Cornell University
College of Agriculture and Life Sciences

Methane emissions make shale gas a bridge to nowhere

Robert Howarth

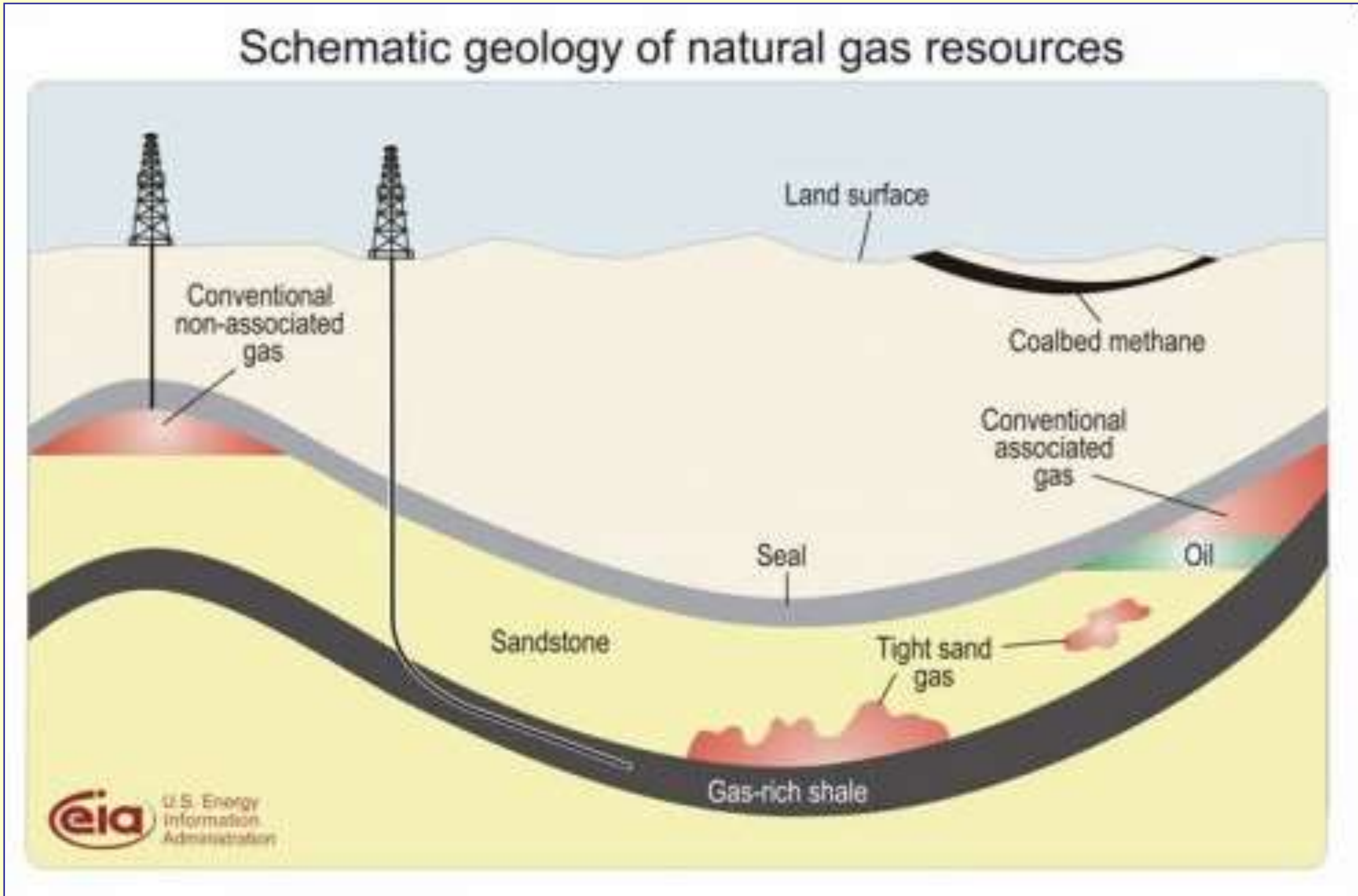
The David R. Atkinson Professor of Ecology & Environmental Biology

Cornell University, Ithaca, NY USA

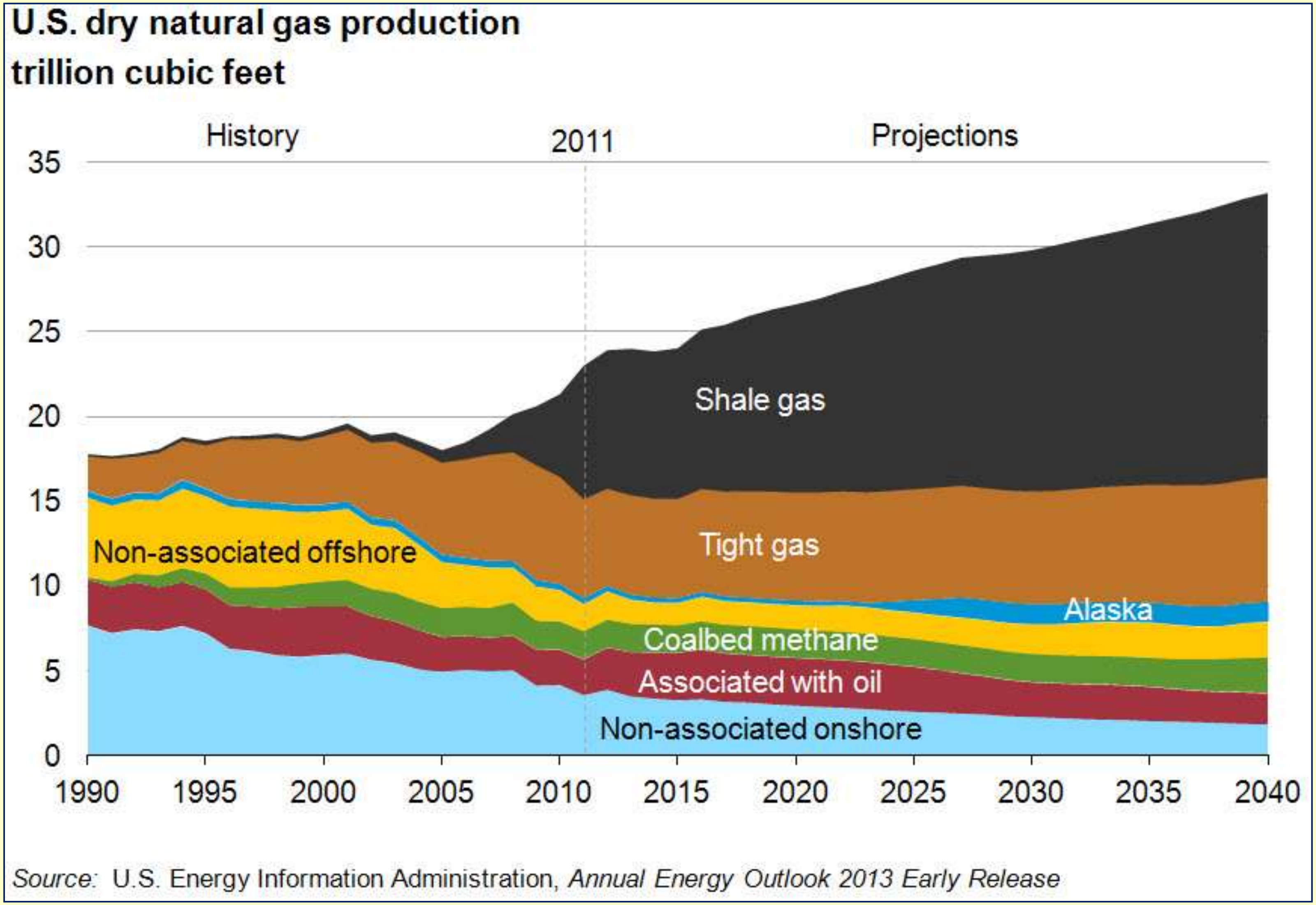
5-College Program Geology Lecture

Smith College

March 3, 2015

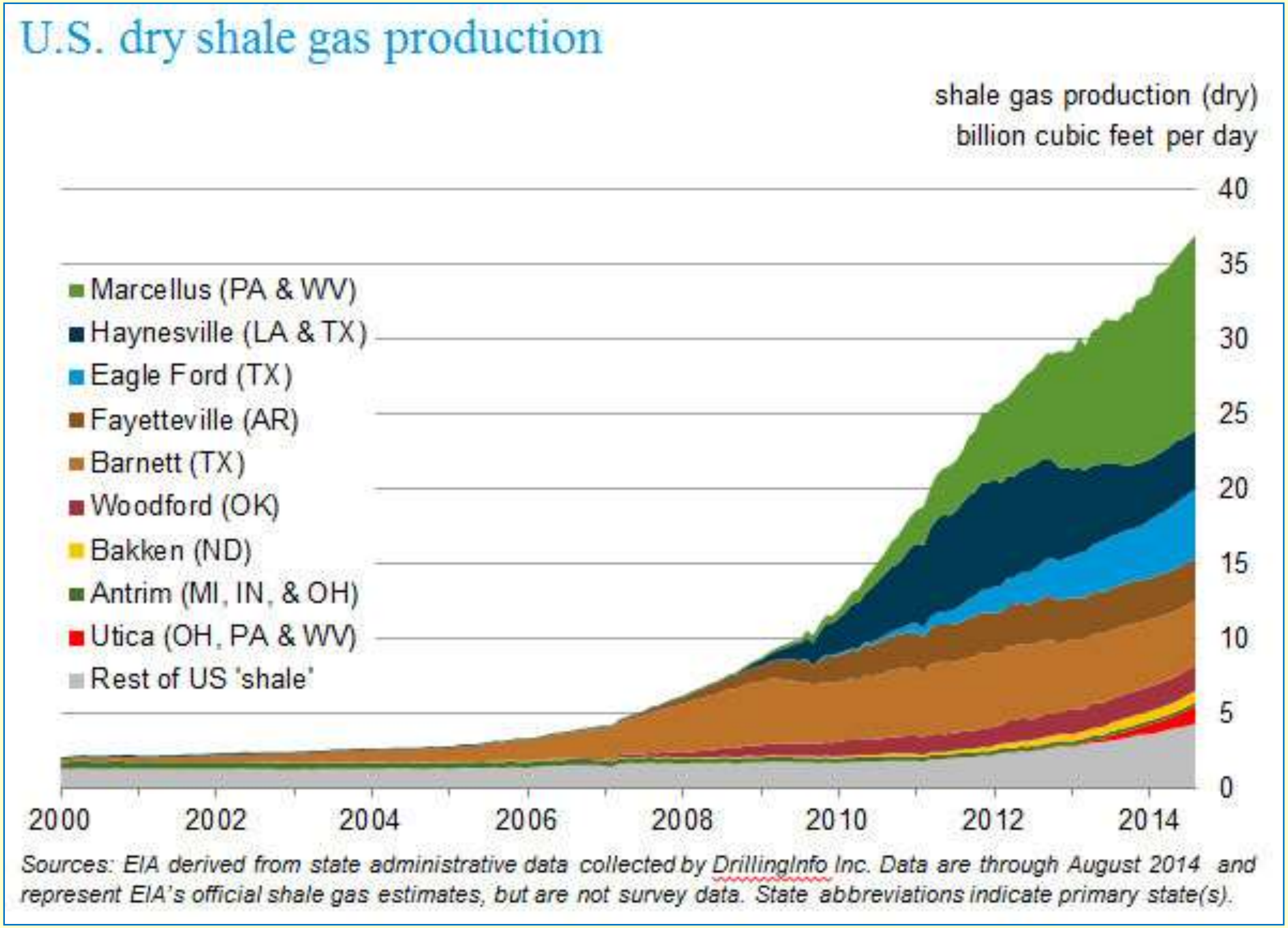

Schematic geology of natural gas resources
Land surface
Conventional non-associated gas
Coalbed methane
Conventional associated gas
Seal
Oil
Sandstone
Tight sand gas
Gas-rich shale
U.S. Energy Information Administration

Increasing supply of natural gas comes from shale gas….

