### Pipeline accidents and explosions happen, due to large leaks.... ..... small leaks are ubiquitous. 500,000

400,000

300,000

Pipelines in US are old!



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. <u>Unconventional gas</u> (shale gas and gas from tight sands), estimates of methane emissions from <u>upstream</u> (at the well site) plus <u>midstream</u> (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 %	Emissions at well site
Hultman et al. (2011)	2.8 %	shale gas and other
Burnham et al. (2011)	1.3 %	unconventional gas
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%)

\* 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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Hultman et al. (2011)	2.8 %	
Burnham et al. (2011)	1.3 %	
Stephenson et al. (2011)	0.6 %	Direct, landscape scale
Cathles et al. (2012)	0.9 %	measurements!!
Petron et al. (2012)	4.0 %	("best estimate;" range = 2.3 to 7.7%)

\* 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)
- Lelieveld et al. (2005)
- Jamarillo et al. (2007)
- Howarth et al. (2011)
- Hughes (2011)
- Venkatesh et al. (2011)
- Jiang et al. (2011)
- Wigley (2011)
- Fulton et al. (2011)
- Stephenson et al. (2011)
- Hultman et al. (2011)
- Skone et al. (2011)
- Burnham et al. (2011)
- Cathles et al. (2012)

**0 to 100 years** 20 & 100 years 100 years 20 & 100 years **20 & 100 years** 100 years 100 years **0 to 100 years** 100 years 100 years 100 years 100 years 100 years

100 years

High potential for massive emissions of ancient CH<sub>4</sub> due to thawing permafrost and release of "frozen" methane (methane hydrates and clathrates).

CH,

Zimov et al. (2006) Science

**CH**<sub>₄</sub>

**CH**<sub>₄</sub>





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<sup>1,\*</sup>, Makiko Sato<sup>1</sup>, Pushker Kharecha<sup>1</sup>, Gary Russell<sup>1</sup>, David W. Lea<sup>2</sup> and Mark Siddall<sup>3</sup>

<sup>1</sup>NASA Goddard Institute for Space Studies and Columbia University Earth Institute, 2880 Broadway, New York, NY 10025, USA <sup>2</sup>Department of Earth Science, University of California, Santa Barbara, CA 93106, USA <sup>3</sup>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 smal increasingly replaces will grow! (40% to 60	l part of gas in 2009. conventional gas, m 0% greater emissions	As shale gas ethane 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<sup>3</sup> ft<sup>3</sup>

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 <u>4 technologies only recently combined</u> to make gas production from shales technically and economically feasible.
- <u>Directional drilling</u>: needed to access a thin layer of shale with long laterals.
- <u>High frac fluid volumes</u>: needed to stimulate gas release from many existing fractures.
- <u>Slickwater</u>: 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.
- <u>Multi-well Pads and Cluster Drilling</u>: needed to access as much of the gas inventory as possible, under constraints of leasing and capital.

# <u>High Volume, Slickwater Fracing from</u> <u>Long Laterals (HVSFLL): The Concept</u>



### 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 <u>Spatially Intense Development</u>: Dallas/Fort Worth Airport Property, Barnett Shale Play



- 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 <sup>14</sup>		
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 <sup>15</sup>	
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 <u>Well</u>?

- 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

### 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**





TARGET PRODUCING ZONE



CONDUCTOR PIPE SURFACE CASING **PRODUCTION CASING** 

Southwestern Energy

TARGET PRODUCING ZONE



INTERMEDIATE PRODUCING ZONE

SHALLOW PRODUCING ZONE

FRESH WATER AQUIFER ZONE

PRESSURE BUILDS UP

### **INSUFFICIENT CEMENT COVERAGE**



### New Scientific Data on Methane Contamination of Water Wells



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

Stephen G. Osborn<sup>a</sup>, Avner Vengosh<sup>b</sup>, Nathaniel R. Warner<sup>b</sup>, and Robert B. Jackson<sup>a,b,c,1</sup>

<sup>a</sup>Center on Global Change, Nicholas School of the Environment, <sup>b</sup>Division of Earth and Ocean Sciences, Nicholas School of the Environment, and <sup>c</sup>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



### World's Largest Frac Job ?????





# Horn River Area, NE British Columbia

### **Two Island Lake Operations Status**





# Encana Says "No!" This One Is It

417 million gallons of water
78,400 tons of sand
8 million gallons of fracing chemicals
500 frac intervals
10,000 foot laterals
40,000 hp for fracing pumps



# 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



Physicians Scientists & Engineers for Healthy Energy

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#### What's Hot

Physician Sign-On Letter to Governor Cuomo 10/5/11 October 5, 2011. Sign-on Letter to Governor of New York State. Andrew Cuomo regarding human health impacts of high-volume hydraulic fracturing. Read More

Should Fracking Stop? Extracting gas from shale increases the availability of this resource, but the health and environmental risks may be too high.

