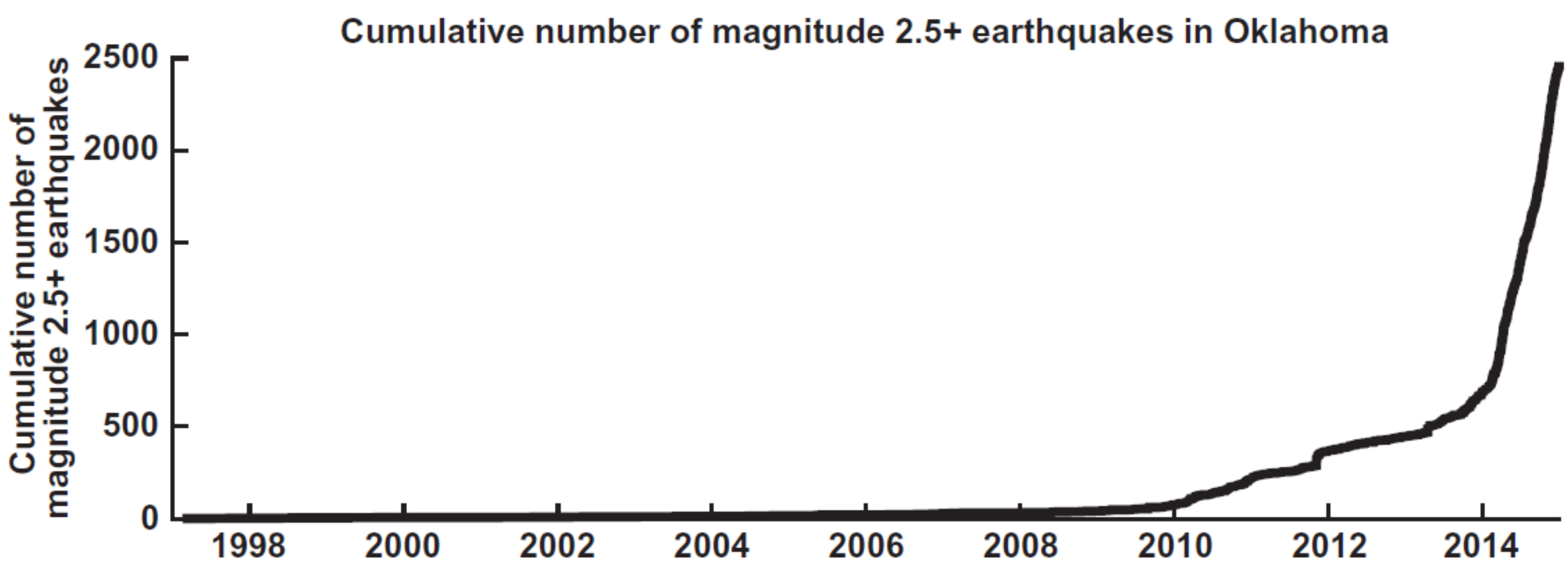
Much better (except if you live by a well)