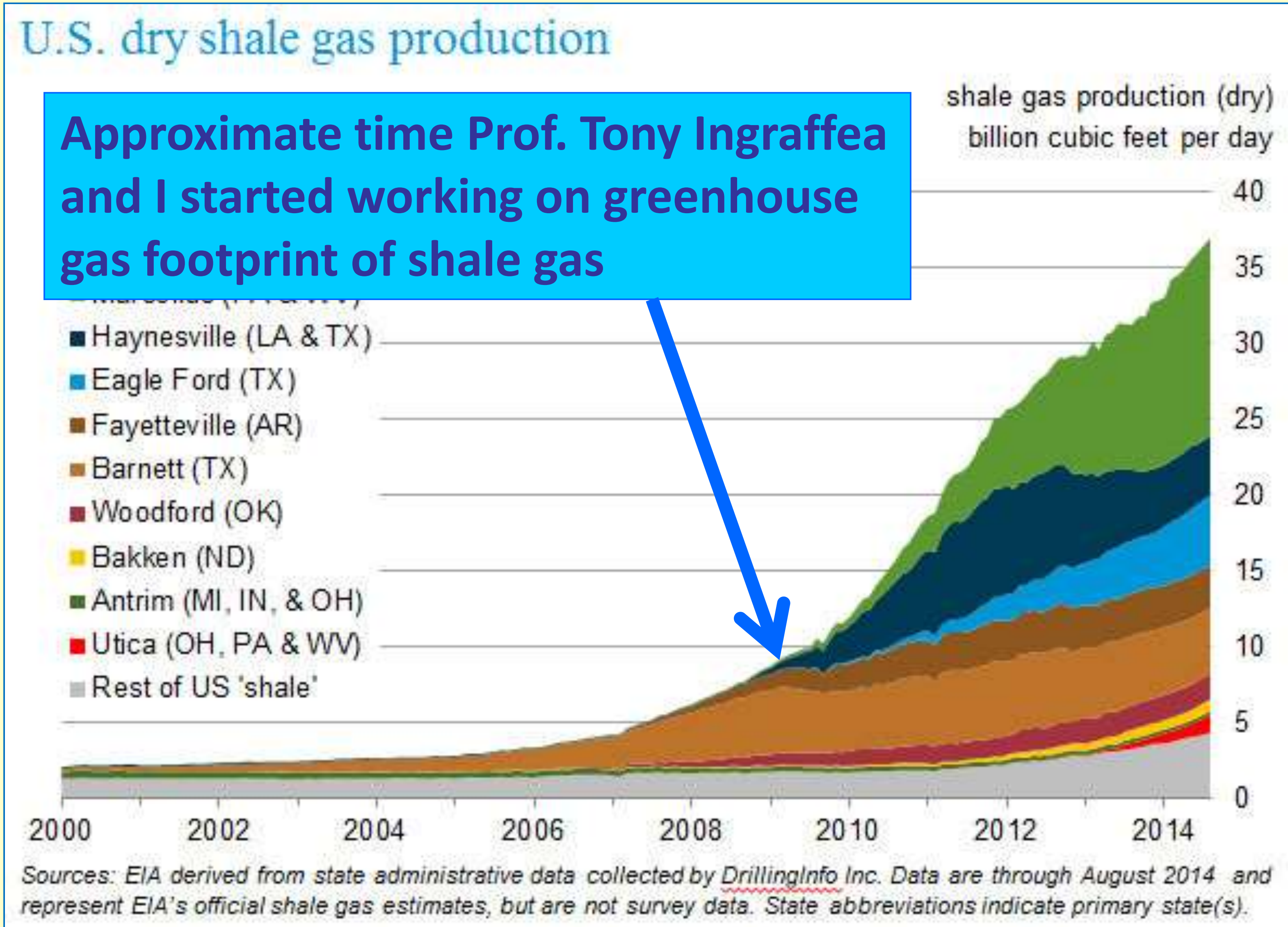


Downloaded 11-4-13: http://www.eia.gov/energy_in_brief/article/about_shale_gas.cfm

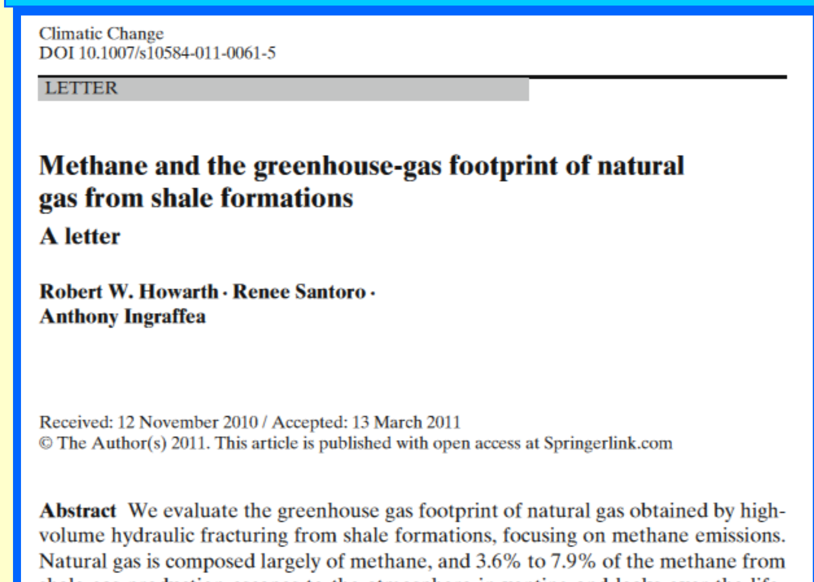
Shale gas is new, the science behind it is new …..



Approximate time Prof. Tony Ingraffea and I started working on greenhouse gas footprint of shale gas



Publication of first peer-reviewed paper on any aspect of environmental risk of shale gas (Howarth, Santoro, & Ingraffea 2011)



Climatic Change
DOI 10.1007/s10584-011-0061-5

LETTER

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

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Robert W. Howarth · Renee Santoro · Anthony Ingraffea

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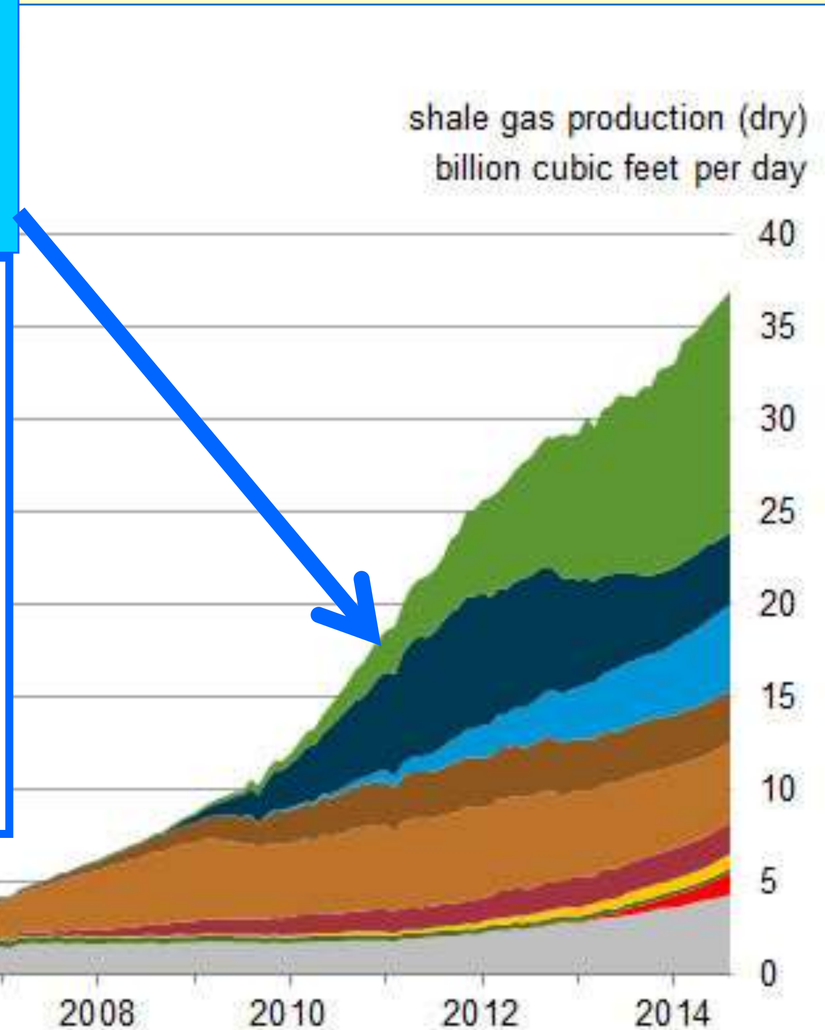
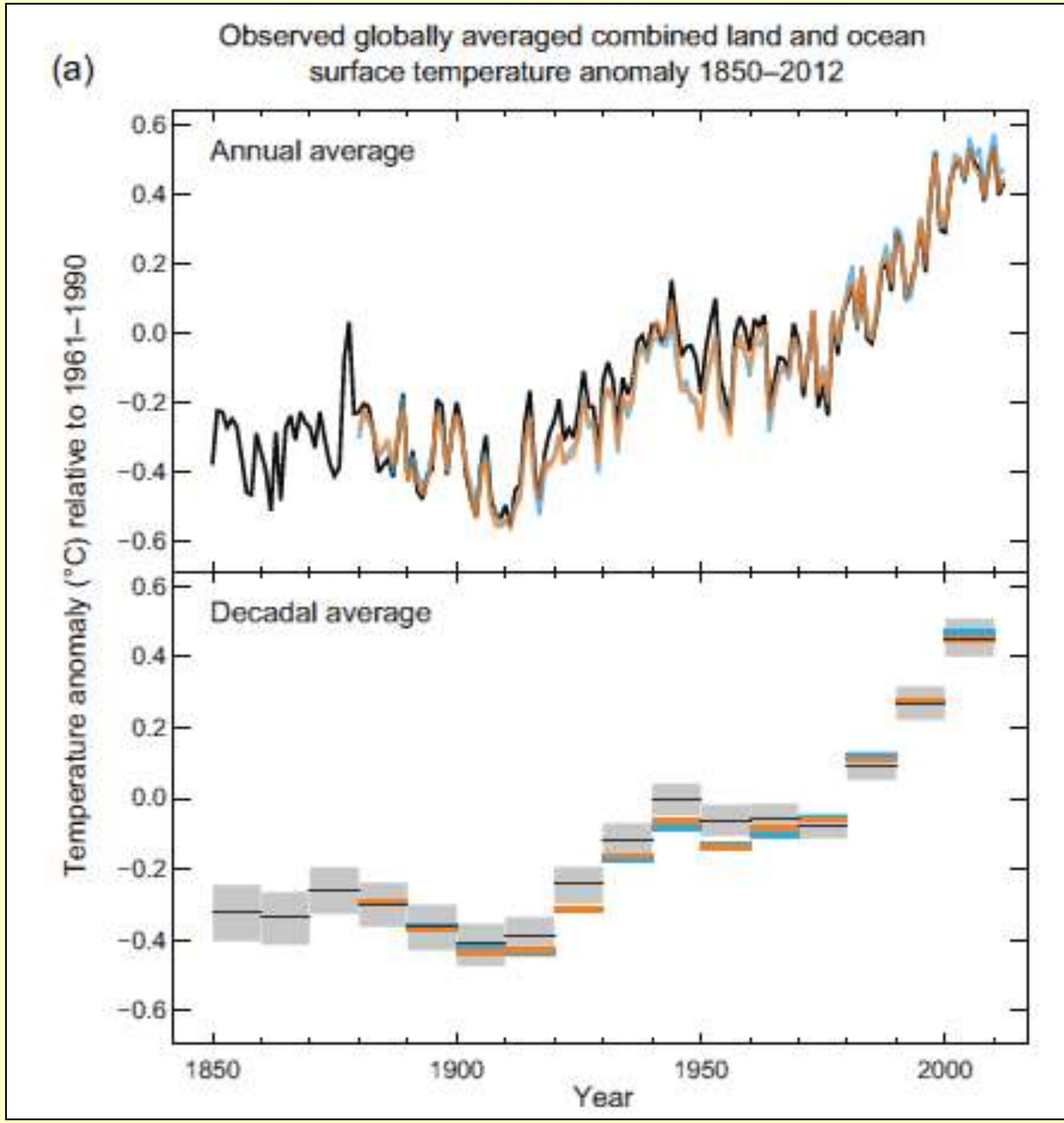


