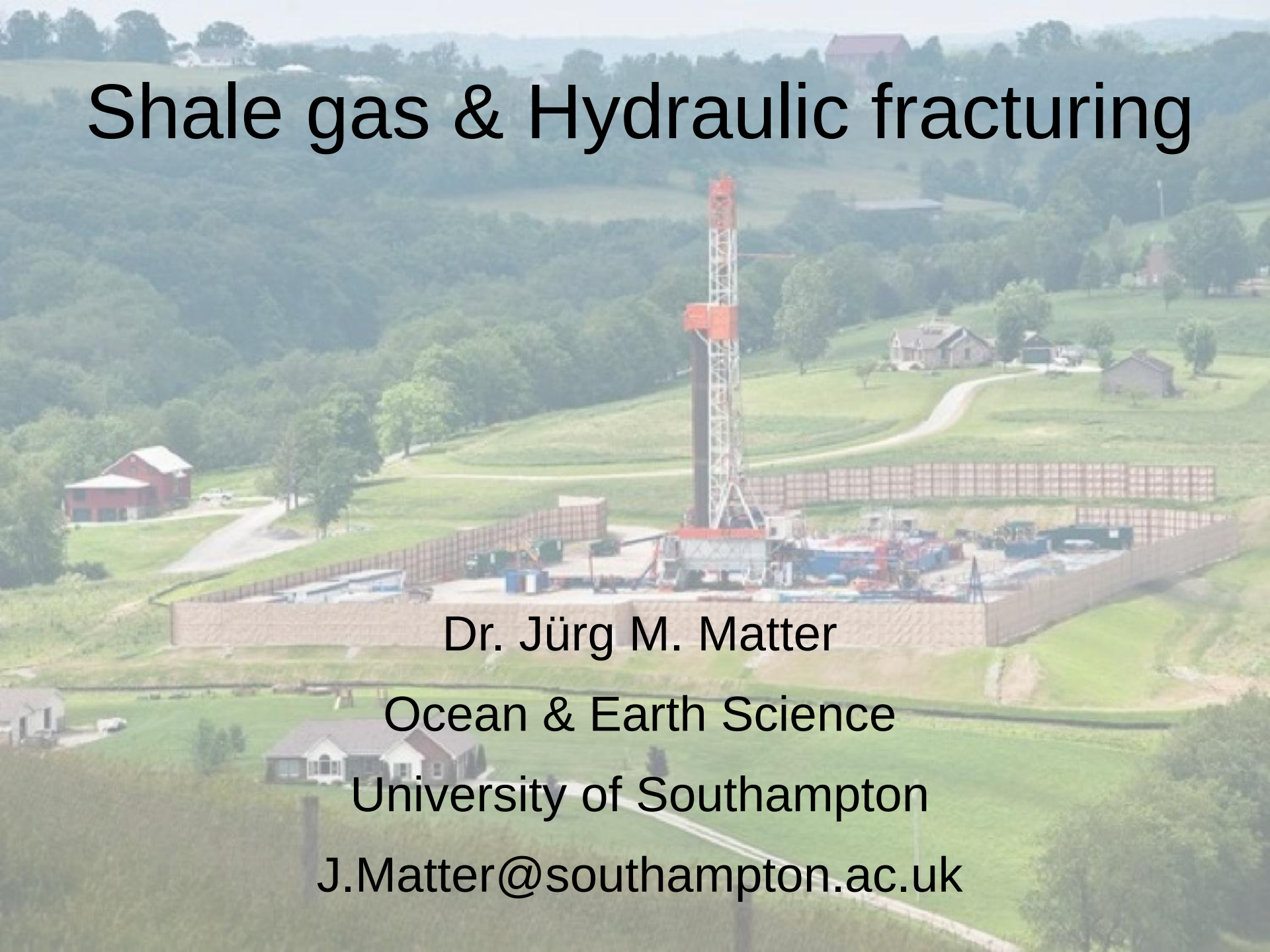
Shale gas & Hydraulic fracturing



Dr. Jürg M. Matter

Ocean & Earth Science

University of Southampton

J.Matter@southampton.ac.uk

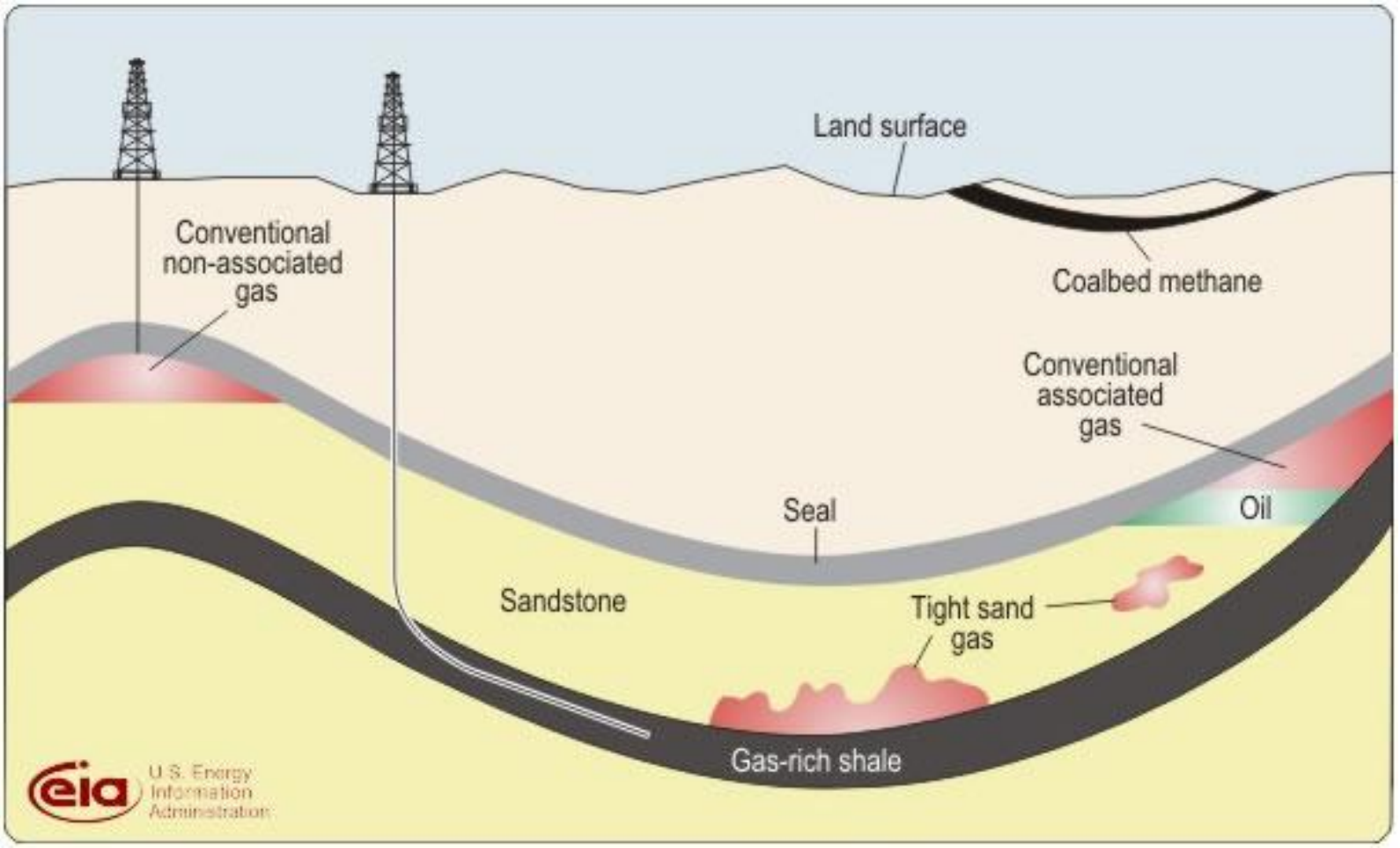
Definitions – unconventional hydrocarbons