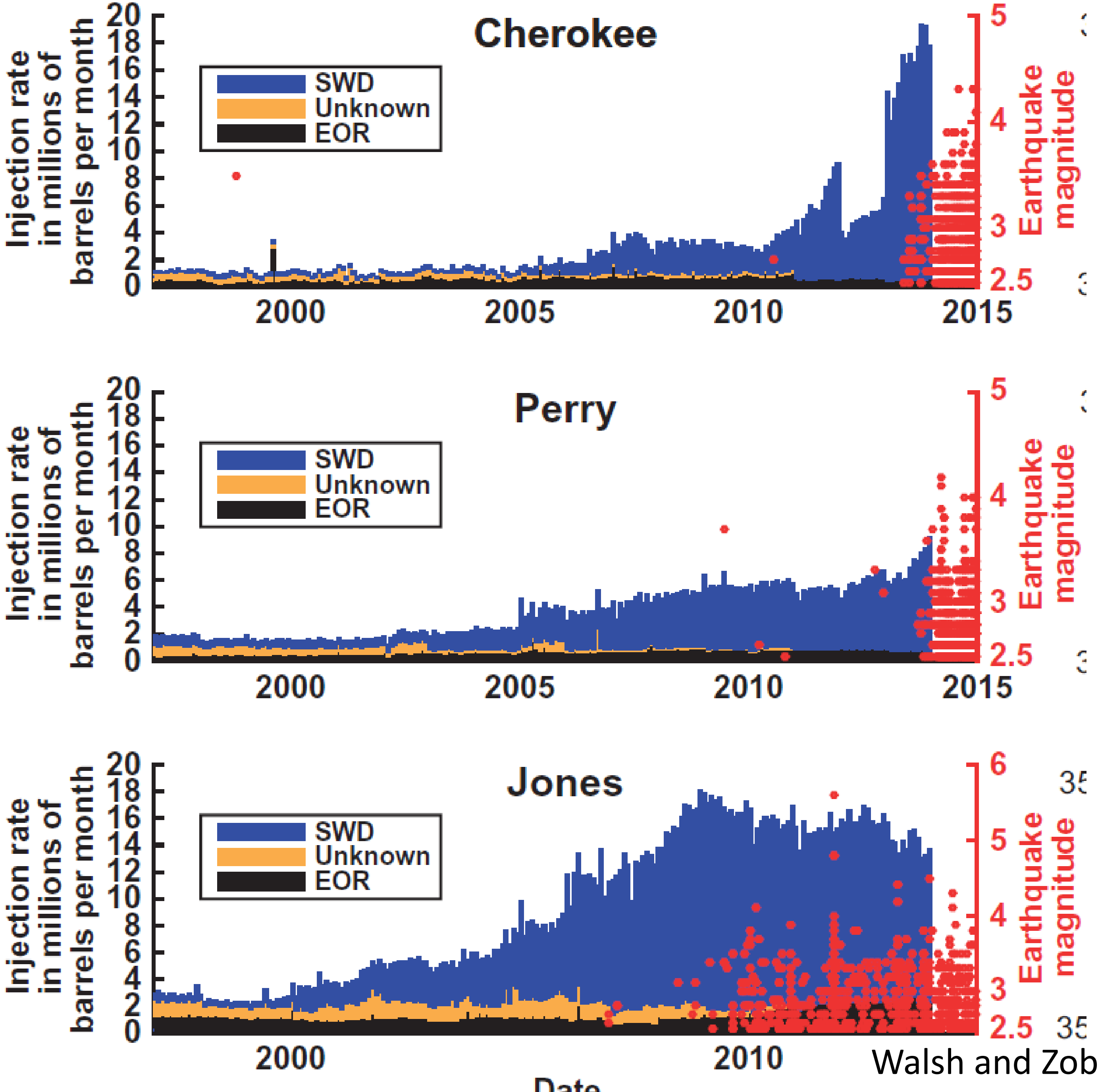
Induced Seismicity

- Due to wastewater injection
- Due to hydraulic fracturing
- Why some places and not others?