Sources: EIA derived from state administrative data collected by DrillingInfo Inc. Data are through August 2014 and represent EIA's official shale gas estimates, but are not survey data. State abbreviations indicate primary state(s).

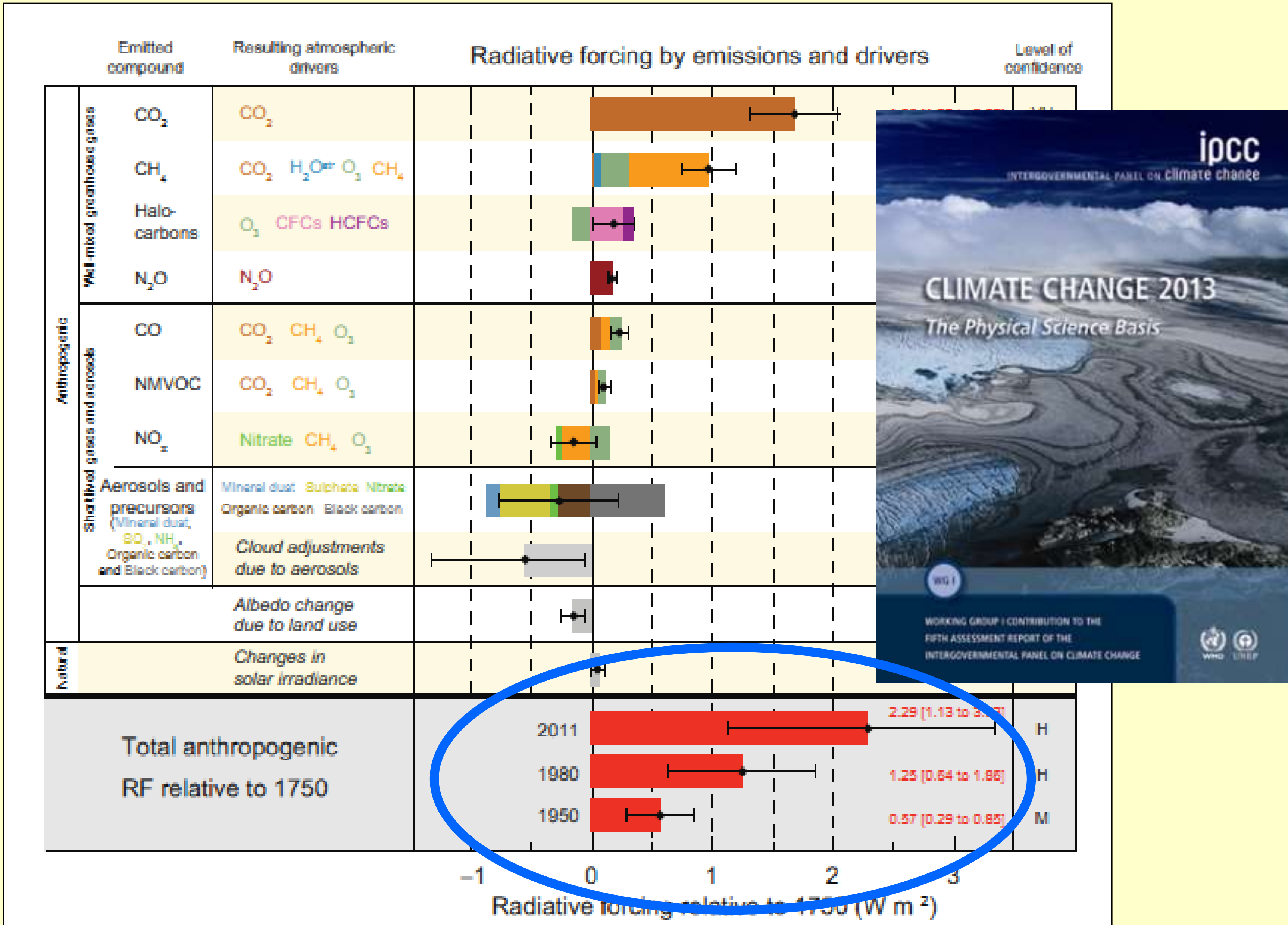
Many environmental issues:

- **Local air quality (ozone, benzene, etc.)**
- **Leaking of well casings (30%), groundwater**
- **Disposal of frack-return fluids**
- **Disposal of drill cuttings and drill muds**
- **Radon in natural gas**
- **GREENHOUSE GAS EMISSIONS**



Each of the past 3 decades has consecutively been the warmest in past 120,000 years.

Rate of warming is the fastest ever on Earth.


Emitted compound
Resulting atmospheric drivers
Radiative forcing by emissions and drivers
Level of confidence
Anthropogenic
Well-mixed greenhouse gases
Short lived gases and aerosols
Natural
CO2
CH4
Halo-carbons
N2O
CO
NMVOC
NOx
Aerosols and precursors (Mineral dust, SO2, NH3, Organic carbon and Black carbon)
CO2 H2Ostr O3 CH4
O3 CFCs HCFCs
CO2 CH4 O3
Nitrate CH4 O3
Mineral dust Sulphate Nitrate Organic carbon Black carbon
Cloud adjustments due to aerosols
Albedo change due to land use
Changes in solar irradiance
Total anthropogenic RF relative to 1750
2011
1980
1950
2.29 [1.13 to 3.33]
1.25 [0.64 to 1.86]
0.57 [0.29 to 0.85]
H
H
M
−1
0
1
2
3
Radiative forcing relative to 1750 (W m⁻²)
ipcc
INTERGOVERNMENTAL PANEL ON climate change
CLIMATE CHANGE 2013
The Physical Science Basis
WG I
WORKING GROUP I CONTRIBUTION TO THE FIFTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
WMO
UNEP

Is natural gas a "bridge fuel?"

For just the release of carbon dioxide during combustion…..

	g C of CO_2 MJ^{-1} of energy
Natural gas	15
Diesel oil	20
Coal	25

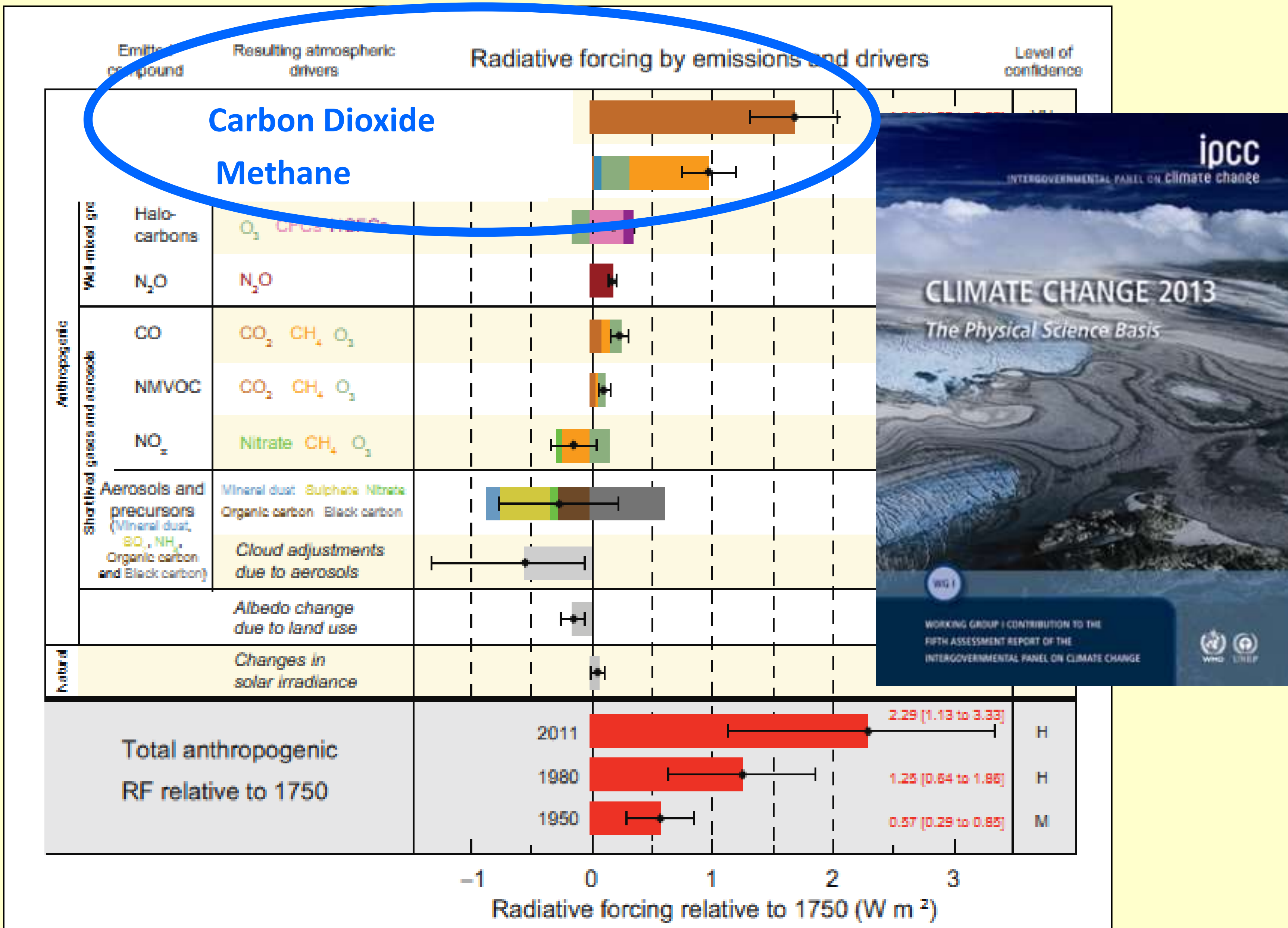
(Hayhoe et al. 2002)

Methane emissions – the Achilles' heel of natural gas

- Natural gas is mostly methane.