- **unconventional gas**
  - **shale gas**
  - tight gas (low porosity/permeability, silt/sand)
  - coal bed methane
  - methane hydrates
- **unconventional oil**
  - oil shales
  - oil sands, extra heavy oil and bitumen
  - synthetic crude products
  - liquids derived from natural gas

International Energy Agency

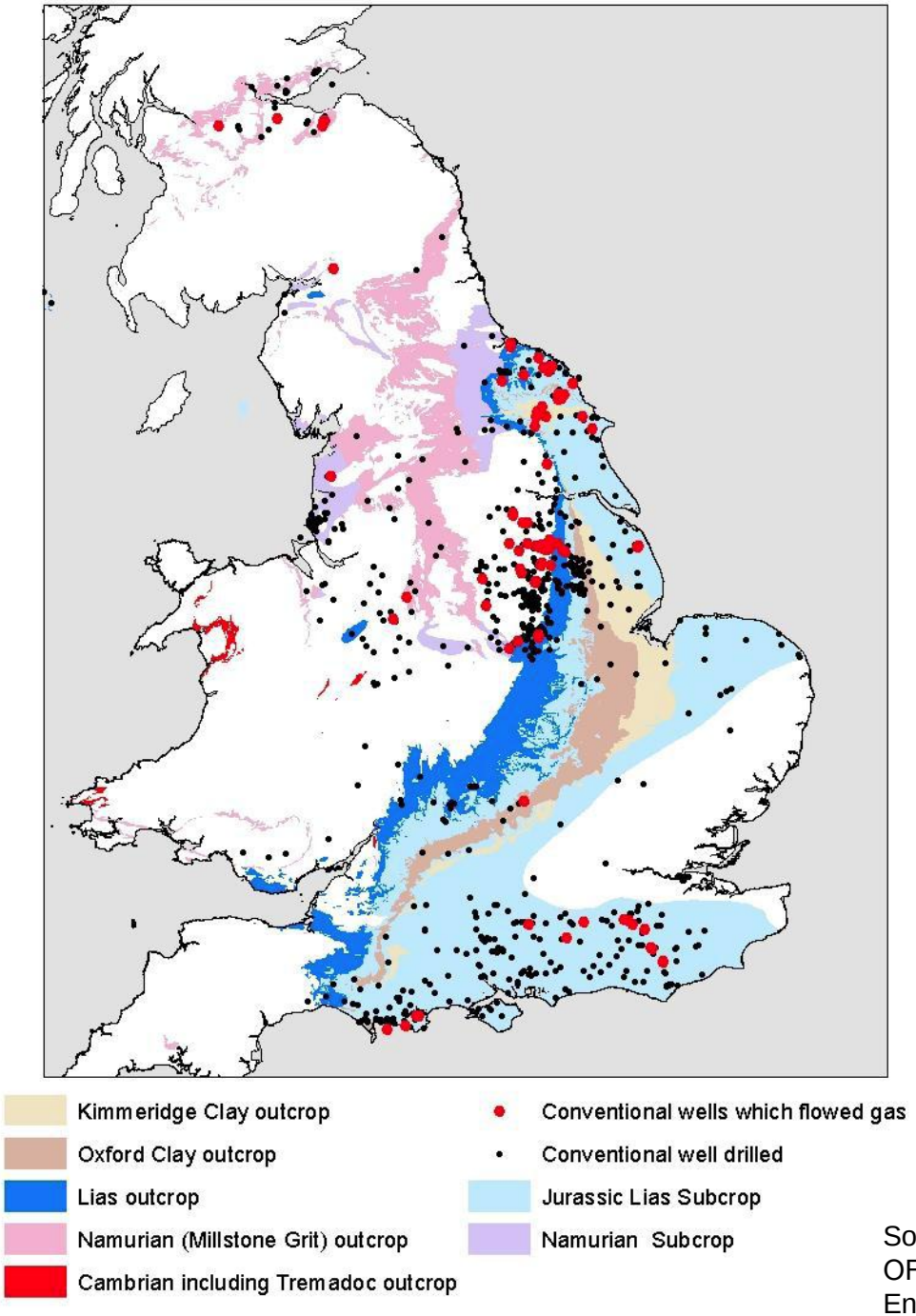
http://climatechange101.blogspot.com/2010/04/trip-to-marcellus-outcrop-with-sara.html

Conventional vs. Unconventional Natural Gas Resources



- Shales are fine grained sedimentary rocks, which can be a rich source of natural gas and petroleum.

Main areas of prospective UK shale formations



- BGS & DECC: central estimate of 1,329 Tcf shale gas resource (gas-in-place) between Wrexham and Blackpool, and Nottingham and Scarborough
- What fraction of it is technically recoverable?
- 2012 UK natural gas consumption was ~3Tcf (DECC/BGS)

Source: THE UNCONVENTIONAL HYDROCARBON RESOURCES OF BRITAIN'S ONSHORE BASINS – SHALE GAS. Department of Energy & Climate Change, UK

What is a trillion cubic feet (Tcf)?

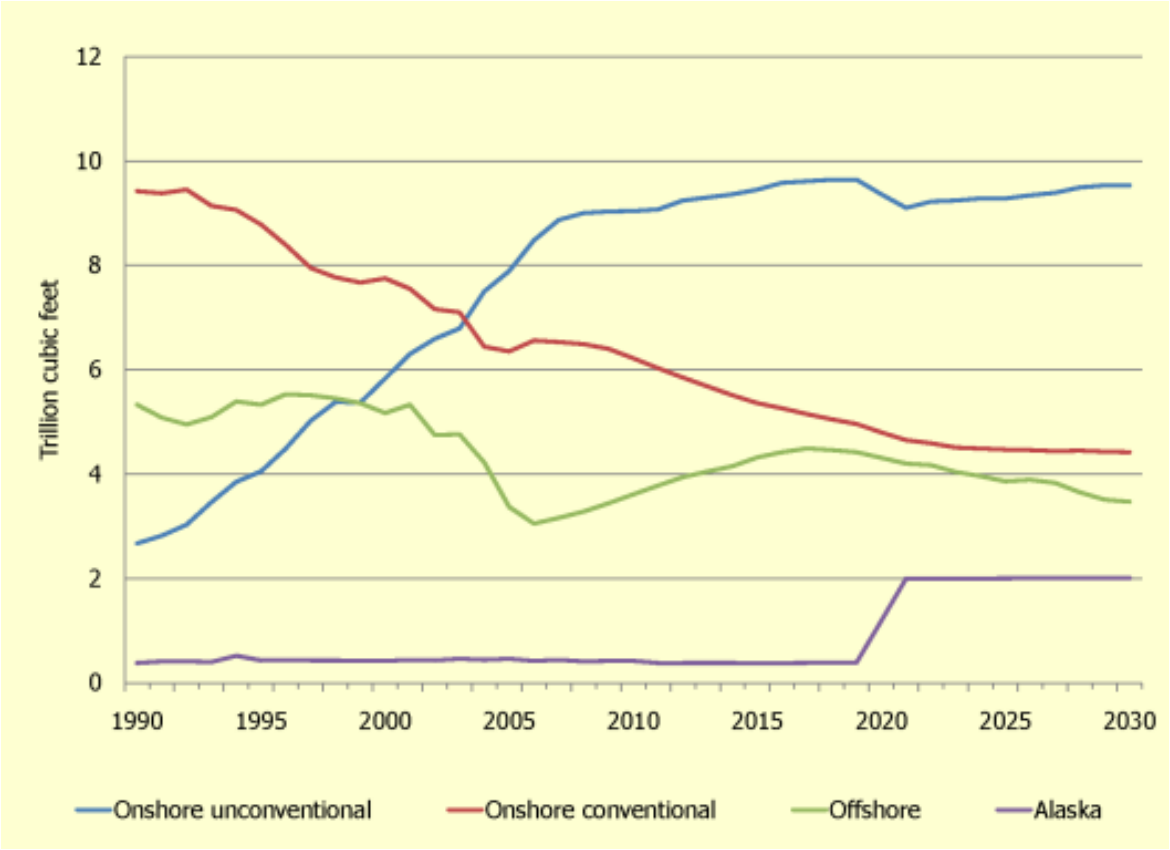
One trillion cubic feet of natural gas is enough gas to:

- Heat 15 million homes for one year
- Generate 100 billion kilowatt-hours of electricity
- Fuel 12 million natural gas-fired vehicles for one year

www.lovekin.co.uk

www.alstom.com

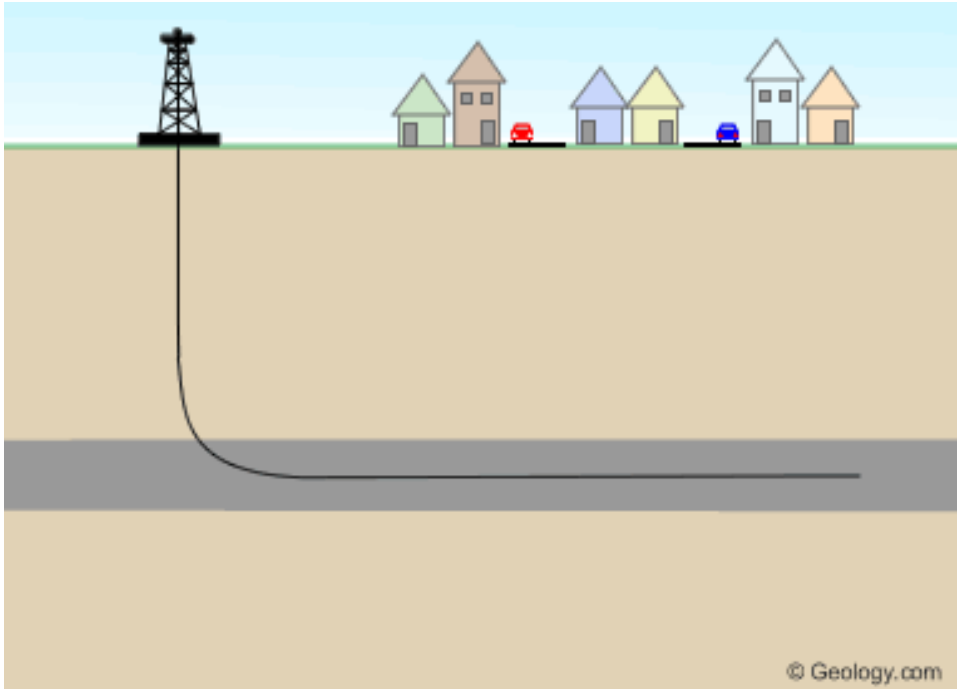
Shale gas production is technically and economically feasible because of:

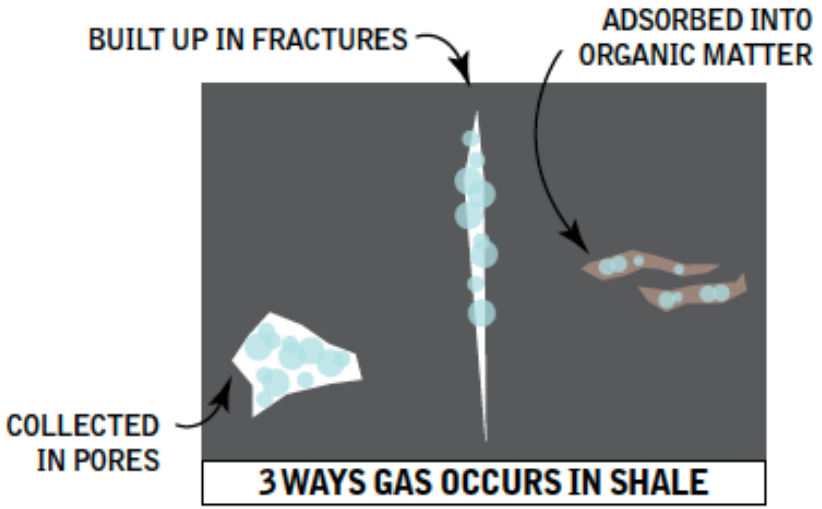


- Horizontal drilling
- Hydraulic fracturing
- Rapid increase in natural gas prices

Source: “MODERN SHALE GAS DEVELOPMENT IN THE UNITED STATES: A PRIMER”. US.DOE/NETL (2009)