Point and counterpoint commentary provided by Howarth, Ingraffea, & Engelder on natural gas extraction of shale formations in Nature. Read More

#### Sign-On Letter to Governor Cuomo 9/15/11

This letter was initiated by Dr. Robert Howarth and signed by fifty-nine scientists from around the world with expertise in water treatment systems, aquatic chemistry or biogeochemistry. and/or with the movement and fate of toxic or radioactive materials

PSE is dedicated to supplying vetted, evidence-based, scientific information and resources on unconventional gas development (high-volume hydrofracking) and other novel energy production methods. PSE's mission is to bring transparency to the important public policy issues surrounding such methods, helping to level the plaving field for citizens, advocacy groups, media, policymakers and politicians.

#### News for 10/5/11:

The physician sign-on letter sent to Governor Andrew M. Cuomo with regard to the revised draft of the Supplemental Generic Environmental Impact Statement (SGEIS) can be found here.

The letter's associated press release can be found here.

In other news:

#### Dr. Robert Howarth is in Brussels this week to discuss the impacts of shale gas development in European Parliament.

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The information and resources on this website have been carefully evaluated and categorized to help you judge their merit. Our LIBRARY contains only peer-reviewed journal papers or reports. NEWS & VIEWS contains written commentaries and presentations from identified individuals we deem qualified to be read and heard. RESOURCES includes a variety of information and links to other qualified and relevant data sources, institutes, and reports.

#### Featured Articles

ANALYSIS , PEER REVIEWED

#### Methane and the Greenhouse-Gas Footprint of Natural Gas from Shale Formations

Climatic Change Letters, Springer Publishing Volume 106, Number 1, April 14, 2011

Robert W. Howarth, Ph.D.; Renee Santoro, Ph.D.; Anthony Ingraffea, Ph.D. Shale gas has a greenhouse gas footprint that is at least 20% greater and perhaps more than twice as great as coal on a 20-year horizon. ...read more.

#### PRESENTATION, ANALYSIS

#### How Environmental Contamination Can Impact Human Health, the Endocrine System in Particular

The Health Implications of Hydrofracking, Upstate Medical University Public Health Symposium April 13, 2011

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author, and

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EARTHWORKS' Oil & Gas Accountability Project works with tribal, urban and rural communities to protect their homes and the environment from the devastating impacts of oil and gas development. Learn more.

#### HOT ISSUES

Mining Reform

#### New Mexico showdowns over common sense drilling protections: drilling rules under attack in court and legislature

*Feb 22* -- The battle over New Mexico's landmark Pit Rule -- the nation's most protective measure to safeguard citizens, water and land from hazardous oil and gas drilling wastes -- is building to a showdown in the courthouse and the Roundhouse (NM's Capitol).

The Albuquerque Journal's recent story gives some political context to the showndown.

in fact, common sense. And why industry's arguments against it are bunk.

newmexicocommonsense.org provides fact sheets that explain why New Mexico's pit rule is,

In December District Judge Barbara Vigil heard arguments from the New Mexico Oil and Gas Association, which is seeking to overturn the Pit Rule in its entirety. Tomorrow (2/23) she will hear

#### COMMUNITY VOICES

Places and Projects

#### Buffalo, WY

"Reaching an Agreement: Luck of the Draw" provides an account of Pete Dube's efforts to achieve a Surface Use Agreement with a company. Even with that agreement, he struggled to get the company to deal with methane gas that started seeping into his stock well soon after the company drilled a CBM well on a neighbor's property.

#### PUBLICATIONS

Joint letter to House

## Where Can You Find Reliable Information?

### http://www.earthworksaction.org/oil\_and\_gas.cfm



#### Rule. More info:

Read our press release.

SIT THE SITE





On November 19th and 20th, the 2010 National People's Oil & Gas Summit was held in Pittsburgh, Pennsylvania, the heart of the Marcellus Shale natural gas drilling boom.

Background on what the New Mexico pit rule is.

The Summit was a huge success with more than 250 citizens from 26 states and Canada joining together to share information, stories, and strategies.



Register for the National People's Oil and Gas Summit PITTSBURGH, PENNSYLVANIA estate amendment. Vote "yes" on passage HR 3534

#### Oil and Gas Pollution Fact Sheet

Contaminants associated with the various stages of oil and gas development

#### Our Drinking Water at Risk

What EPA and the Oil and Gas Industry Don't Want Us to Know About Hydraulic Fracturing. (Full Report)

#### Oil and Gas at Your Door? (2005 Edition)

A landowner's guide to oil and gas development.

Click here to view the agenda and download copies of presentations and materials from the 2010 National People's Oil & Gas Summit. (Video clips from the Summit will be available

# **MIT Study On Economics of Shale Gas**



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



ind others Get \$ quick. Top \$ Paid

ure ouca can be less than 3000 leet below the Marcellus.

Roadside Geology Rock & Mineral Books

[4].

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