- Methane is 2nd most important gas behind human-caused global warming.

- Methane is much more potent greenhouse gas than carbon dioxide, so even small emissions matter.



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Resulting atmospheric drivers
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In fall 2009, Tony Ingraffea, Renee Santoro, and I took on as research questions:

1) **The role of methane emissions in the greenhouse gas footprint of natural gas.**

2) **Evaluation of methane emissions from shale gas in comparison to conventional natural gas.**

Methane emissions

(full life-cycle, well site to consumer), shown chronologically by date of publication (% of life-time production of well)

	Conventional gas	Shale gas
EPA (1996, through 2010)	1.1 %	-----
Hayhoe et al. (2002)	3.8 %	-----
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Good agreement, with largely independent data sources

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Clearly too low, based on Lelieveld et al. (2005) and GAO (2010)

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50% greater emissions from shale gas, based on estimates of venting during frack-return flow back

Methane emissions

One of our major conclusions in Howarth et al. (2011): pertinent data were extremely limited, and poorly documented.

Great need for better data, conducted by researchers free of industry control and influence.

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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

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material, which is available

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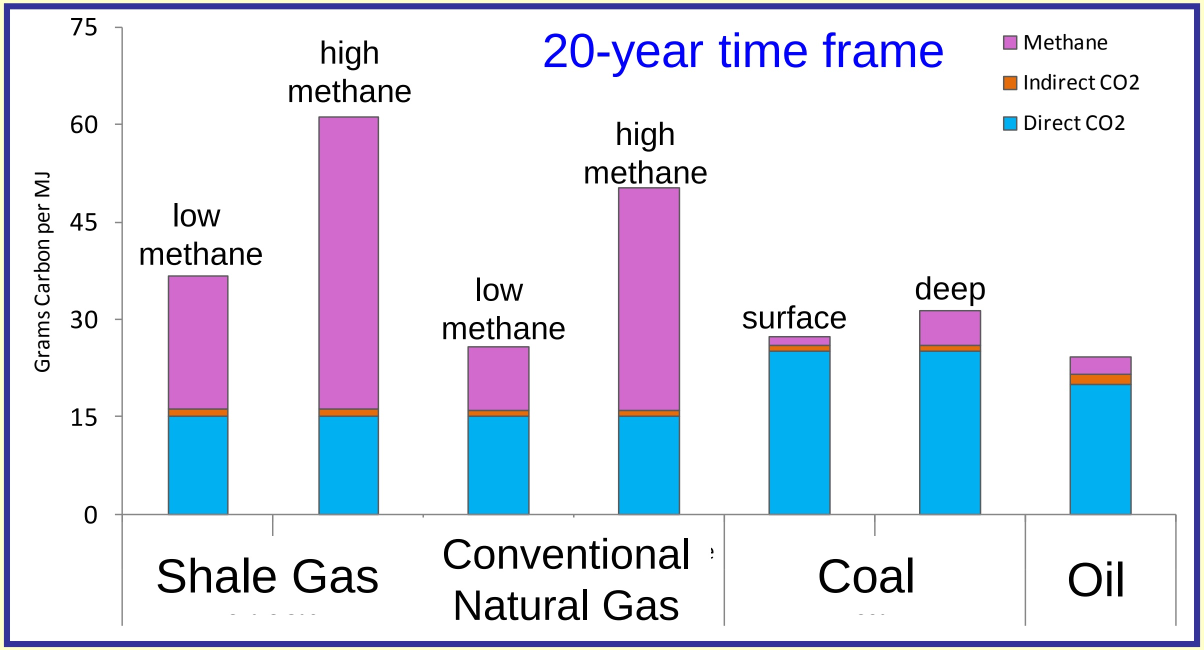
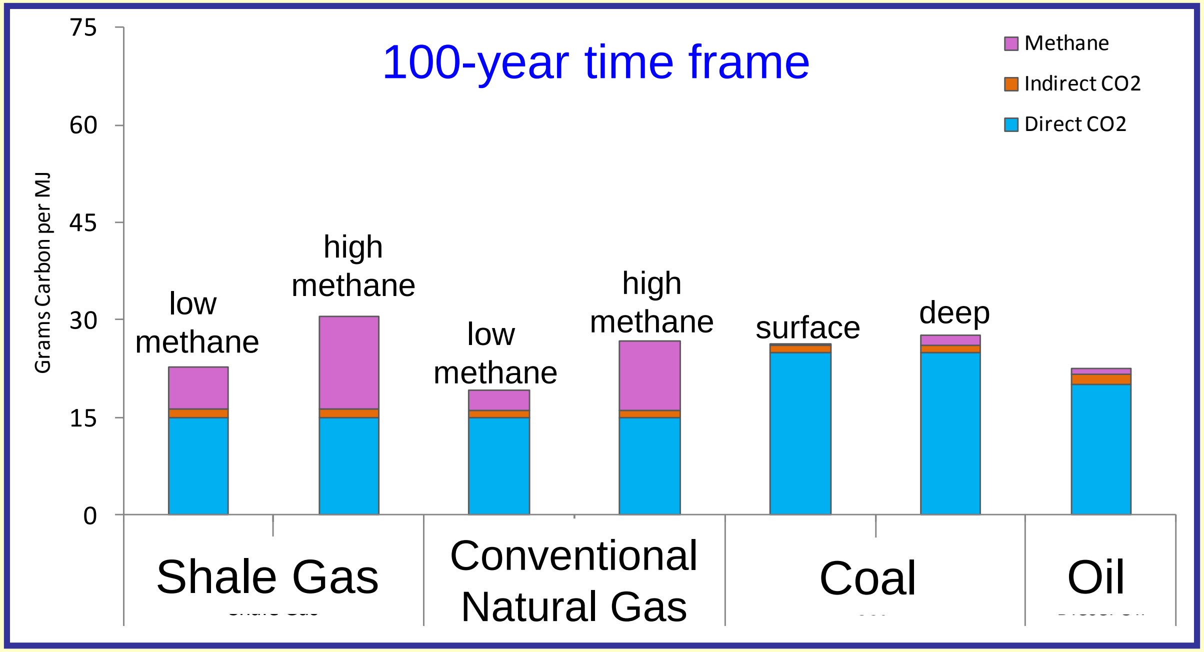
Springer

April 2011





TIME Person of the Year

People who Mattered

Mark Ruffalo, Anthony Ingraffea, Robert Howarth
By Bryan Walsh Wednesday, Dec. 14, 2011

The biggest environmental issue of 2011 — at least in the U.S. — wasn't global warming. It was hydraulic fracturing, and these three men helped represent the determined opposition to what's more commonly known as fracking. **Anthony Ingraffea** is an engineer at Cornell University who is willing to go anywhere to talk to audiences about the geologic risks of fracking, raising questions about the threats that shale gas drilling could pose to water supplies. **Robert Howarth** is his colleague at Cornell, an ecologist who produced one of the most controversial scientific studies of the year: **a paper arguing that natural gas produced by fracking may actually have a bigger greenhouse gas footprint than coal. That study — strenuously opposed by the gas industry and many of Howarth's fellow scientists — undercut shale gas's major claim as a clean fuel**. And while he's best known for his laidback hipster performances in films like *The Kids Are All Right*, Mark Ruffalo emerged as a tireless, serious activist against fracking — especially in his home state of New York.

TIME Person of the Year

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Other "People who Mattered" in 2011:

Newt Gingrich, Osama bin Laden, Joe Paterno, Adele, Mitt Romney, Muammar Gaddafi, Barack Obama, Bill McKibben, Herman Cain, Rupert Murdoch, Vladimir Putin, Benjamin Netanyahu…

Methane emissions

(% of life-time production of well)

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EPA (2011)	2.5 %	3.9 %
Venkatesh et al. (2011)	2.2 %	----
Jiang et al. (2011)	----	2.0 %
Stephenson et al. (2011)	0.5 %	0.7 %
Hultman et al. (2011)	2.3 %	3.8 %
Burnham et al. (2011)	2.6 %	1.9 %
Cathles et al. (2012)	1.8 %	1.8%

Methane emissions

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Many things to critique here….

But fundamentally, these are all just reinterpretations of the same pretty limited data set.

Methane emission estimates:

	Upstream (well site)	Downstream (storage, distribution, etc.)	Total
Hayhoe et al. (2002), conventional	1.3 %	2.5 %	3.8 %
EPA (2010), US average for 2009	0.16 %	0.9 %	1.1 %
Howarth et al. (2011), US average	1.7 %	2.5 %	4.2 %
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Allen et al. (2013), US average	0.42 %	------	-----
Miller et al. (2013), US average	-----	------	> 3.6 %
Brandt et al. (2014), US average	-----	------	5.4 %
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First re-analysis by EPA since 1996

Re-analyzed again, under pressure from industry, and ignoring Petron et al. (2012)

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Low-end, best-case estimate from Howarth et al. (2011) for US average for 2009 = 0.5%

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Range for shale gas in Howarth et al. (2011) = 2.2 % to 4.3%

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Miller et al. (2013) PNAS national analysis for methane from all sources, 2007 – 2008, based on all monitoring data on methane in atmosphere (12,694 observations). EPA (2013) estimate at least 2-X too low…

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Methane (natural gas) leaks from tanks, pipelines, compressors, etc.

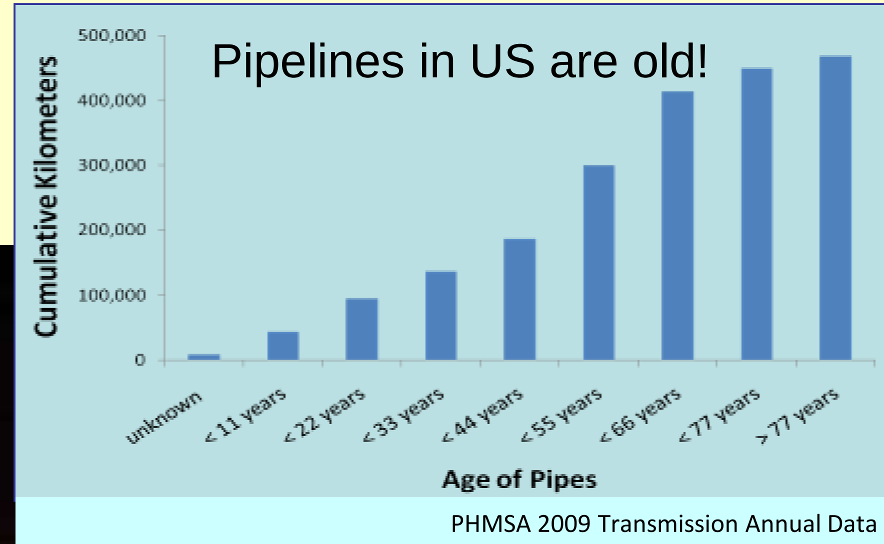
Naked eye Infra-red (42)

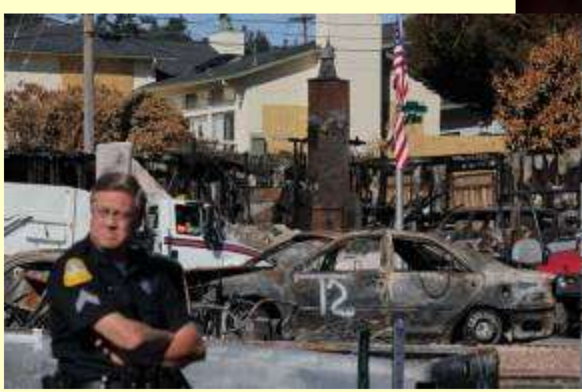
Methane is not visible to naked eye, but can be “seen” with infra-red cameras.