Horizontal drilling

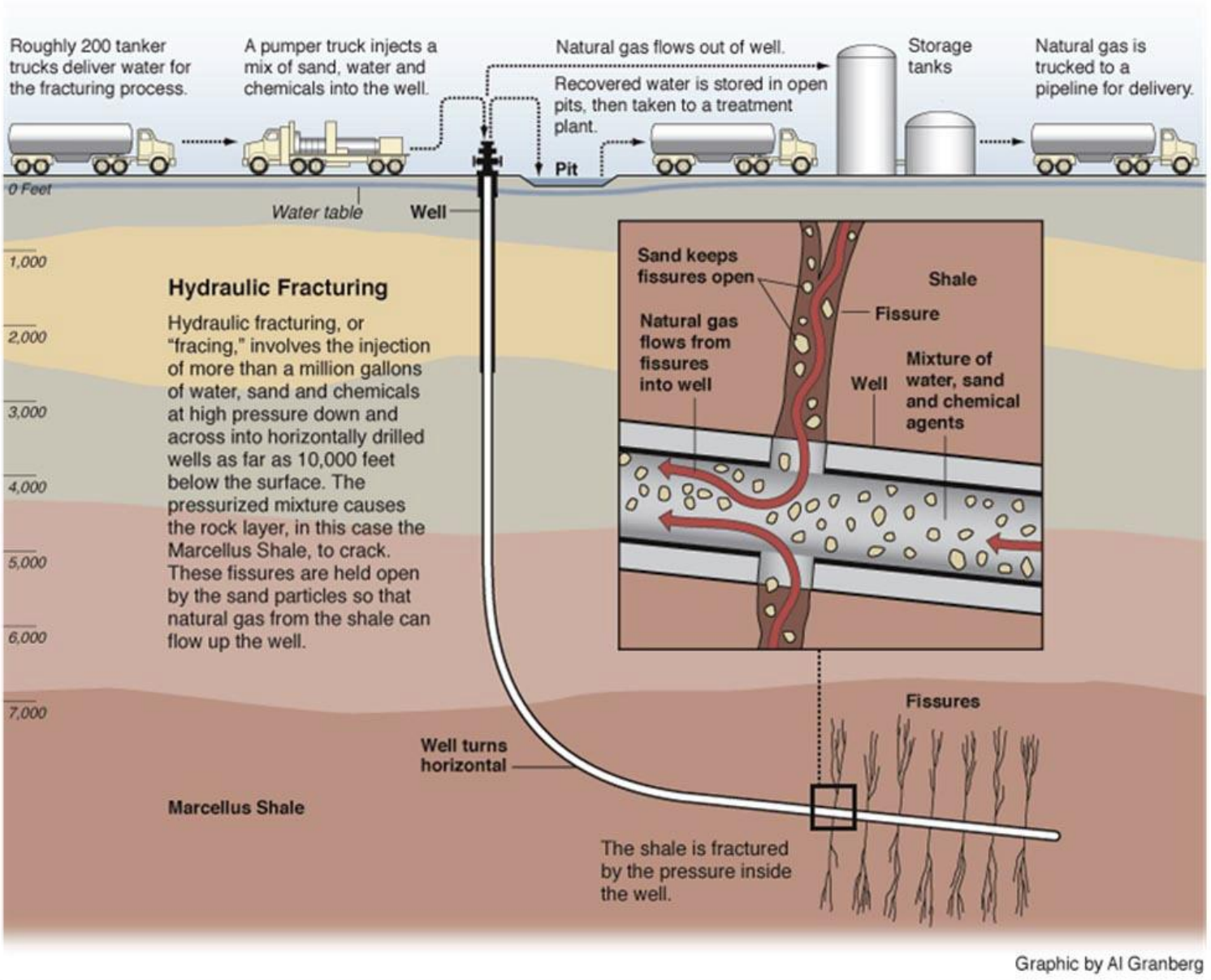




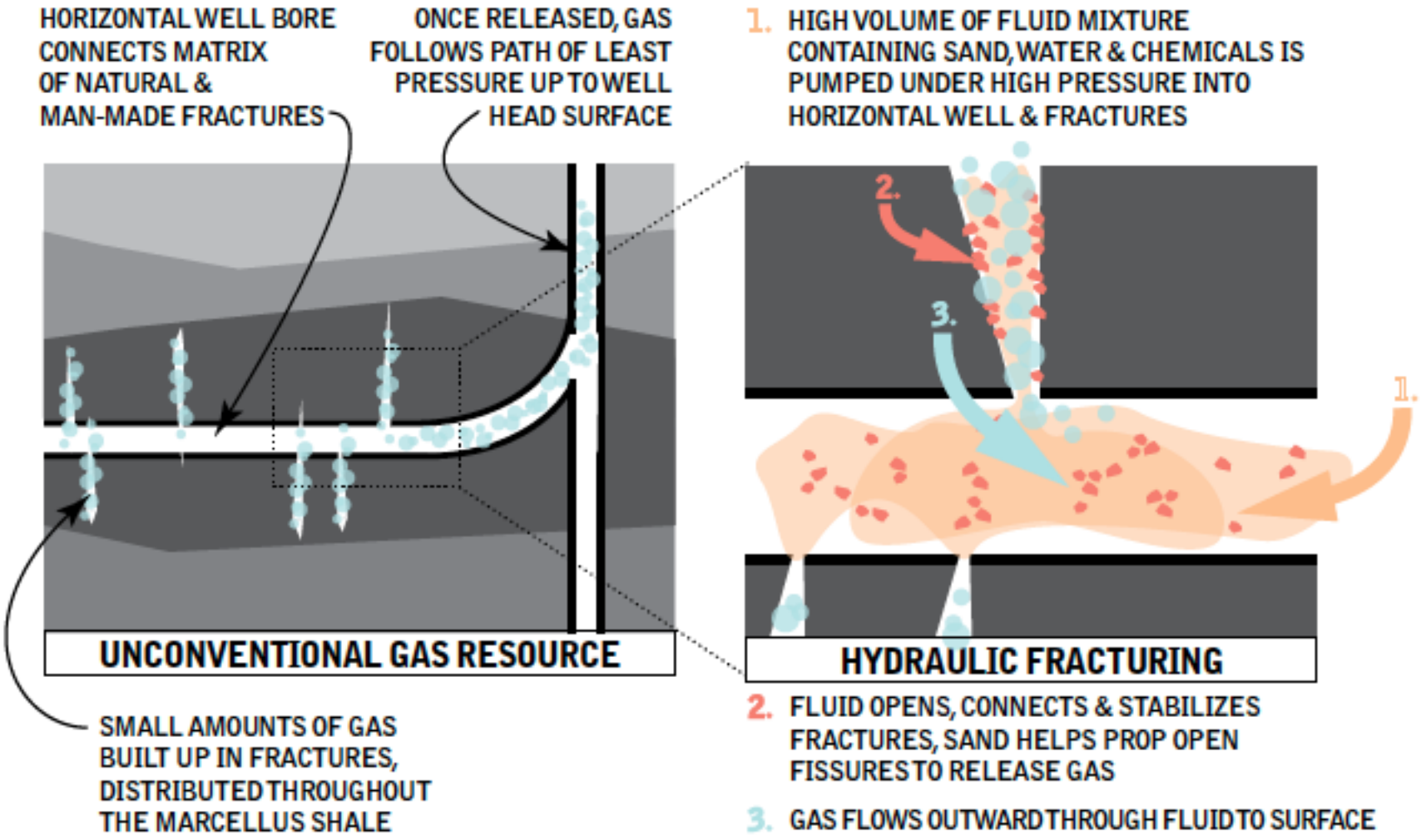
Source: Hancock & The Marcellus Shale. Emily Weidenhof (ed) with V. Ngo and R. Gonzalez. Columbia University Urban Design Research Seminar (2009)

- Hit targets that cannot be reached by vertical drilling
- Increases accessibility within the target rock unit (“pay zone”)
- Reduces surface footprint while increasing the production area from a single drilling pad
- Improve the productivity of wells in fractured reservoirs (e.g. shales)

Hydraulic Fracturing (fracking)



Hydraulic fracturing (HF)