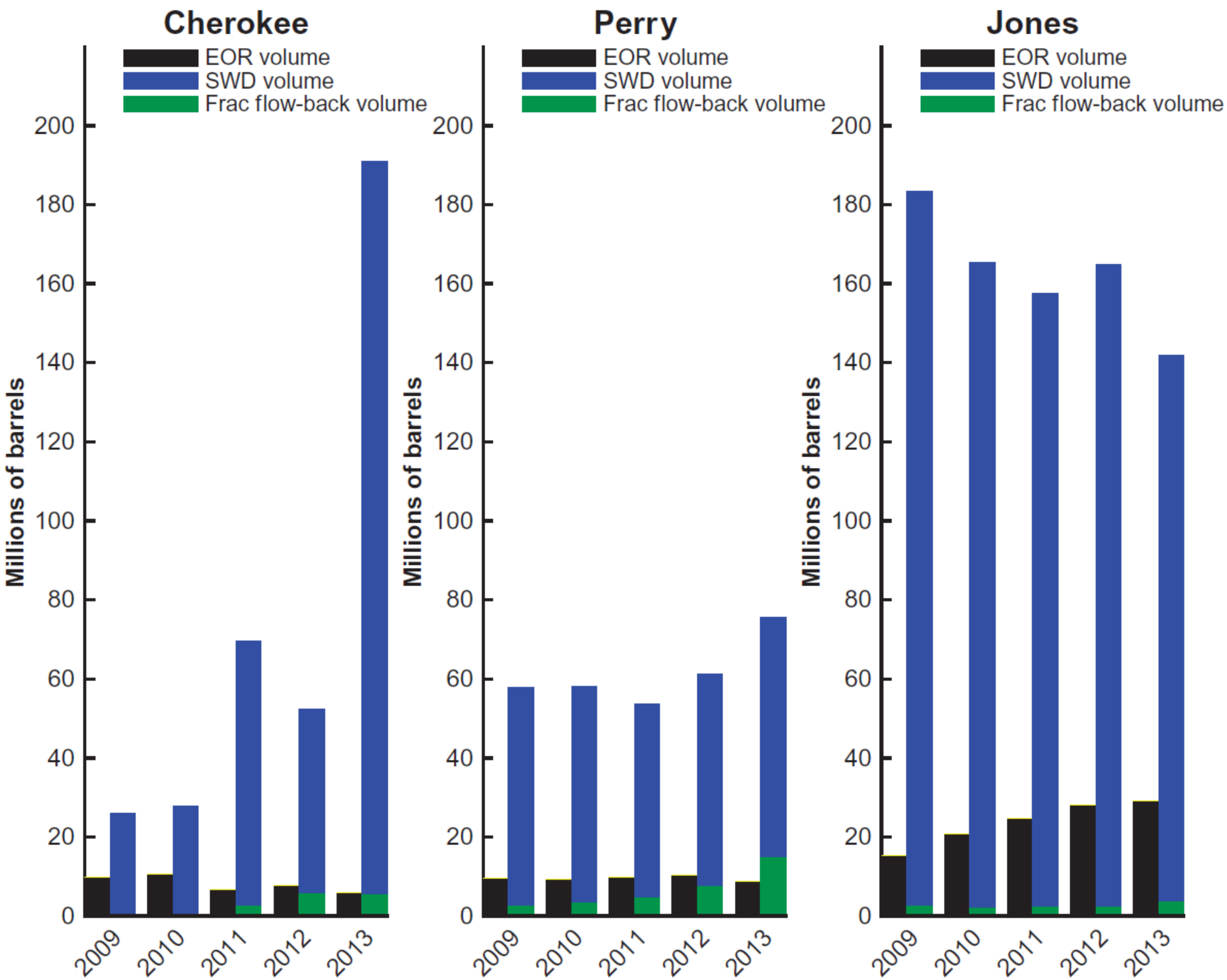
Dramatic increase in seismicity





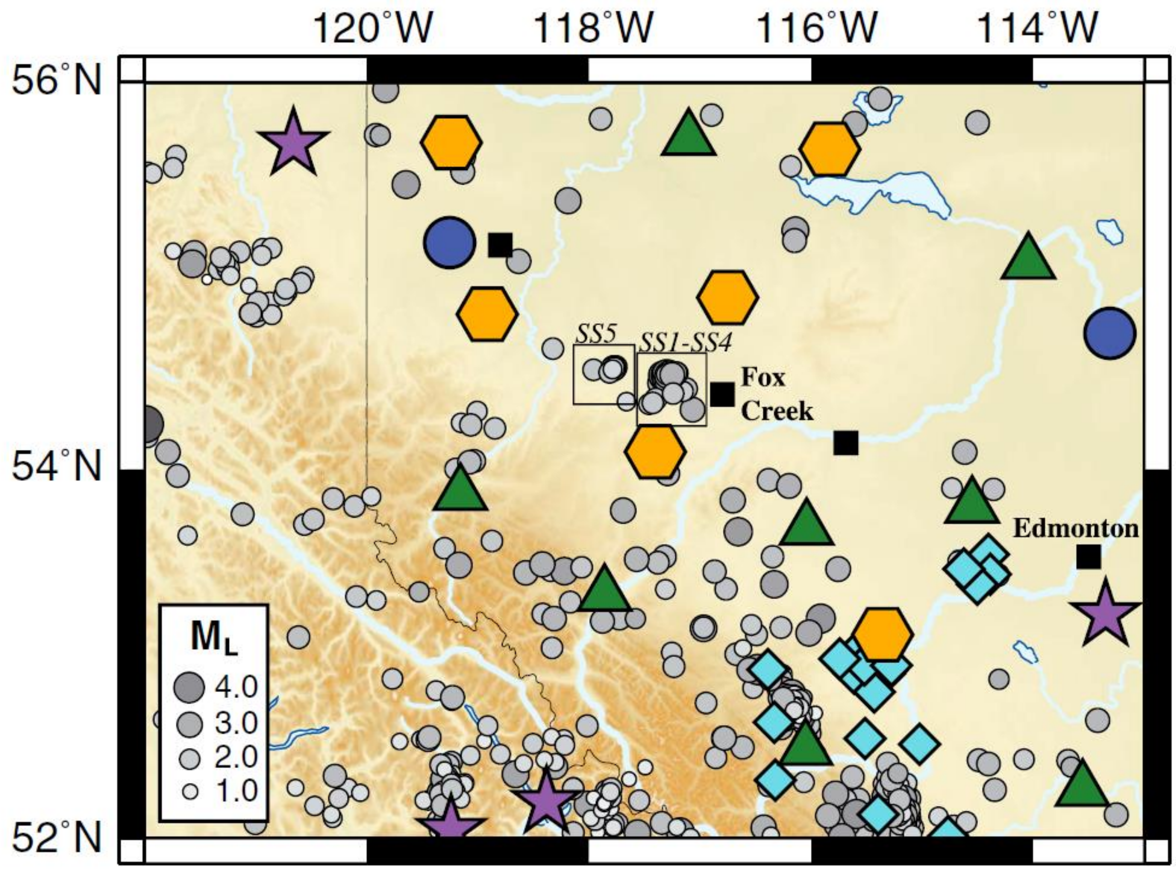


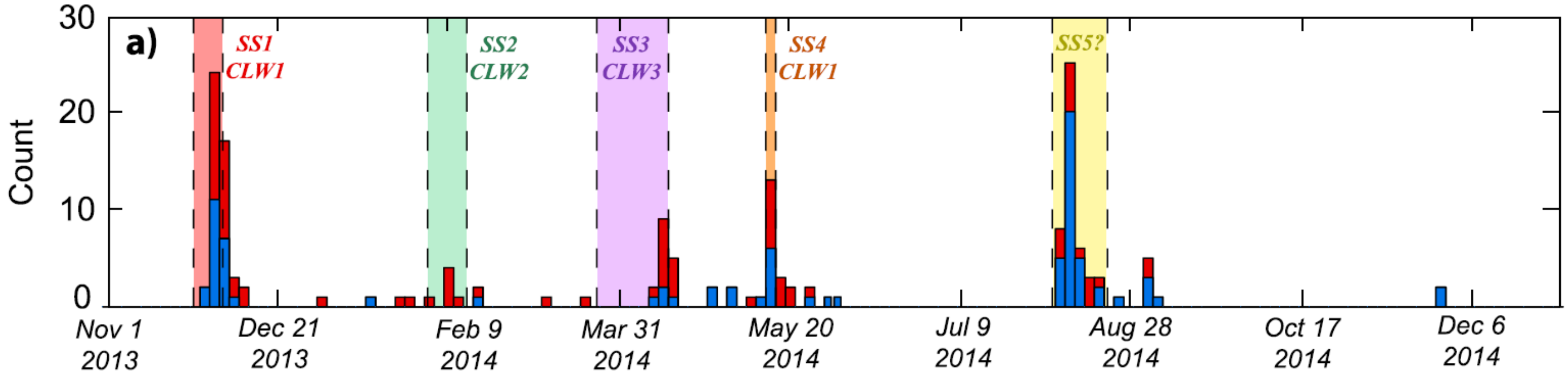
Walsh and Zoback, 2015



Walsh and Zoback, 2015

Hydraulic fracturing has been tied to events in Canada
With magnitudes as high as 4.4





Why some places and not others?

- Little to no induced seismicity in the Bakken
- Regional stress field
- Orientation of faults
- Low pre-pumping pressures
- We don’t really know

Questions