Bruce Gellerman, “Living on Earth,” Jan. 13, 2012, based on work of Nathan Phillips

http://www.loe.org/shows/segments.html?programID=12-P13-00002&segmentID=3

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





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

March 12, 2014 – 7 killed in explosion in NYC (127-year old gas mains)

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5.4 % (+/- 1.8%) **is best estimate for average US methane emissions from natural gas BEFORE the shale gas revolution**

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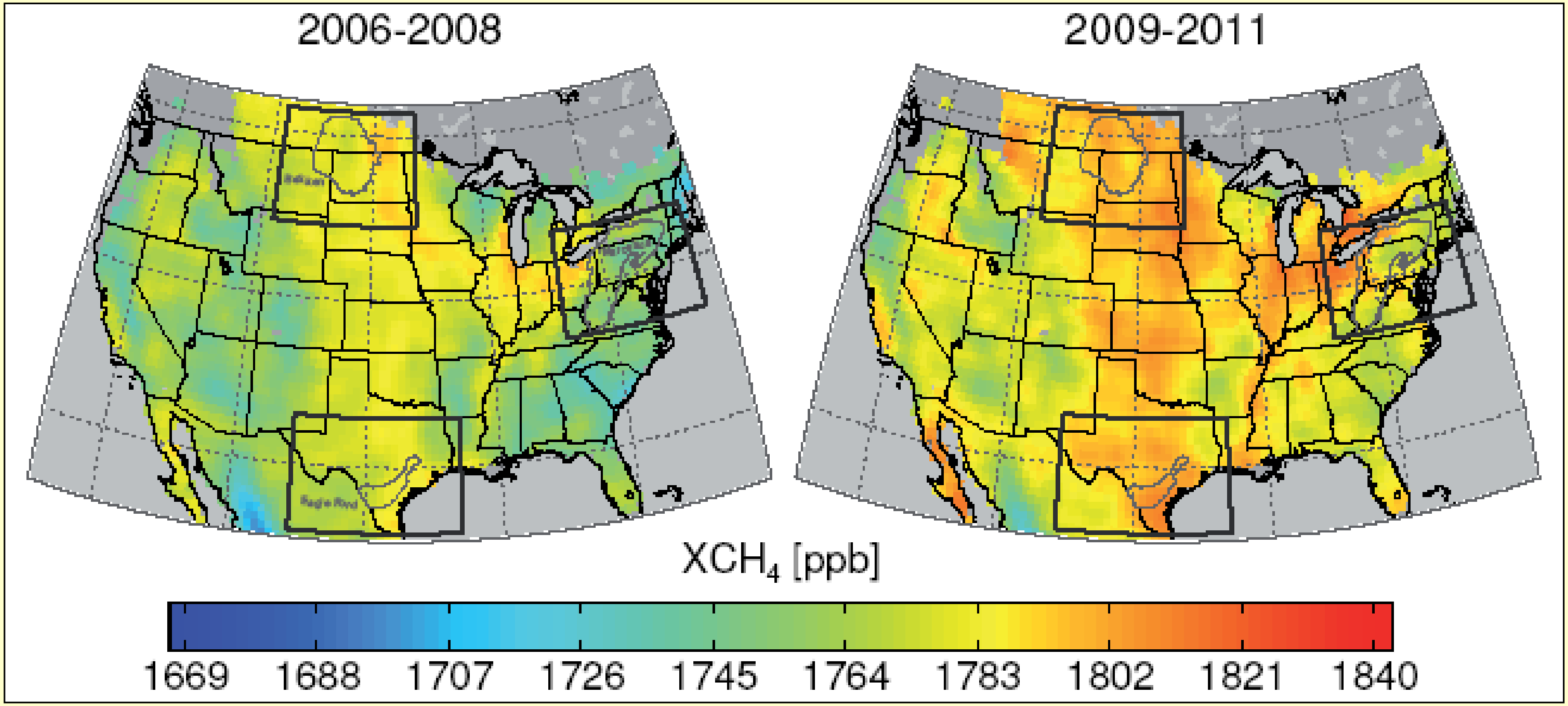
Perhaps 12% (+/- 8%) for shale gas, including downstream emissions?

Schneising et al. (2014) – "Remote sensing of fugitive methane emissions from oil and gas production in North American tight geologic formations"



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
• Alvarez et al. (2012)	0 to 100 years

Relative global warming potential for methane compared to carbon dioxide, averaged over two time periods following emission

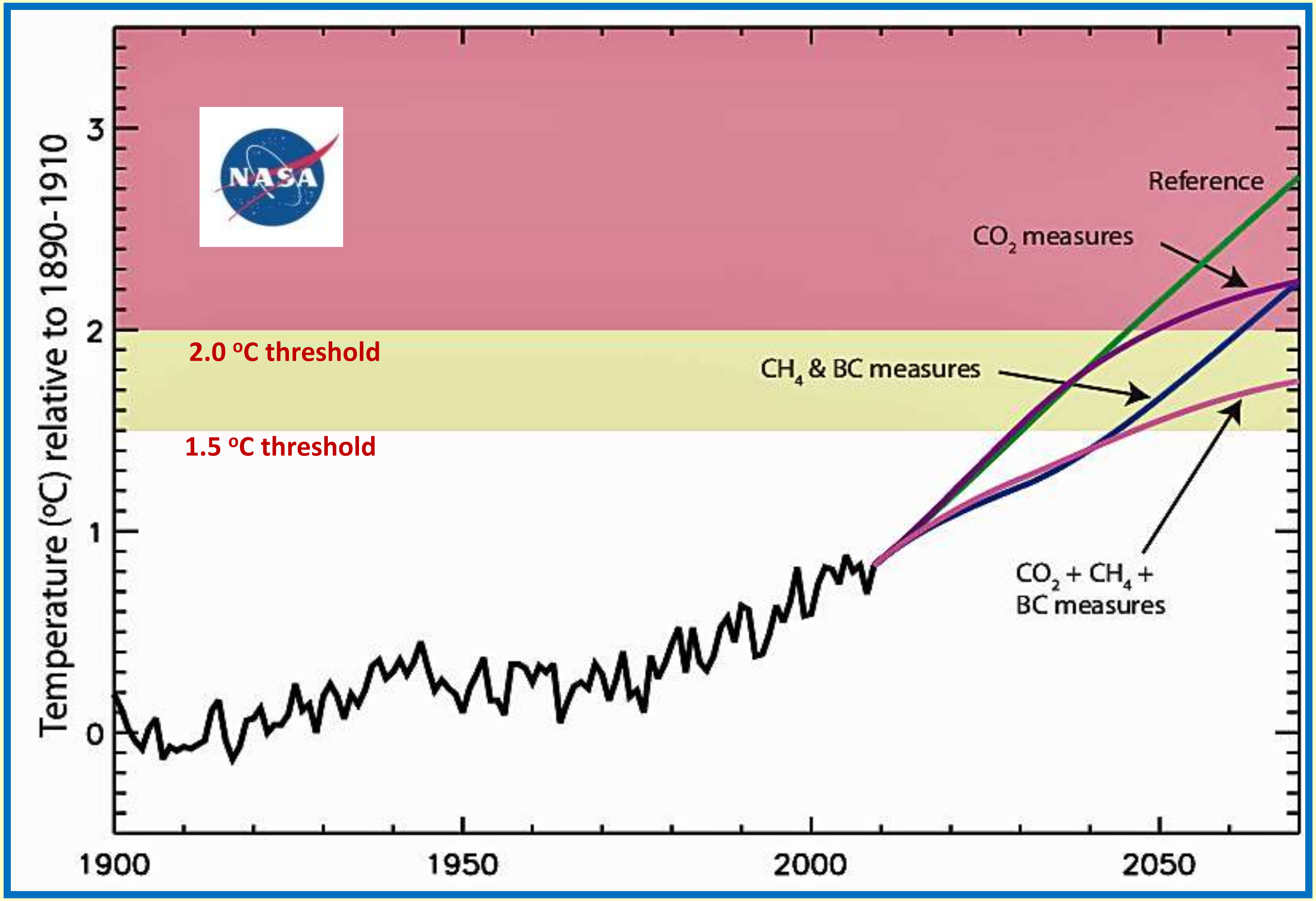
	20 years	100 years
IPCC 1996	56	21
IPCC 2007	72	25
Shindell et al. 2009	105	33
IPCC 2013	86	34

IPCC (2013): "There is no scientific argument for selecting 100 years compared with other choices."

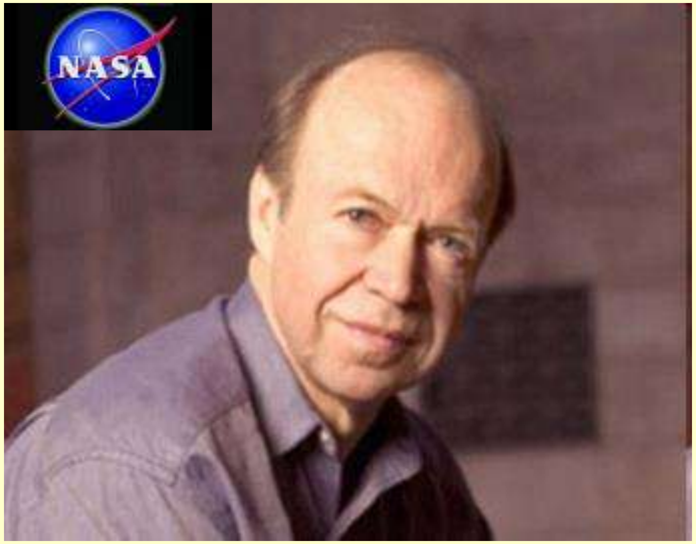
"The choice of time horizon …. depends on the relative weight assigned to the effects at different times."

Dangerous temperatures (increased risk of climatic tipping points and runaway global warming) in 15 to 35 years.

Controlling methane is ***CRITICAL*** to the solution!