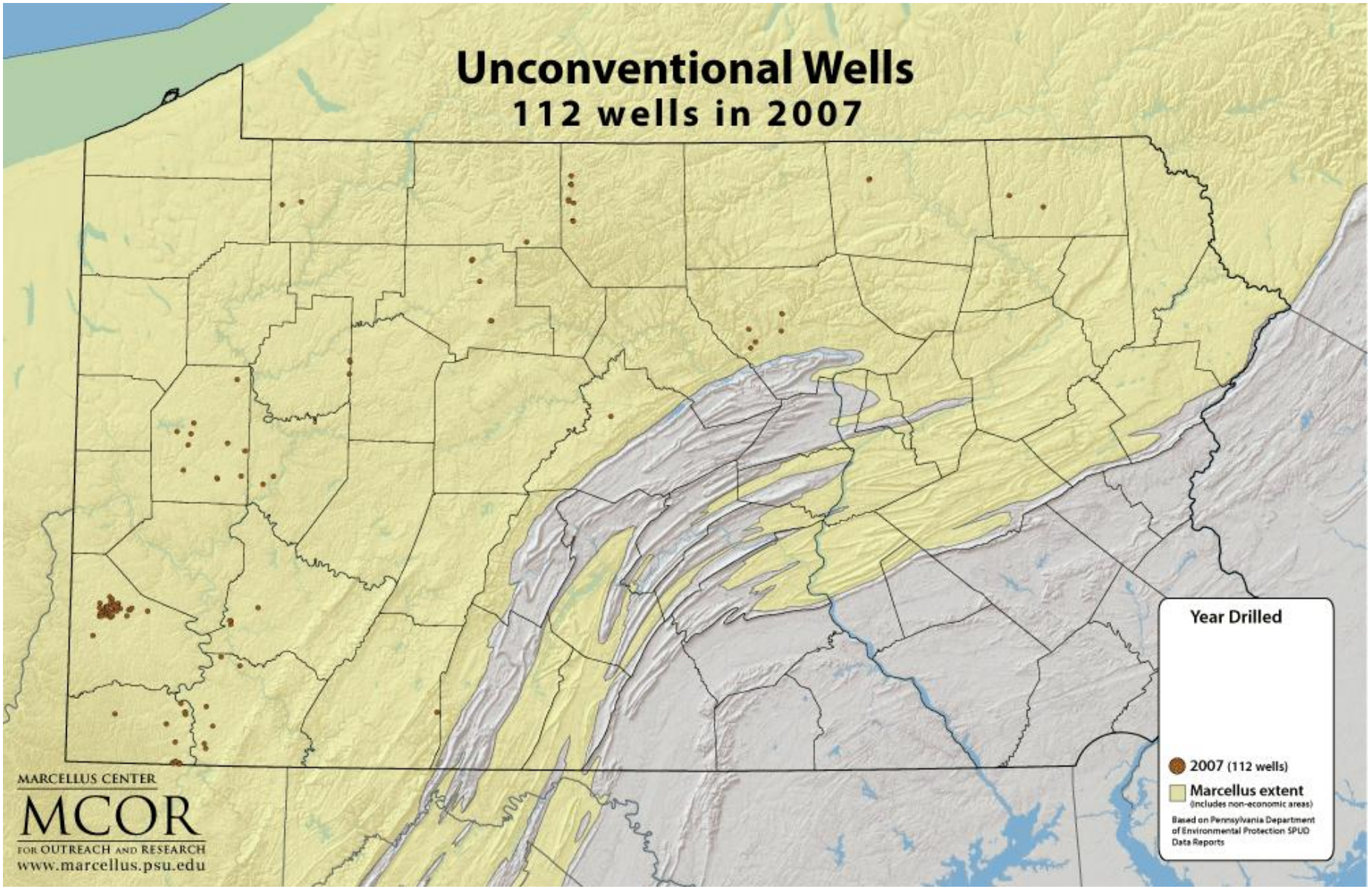


Source: Hancock & The Marcellus Shale. Emily Weidenhof (ed) with V. Ngo and R. Gonzalez. Columbia University Urban Design Research Seminar (2009)

Typical drilling & hydraulic fracturing site

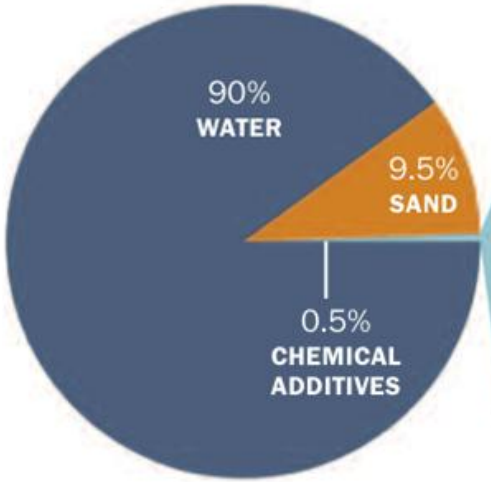
Columbia University Urban Design Research Seminar, 2009
http://www.urbandesignlab.columbia.edu/?pid=gas_extraction

Well Density – Pennsylvania USA



http://www.marcellus.psu.edu/images/well_animation.gif

Composition of Hydraulic Fracturing Fluid



Compound	Purpose	Common application
Acids	Helps dissolve minerals and initiate fissure in rock (pre-fracture)	Swimming pool cleaner
Sodium Chloride	Allows a delayed breakdown of the gel polymer chains	Table salt
Polyacrylamide	Minimizes the friction between fluid and pipe	Water treatment, soil conditioner
Ethylene Glycol	Prevents scale deposits in the pipe	Automotive anti-freeze, deicing agent, household cleaners
Borate Salts	Maintains fluid viscosity as temperature increases	Laundry detergent, hand soap, cosmetics
Sodium/Potassium Carbonate	Maintains effectiveness of other components, such as crosslinkers	Washing soda, detergent, soap, water softener, glass, ceramics
Glutaraldehyde	Eliminates bacteria in the water	Disinfectant, sterilization of medical and dental equipment
Guar Gum	Thickens the water to suspend the sand	Thickener in cosmetics, baked goods, ice cream, toothpaste, sauces
Citric Acid	Prevents precipitation of metal oxides	Food additive; food and beverages; lemon juice
Isopropanol	Used to increase the viscosity of the fracture fluid	Glass cleaner, antiperspirant, hair coloring

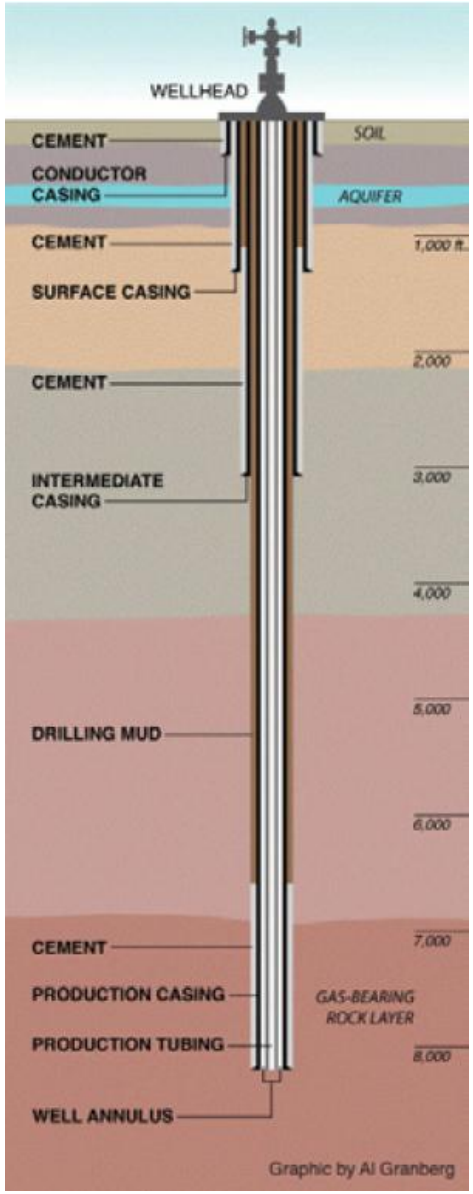
Source: DOE, GWPC: Modern Gas Shale Development in the United States: A Primer (2009).

Water Consumption – Waste Water

Fracking site in Colorado, NY Times, 5/2/2013

- 4,200 gallons per minute -> ~4 million gallons per well
- 10-50% of injected water returns as waste water after pressure release and gas production
- Flowback + produced water:
  - chemical additives from hydraulic fracturing + native chemical compounds from shale formation
  - stored in surface ponds for re-use
  - injection into deep waste disposal wells
  - water treatment plant