Shindell et al. 2012



PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A

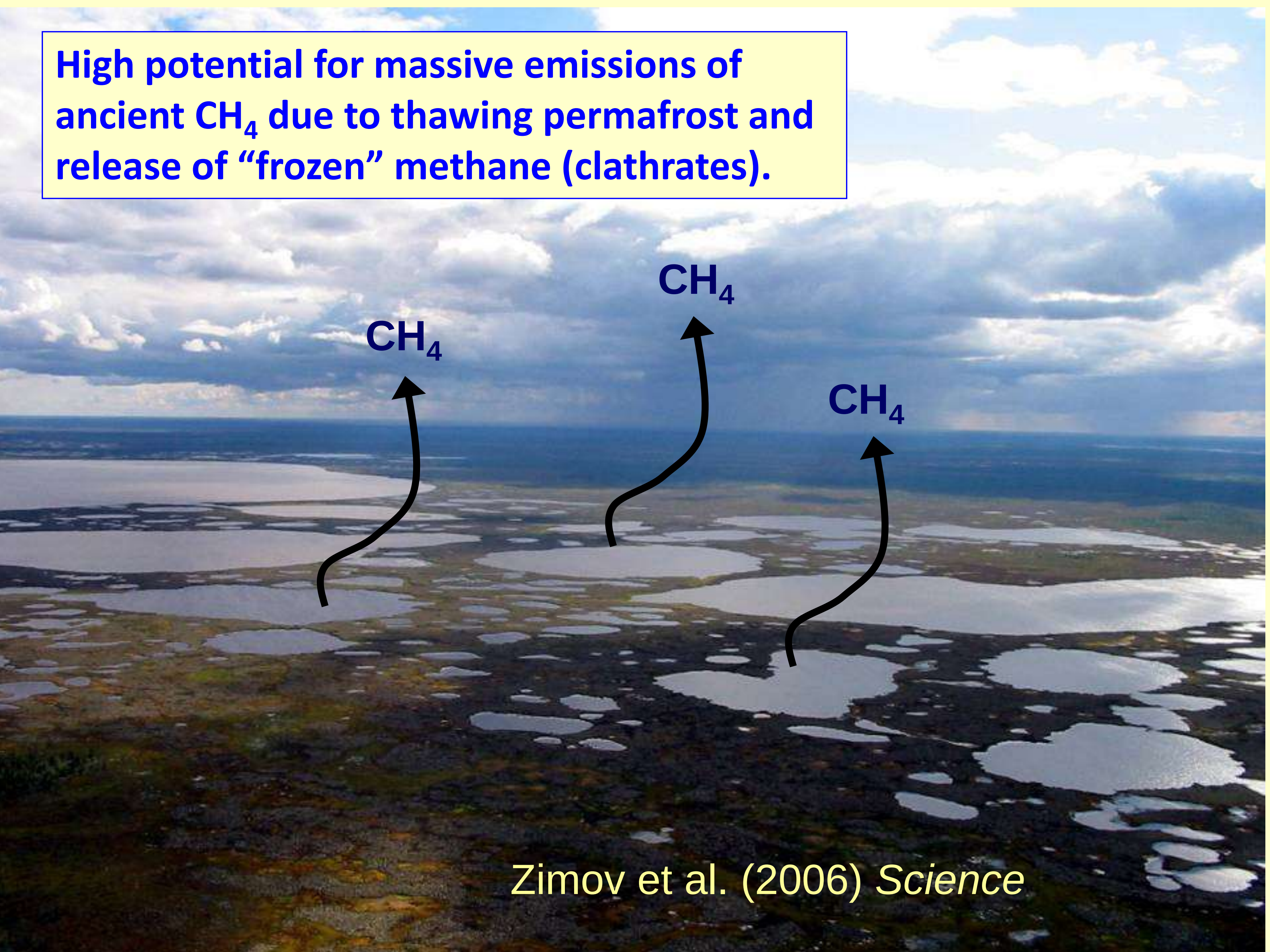
Phil. Trans. R. Soc. A (2007) **365**, 1925–1954
doi:10.1098/rsta.2007.2052
Published online 18 May 2007

Climate change and trace gases

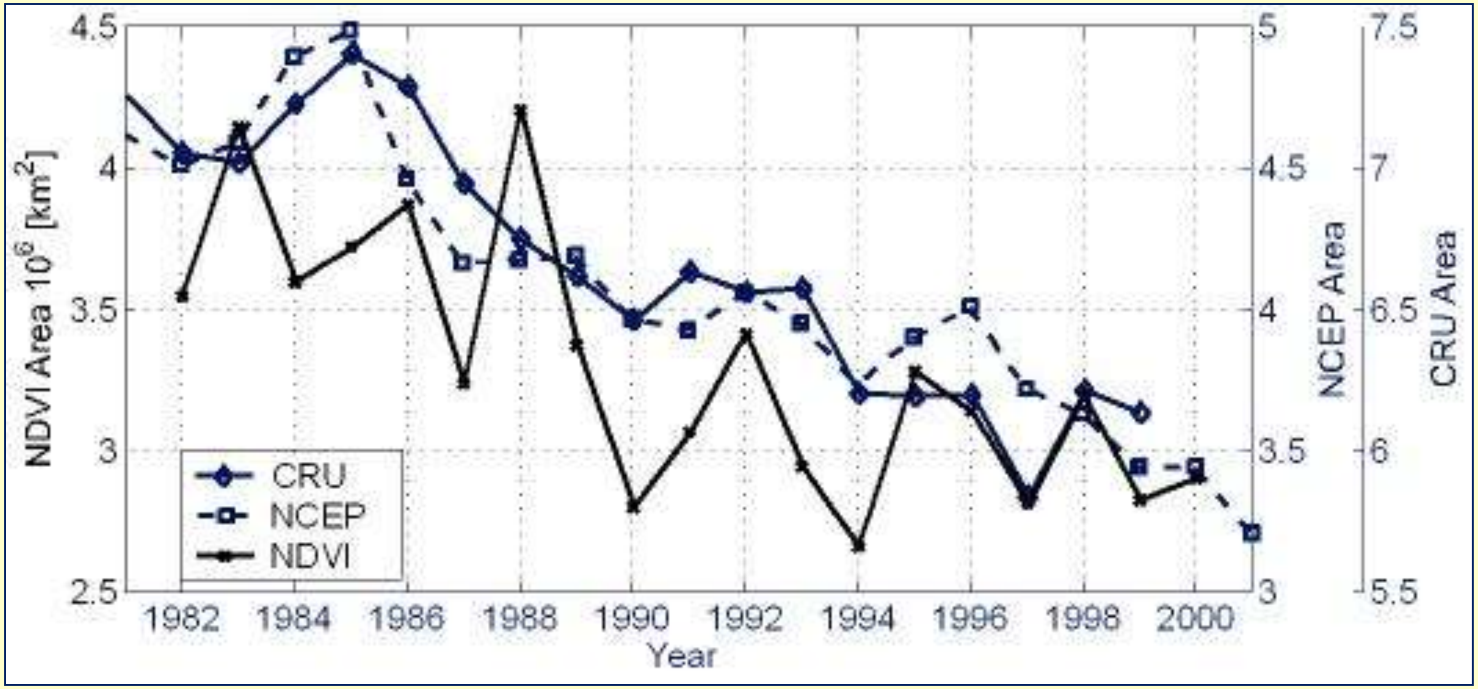
By James Hansen[1,*], Makiko Sato[1], Pushker Kharecha[1], Gary Russell[1], David W. Lea[2] and Mark Siddall[3]

[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) suggested critical threshold in climate system, to avoid melting of natural methane hydrates, at ~ 1.8° C.


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

The global area of tundra decreased 18% in past 20 years (Wang et al. 2004)



http://www.arctic.noaa.gov/detect/land-tundra.shtml

(downloaded June 9, 2014)

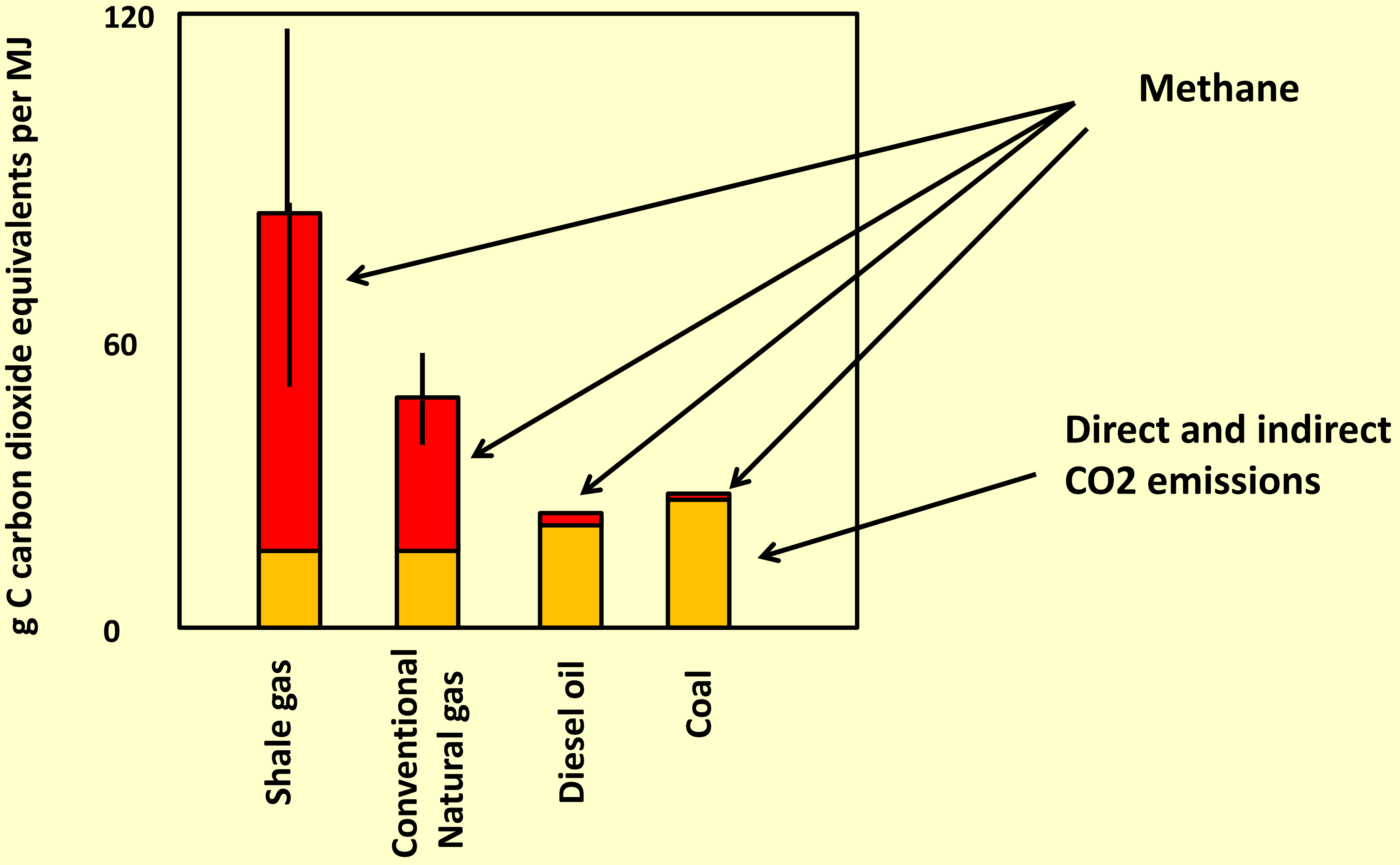
Same location in Alaska, showing transition from tundra to wetlands over the last 20 years