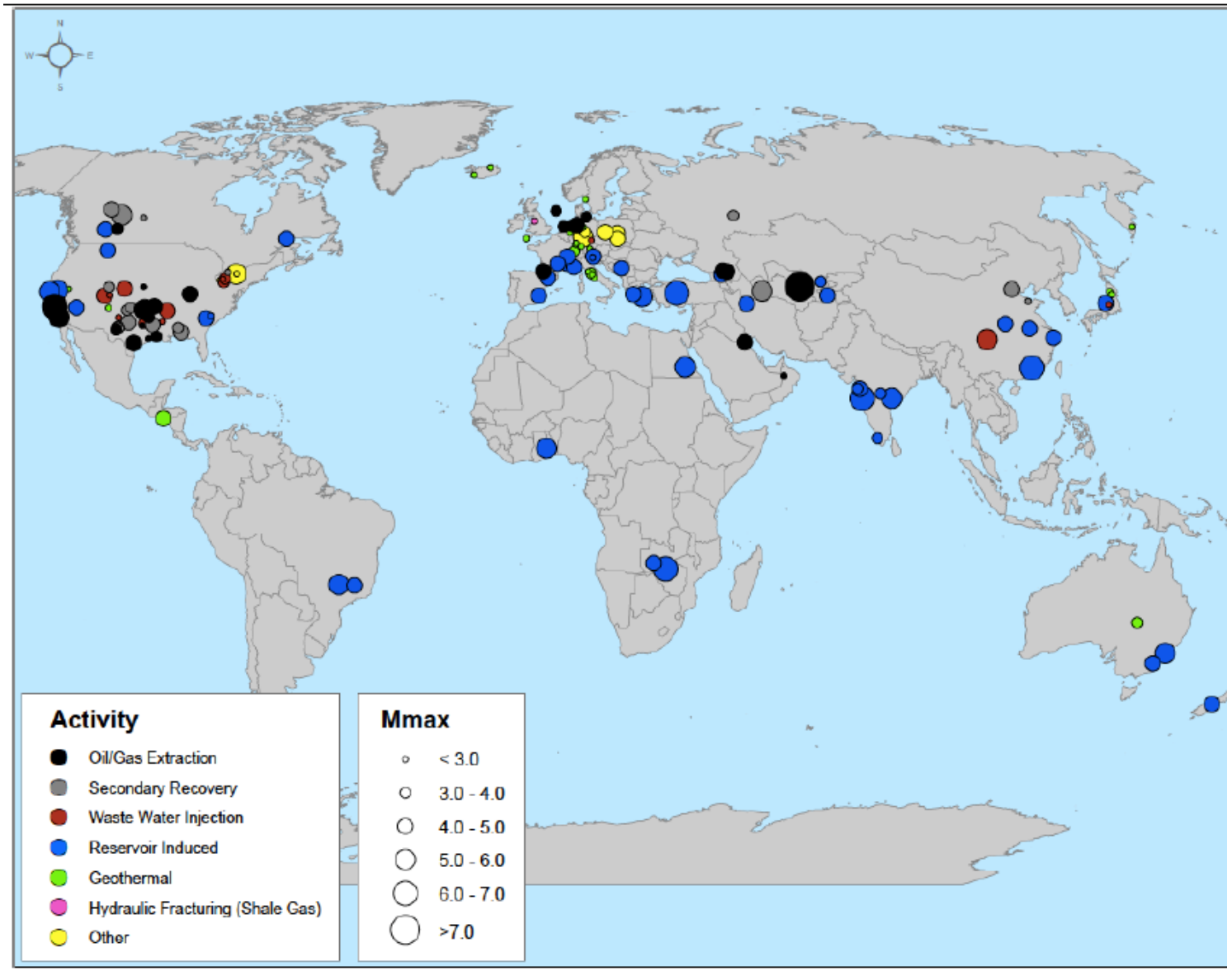
Shale gas well – risk of leakage



e.g. Marcellus Shale gas wells (USA)

- 4,000 wells drilled between 2008-2011
- ~13% of wells had faulty pollution prevention
- ~10% had an actual pollution discharge
- Environmental violations spread unequally amongst gas companies
- Some companies had one violation every 5-10 wells drilled (Staff, 2012)
- Other companies had 2 violations per well (Staff, 2012)

Induced (micro) earthquakes



National Academy of Sciences, 2012

Greenhouse gas emissions

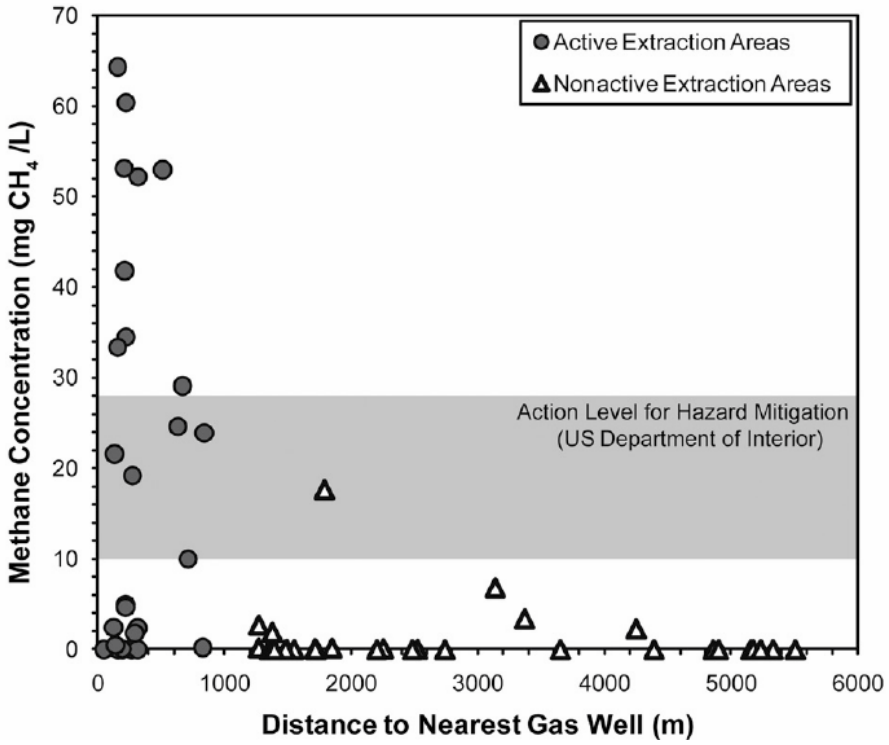
Natural gas is the cleanest fossil fuel

EXHIBIT 4: COMBUSTION EMISSIONS
(POUNDS/BILLION BTU OF ENERGY INPUT)

Air Pollutant	Combusted Source		
	Natural Gas	Oil	Coal
Carbon dioxide (CO_2)	117,000	164,000	208,000
Carbon monoxide (CO)	40	33	208
Nitrogen oxides (NO_x)	92	448	457
Sulfur dioxide (SO_2)	0.6	1,122	2,591
Particulates (PM)	7.0	84	2,744
Formaldehyde	0.750	0.220	0.221
Mercury (Hg)	0.000	0.007	0.016

Source: EIA, 1998

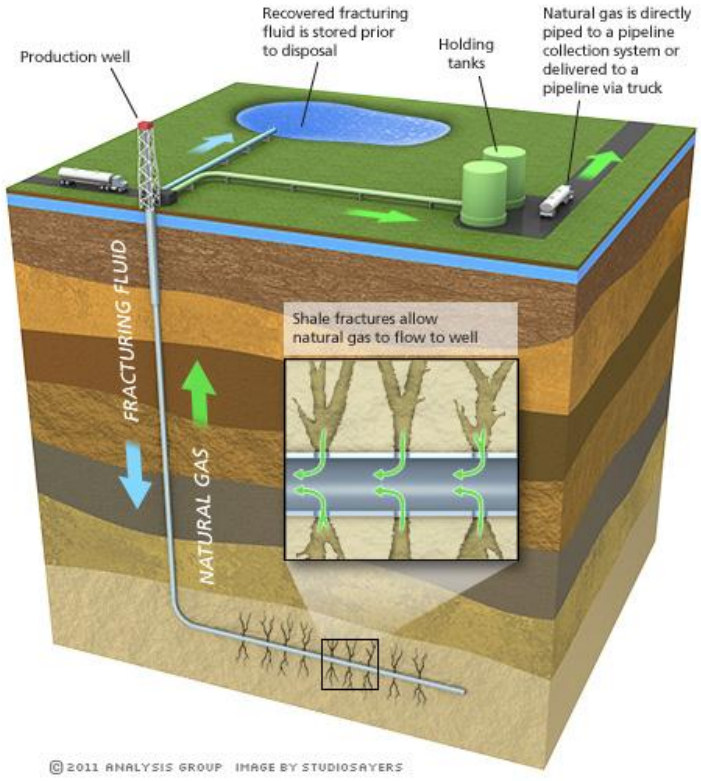
Elevated methane emissions near shale gas production sites