http://www.arctic.noaa.gov/detect/land-tundra.shtml

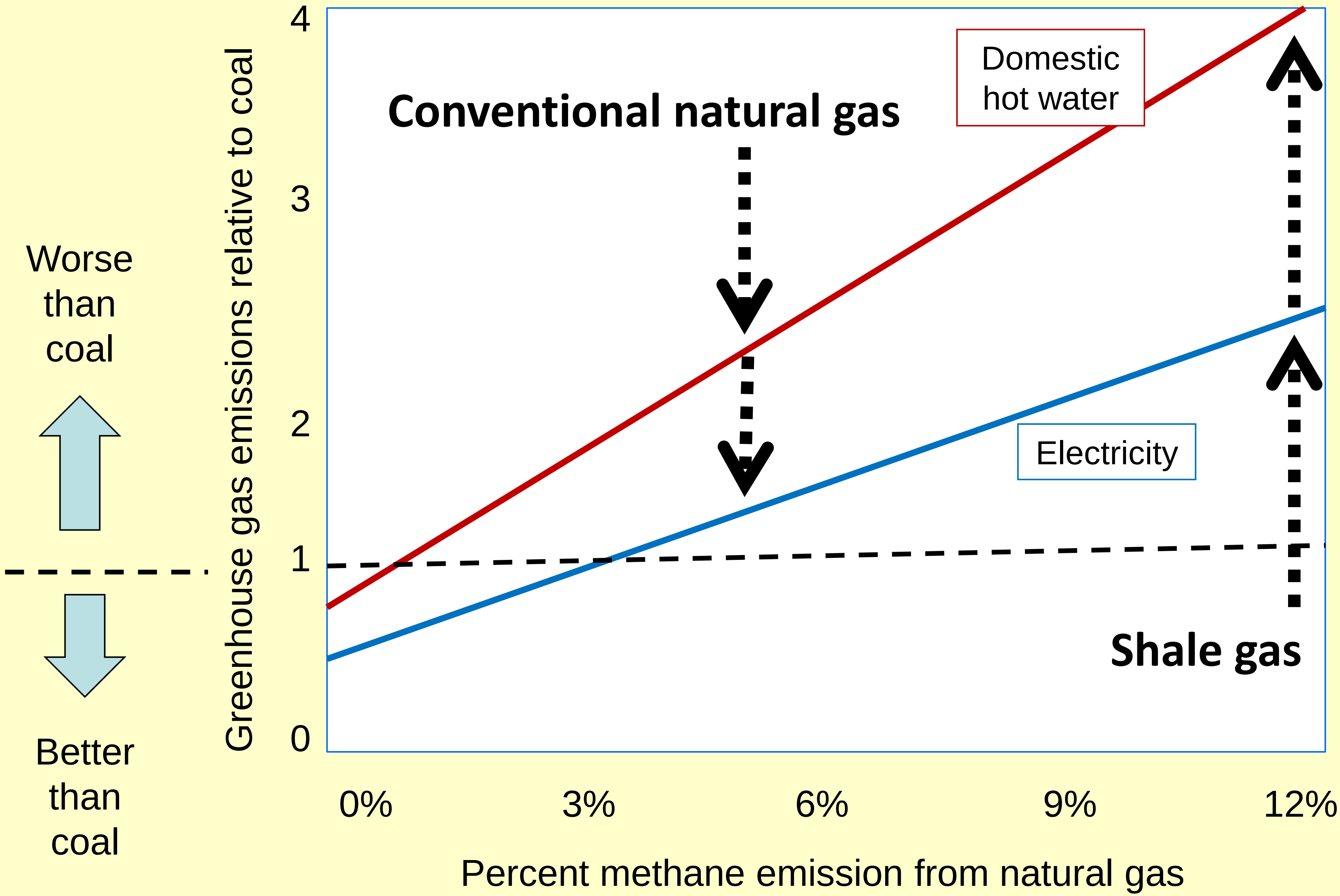
(downloaded June 9, 2014)

(Torre Jorgenson)

Greenhouse gas footprints per unit of heat generated, with methane converted to CO2 equivalents using 20-year GWP from IPCC (2013)



Greenhouse gas consequences for natural gas compared to coal
(compared over integrated 20-year time frame)




METHANE
FOSSIL FUELS CAN BE USED RESPONSIBLY
THERE SEEMS TO BE A HOLE IN THAT ARGUMENT...
BUT PEOPLE CAN'T SEE IT.—
TOLES
UNIVERSAL UCLICK
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1-2-15

The two faces of Carbon

Carbon dioxide (CO_2)

Methane (CH_4)

The two faces of Carbon

Carbon dioxide (CO_2)

- Emissions today will influence climate for 1,000s of years

Methane (CH_4)

- Persists in the atmosphere for only 12 years
- Only modest long-term influence, unless global warming leads to tipping points in the climate system

The two faces of Carbon

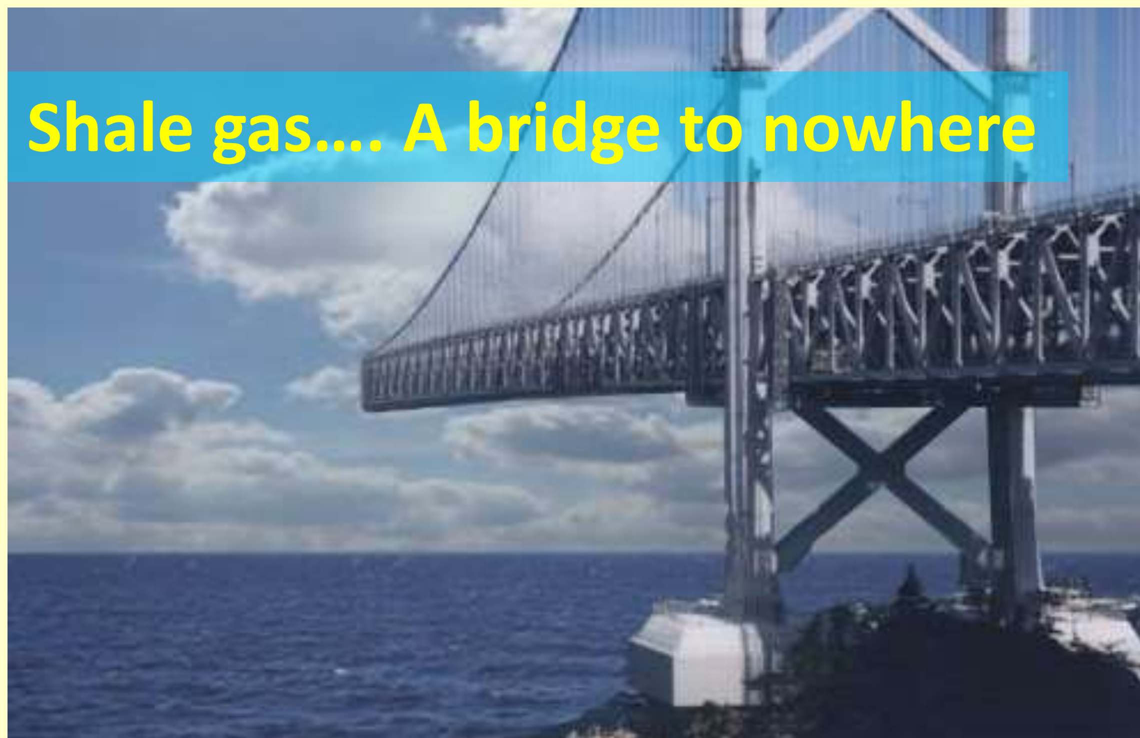

Carbon dioxide (CO_2)

- Emissions today will influence climate for 1,000s of years
- Because of lags in climate system, reducing emissions now will have little influence during next 40 years

Methane (CH_4)

- Persists in the atmosphere for only 12 years
- Only modest long-term influence, unless global warming leads to tipping points in the climate system
- Reducing emissions <u>immediately</u> slows global warming

So what should our energy future be?



Jacobson and Delucchi 2009

Powering New York and California with no fossil fuels, largely by 2030, using only current technologies

Energy Policy ■ (■■■) ■■■–■■■

Contents lists available at SciVerse ScienceDirect

Energy Policy

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

Examining the feasibility of converting New York State's all-purpose energy infrastructure to one using wind, water, and sunlight

Mark Z. Jacobson[a,*], Robert W. Howarth[b], Mark A. Delucchi[c], Stan R. Scobie[d], Jannette M. Barth[e], Michael J. Dvorak[a], Megan Klevze[a], Hind Katkhuda[a], Brian Miranda[a], Navid A. Chowdhury[a], Rick Jones[a], Larson Plano[a], Anthony R. Ingraffea[f]

[a] Atmosphere/Energy Program, Department of Civil and Environmental Engineering, Stanford University, Stanford, CA 94305, USA
[b] Department of Ecology and Evolutionary Biology, Cornell University Ithaca, NY 14853, USA
[c] Institute of Transportation Studies, U.C. Davis, Davis, CA 95616, USA
[d] PSE Healthy Energy, NY, USA
[e] Pepacton Institute LLC, USA
[f] School of Civil and Environmental Engineering, Cornell University, Ithaca, NY 14853, USA

HIGHLIGHTS

- New York State's all purpose energy can be derived from wind, water, and sunlight.
- The conversion reduces NYS end use power demand by ~37%.
- The plan creates more jobs than lost since most energy will be from in state.
- The plan creates long term energy price stability since fuel costs will be zero.
- The plan decreases air pollution deaths 4000/yr ($33 billion/yr or 3% of NYS GDP).

ARTICLE INFO

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ABSTRACT

This study analyzes a plan to convert New York State's (NYS's) all purpose (for electricity, transportation, heating/cooling, and industry) energy infrastructure to one derived entirely from wind, water, and sunlight (WWS) generating electricity and electrolytic hydrogen. Under the plan, NYS's 2030 all purpose end use power would be provided by 10% onshore wind (4020 5 MW turbines), 40% offshore wind (12,700 5 MW turbines), 10% concentrated solar (387 100 MW plants), 10% solar PV

Contents lists available at ScienceDirect

Energy

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

A roadmap for repowering California for all purposes with wind, water, and sunlight

Mark Z. Jacobson, Mark A. Delucchi, Anthony R. Ingraffea, Robert W. Howarth, Guillaume Bazouin, Brett Bridgeland, Karl Burkart, Martin Chang, Navid Chowdhury, Roy Cook, Giulia Escher, Mike Galka, Liyang Han, Christa Heavey, Angelica Hernandez, Daniel F. Jacobson, Dionna S. Jacobson, Brian Miranda, Gavin Novotny, Marie Pellat, Patrick Quach, Andrea Romano, Daniel Stewart, Laura Vogel, Sherry Wang, Hara Wang, Lindsay Willman, Tim Yeskoo