2-8% loss of methane from a typical well

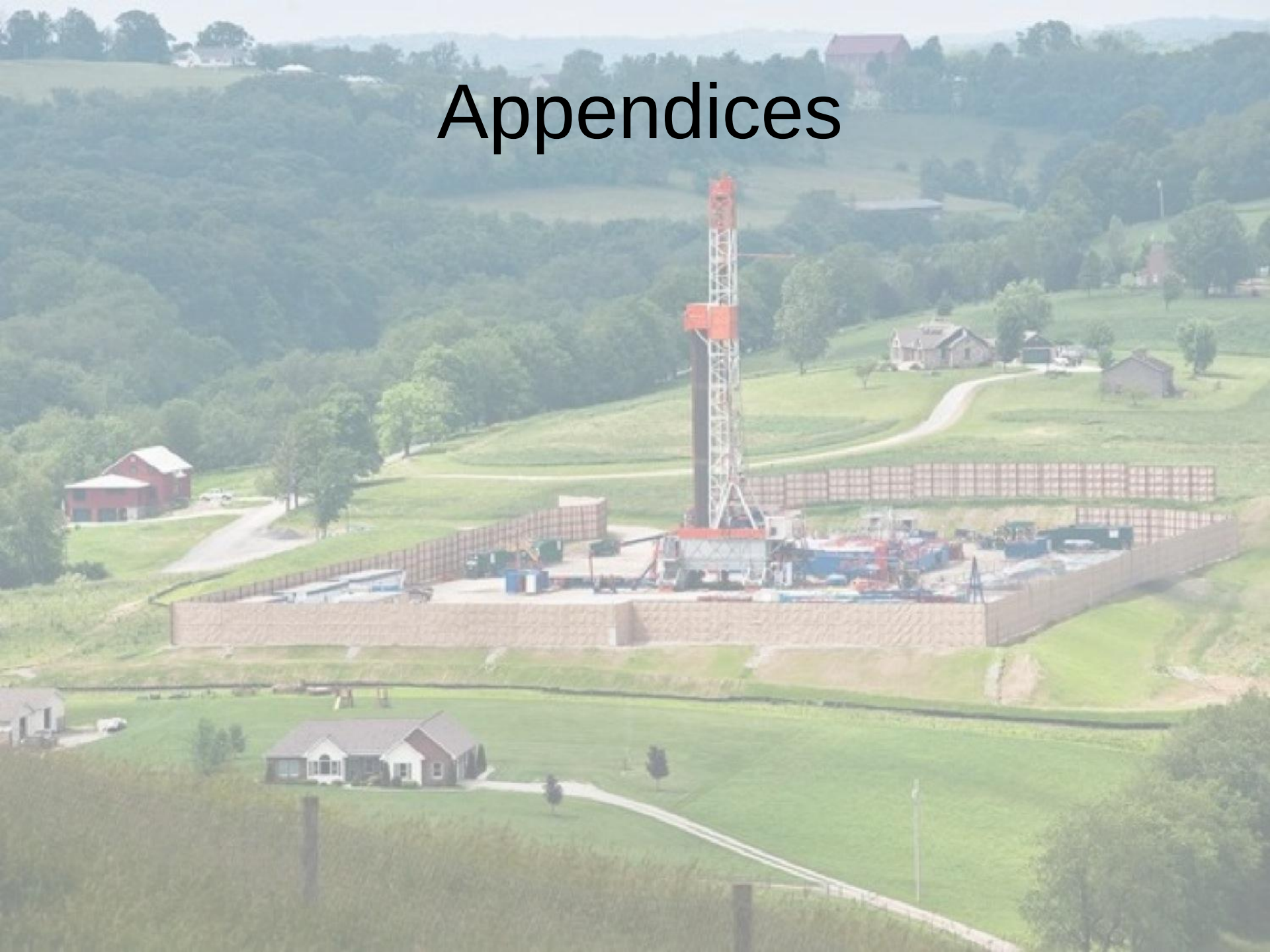
Howarth et al. Climate Change 2001; Cathles et al. G^3, 2012; Osborn et al., PNAS, 2011

Research needs



- develop less hazardous fracking fluids
- reduce amount of water used in the process
- reduce gas leaks
- prevent release of hazardous substances into the environment (water & air)
- evaluate and minimize health effects
- minimize occurrence of micro-earthquakes

Appendices

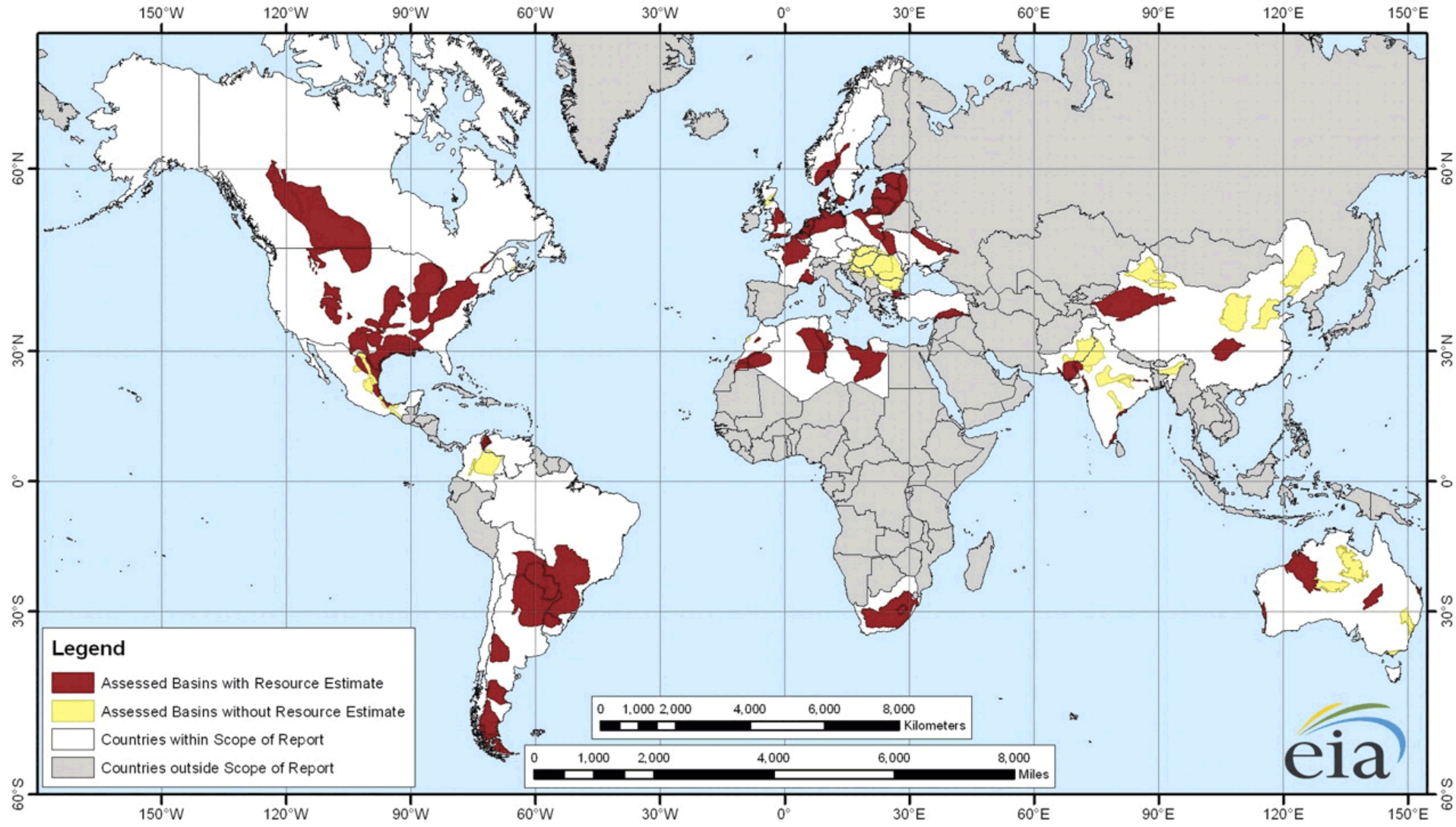


Appendix: History of shale gas

- 1821: First Commercial Gas well – Fredonia, NY
  - Production from “Dunkirk Shale” at a depth of < 30 feet
- 1982: Barnett Shale – Ft. Worth Basin development
- 1980s: Horizontal wells in Ohio Shales
- 1986: First use of hydraulic fracturing in Barnett Shale
- 1992: First horizontal well drilled in Barnett Shale
- 2006: Horizontal drilling in Appalachian Basin Shales