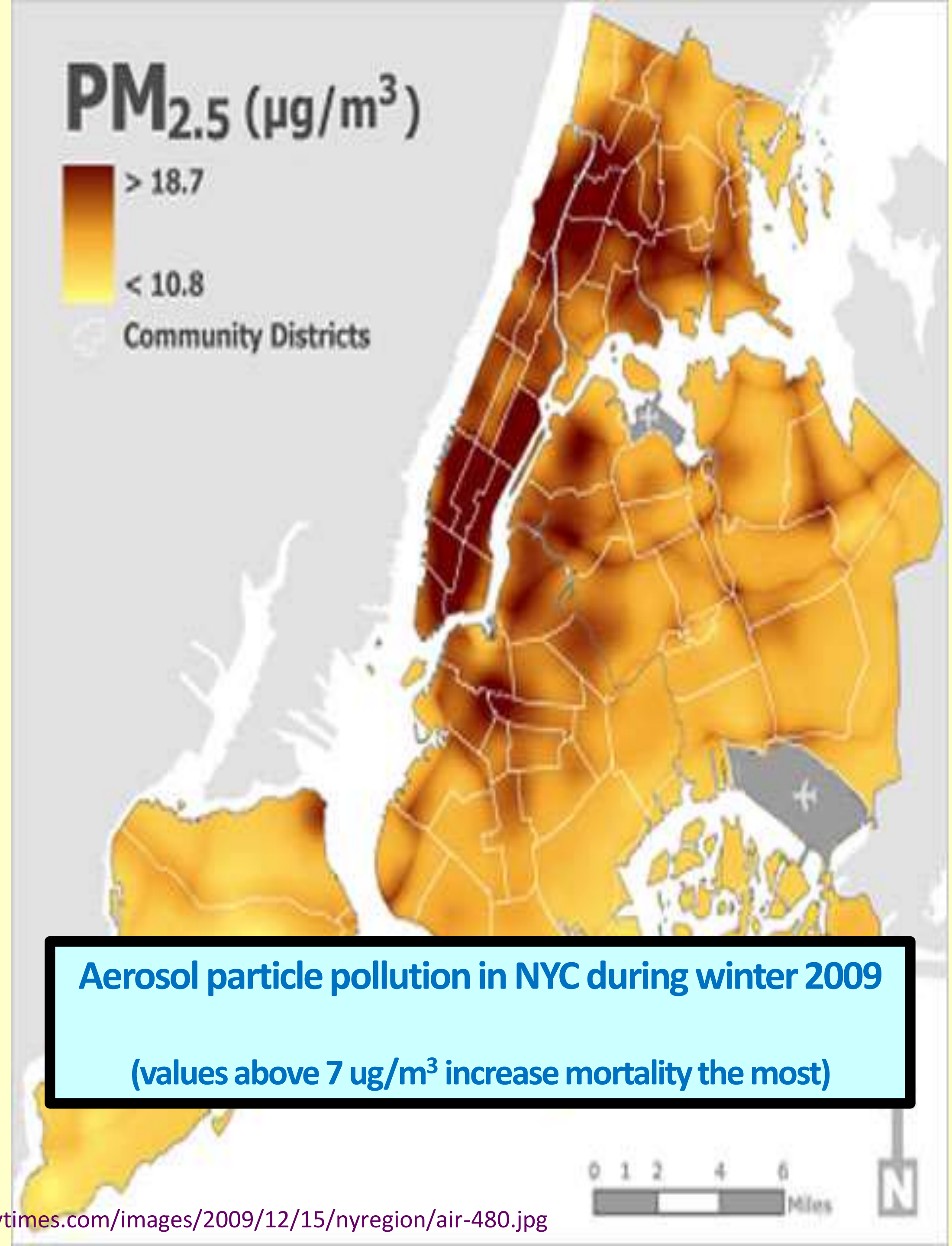
ARTICLE INFO

ABSTRACT

This study presents a roadmap for converting California's all-purpose (electricity, transportation, heating/cooling, and industry) energy infrastructure to one derived entirely from wind, water, and sunlight (WWS) generating electricity and electrolytic hydrogen.

Fossil-fuel air pollution causes 4,000 deaths per year in New York State.

Deaths and other health costs = $33 billion per year in New York State.



Aerosol particle pollution in NYC during winter 2009

(values above 7 ug/m^3 increase mortality the most)

http://graphics8.nytimes.com/images/2009/12/15/nyregion/air-480.jpg

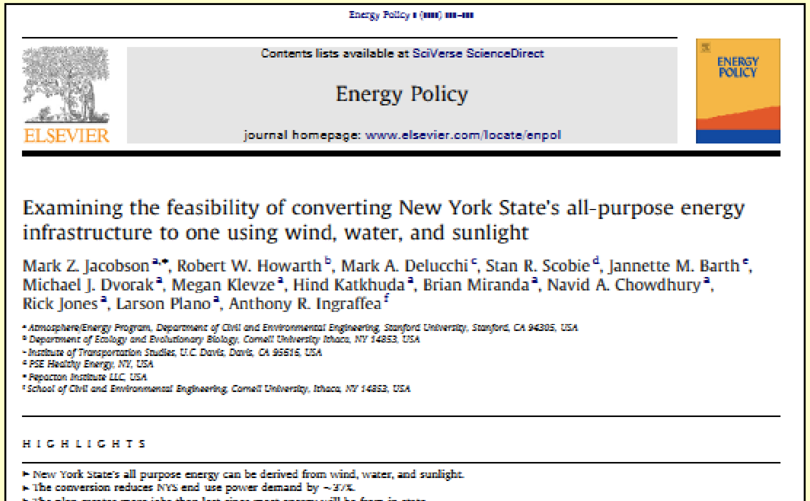
Prof. Mark Jacobson

Our Plan:

- Electrify transportation and commercial and d domestic heating – greater efficiencies lower total energy consumption (37%).
- Choose most environmentally benign generation technologies (50% wind, 28% photovoltaic, 10% concentrated solar, and 12% geothermal, hydro, tidal, and waves).
- Rely on technologies that are commercially available today.
- Use a variety of energy storage techniques, and approaches for balancing demand to production.

Jacobson et al. (2013) *Energy Policy* plan for New York State:

- **Is cost effective ($570 billion price tag equals the health-cost savings of $33 billion per year over 17 years)**
- **Creates large number of net new jobs in New York.**
- **Stabilizes energy prices, and greatly improves energy security; reduces energy prices on the time scale of 10 or more years into the future.**
- **Hugely decreases air pollution and greenhouse gas emissions from New York.**



Energy Policy ∎ (∎∎∎∎) ∎∎∎–∎∎∎

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ENERGY POLICY

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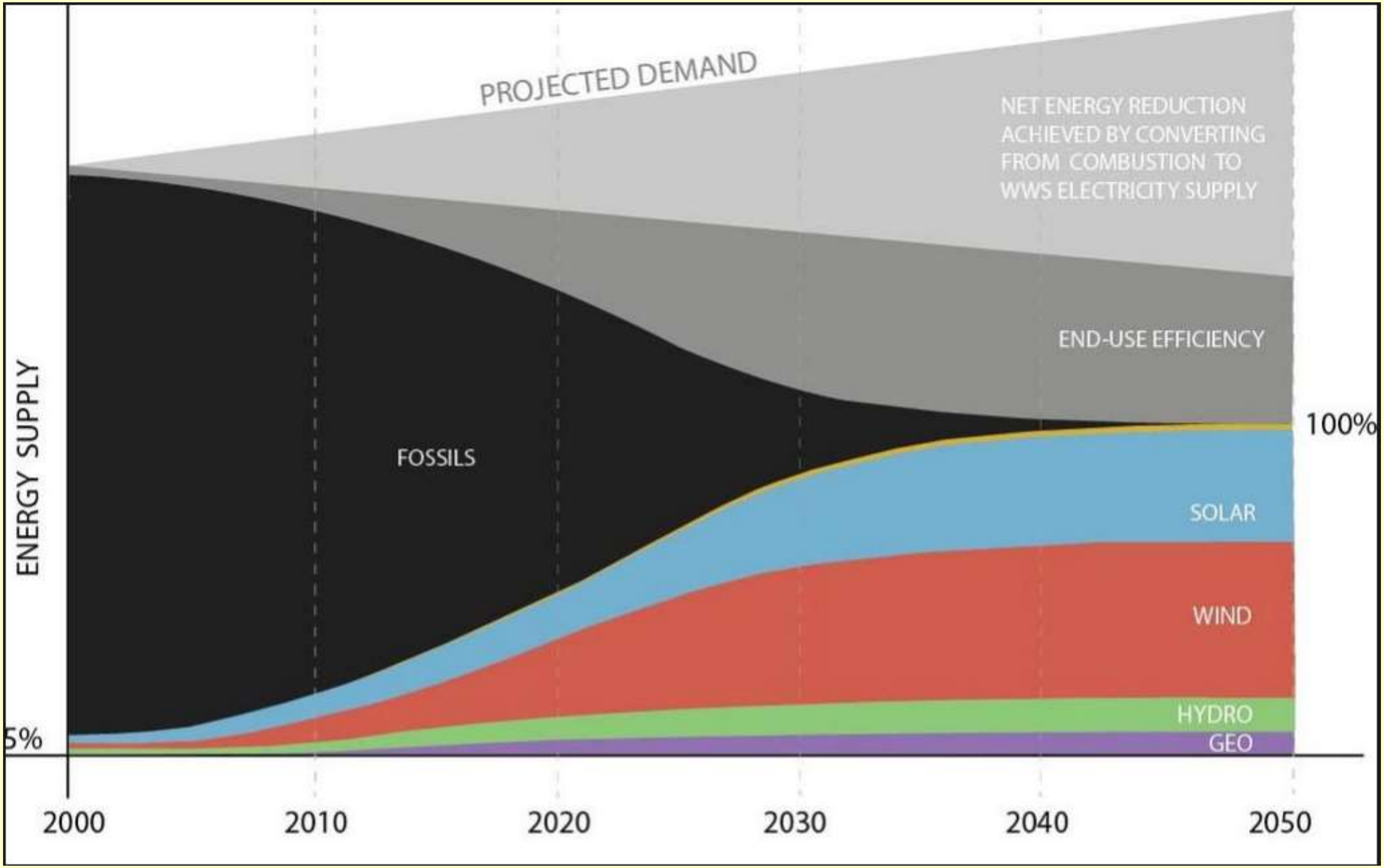
H I G H L I G H T S

► New York State's all purpose energy can be derived from wind, water, and sunlight.
► The conversion reduces NYS end use power demand by ~37%.

Our Energy Plan for New York State



Jacobson et al., *Energy Policy*, Feb. 2013

Average cost of delivered electricity by power generation source (cents per kWh)

ENERGY TECHNOLOGY	2008 – 2010	2020 - 2030
Wind onshore	4 to 7	≤ 4
Wind offshore	10 to 1 7	8 to 1 3
Geothermal	4 to 7	4 to 7
Hydroelectric	4	4
Solar PV	9 to 13	5 to 7
Conventional (fossil fuels)	7	8 to 10
Conventional + externalities	12.3	14 to 15

Conversion to Renewable Energy will Create Jobs in New York State

Average number of jobs in the US per million dollars spent on energy production:

3.7 for fossil fuels
9.5 for wind
9.7 for solar

Pollin et al. (2009)

Estimated Job Creation in New York State with SOLUTIONS PLAN

Energy Technology	Construction Jobs	Operations Jobs
Onshore wind	1,832	2,745
Offshore wind	10,148	37,128
Wave device	474	3,325
Geothermal plant	1,214	411
Hydroelectric plant	275	275
Tidal turbine	752	5,770
Res. roof PV system	62,514	19,206
Com/gov roof PV system	110,213	22,259
Solar PV plant	51,510	16,808
TOTALS	**238,931**	**107,926**

My family and I practice what we preach:

Air-sourced heat pump for domestic hot water since 2011 and electric vehicle for ~ 40% of travel since 2012. Both are very cost effective.

Ground-sourced heat pump ("geothermal") in 1890s farm house in Trumansburg, NY, as only source of heat

- 320% efficiency
- Cost effective
- Zero emissions, since electricity is from renewables

<u>Some concluding thoughts</u>:

Natural gas is no bridge fuel.

Urgent need to reduce methane emissions, to slow down arrival time of potential tipping points in the climate system.

We must also control carbon dioxide emissions, because of consequences running 1,000s of years into the future.

We should embrace the 21st Century, and power our economy on renewable energy and use energy efficient technologies (electric vehicles, heat pumps) rather than fossil fuels.

Cornell University
College of Agriculture and Life Sciences

Thank you for inviting me.

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