Arthur & Seekins, ALL Consulting, 2010

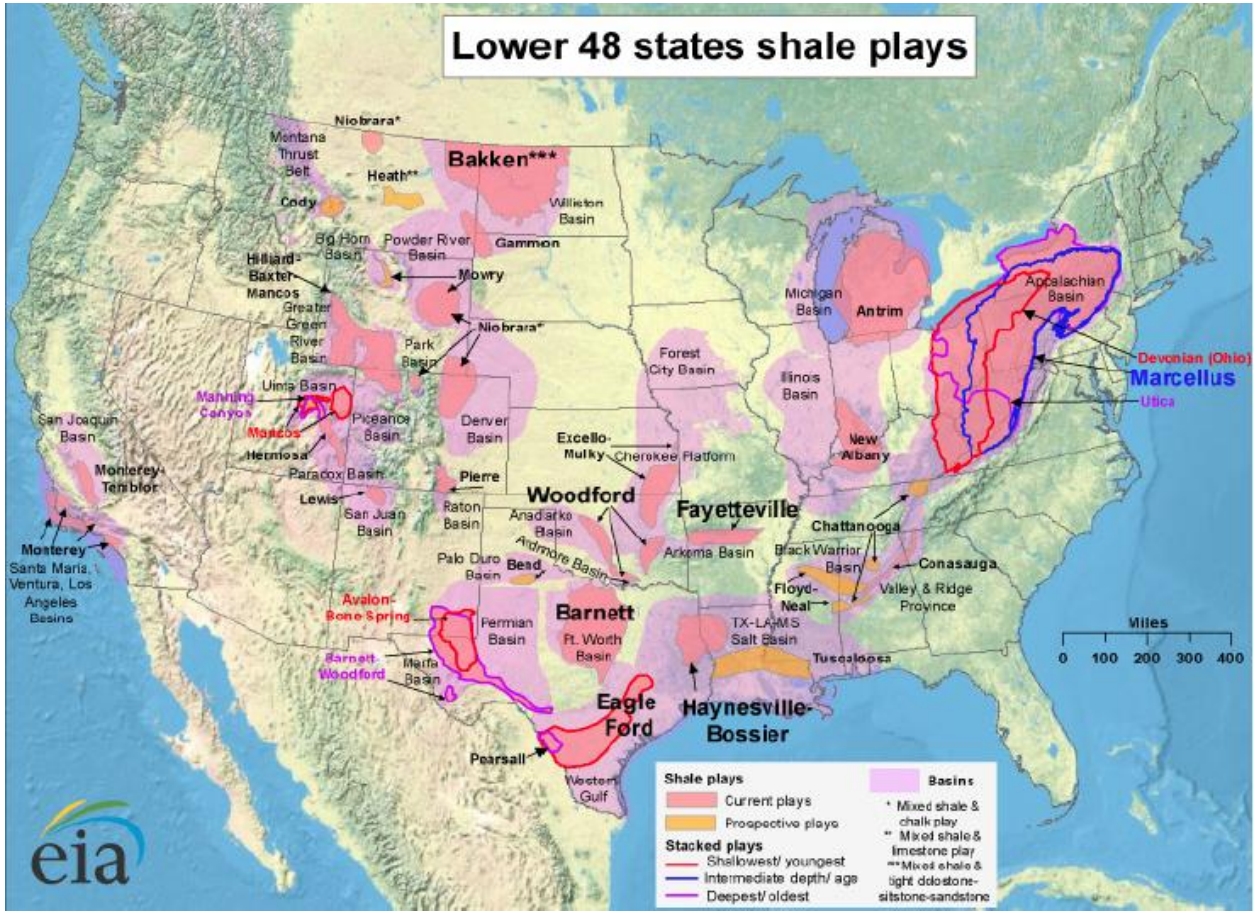
Appendix: Global shale gas resources



China > U.S. > Argentina > Mexico

Energy Information Administration, 2011
http://www.eia.gov/analysis/studies/worldshalegas/

Appendix: Shale gas & oil shales in USA



- ~1,700 trillion cubic feet (Tcf) of technically recoverable natural gas (~60% is unconventional gas)
- US total natural gas consumption in 2012 was 25.46 Tcf (EIA, 2012).

Source: U.S. Energy Information Administration based on data from various published studies.

HF Cocktail

Table 3. Chemicals Components of Concern: Carcinogens, SDWA-Regulated Chemicals, and Hazardous Air Pollutants

Chemical Component	Chemical Category	No. of Products
Methanol (Methyl alcohol)	HAP	342
Ethylene glycol (1,2-ethanediol)	HAP	119
Diesel[19]	Carcinogen, SDWA, HAP	51
Naphthalene	Carcinogen, HAP	44
Xylene	SDWA, HAP	44
Hydrogen chloride (Hydrochloric acid)	HAP	42
Toluene	SDWA, HAP	29
Ethylbenzene	SDWA, HAP	28
Diethanolamine (2,2-iminodiethanol)	HAP	14
Formaldehyde	Carcinogen, HAP	12
Sulfuric acid	Carcinogen	9
Thiourea	Carcinogen	9
Benzyl chloride	Carcinogen, HAP	8
Cumene	HAP	6
Nitrilotriacetic acid	Carcinogen	6
Dimethyl formamide	HAP	5
Phenol	HAP	5
Benzene	Carcinogen, SDWA, HAP	3
Di (2-ethylhexyl) phthalate	Carcinogen, SDWA, HAP	3
Acrylamide	Carcinogen, SDWA, HAP	2
Hydrogen fluoride (Hydrofluoric acid)	HAP	2
Phthalic anhydride	HAP	2
Acetaldehyde	Carcinogen, HAP	1
Acetophenone	HAP	1
Copper	SDWA	1
Ethylene oxide	Carcinogen, HAP	1
Lead	Carcinogen, SDWA, HAP	1
Propylene oxide	Carcinogen, HAP	1
p-Xylene	HAP	1
Number of Products Containing a Component of Concern		**652**

Table 1. Chemical Components Appearing Most Often in Hydraulic Fracturing Products Used Between 2005 and 2009

Chemical Component	No. of Products Containing Chemical
Methanol (Methyl alcohol)	342
Isopropanol (Isopropyl alcohol, Propan-2-ol)	274
Crystalline silica - quartz (SiO2)	207
Ethylene glycol monobutyl ether (2-butoxyethanol)	126
Ethylene glycol (1,2-ethanediol)	119
Hydrotreated light petroleum distillates	89
Sodium hydroxide (Caustic soda)	80

The oil and gas service companies used hydraulic fracturing products containing 29 chemicals that are

(1) known or possible human carcinogens,

(2) regulated under the Safe Drinking Water Act for their risks to human health, or

(3) listed as hazardous air pollutants under the Clean Air Act