Cornell University
College of Agriculture and Life Sciences

Greenhouse Gas Emissions from Shale Gas: Is this a "Clean" Fuel?


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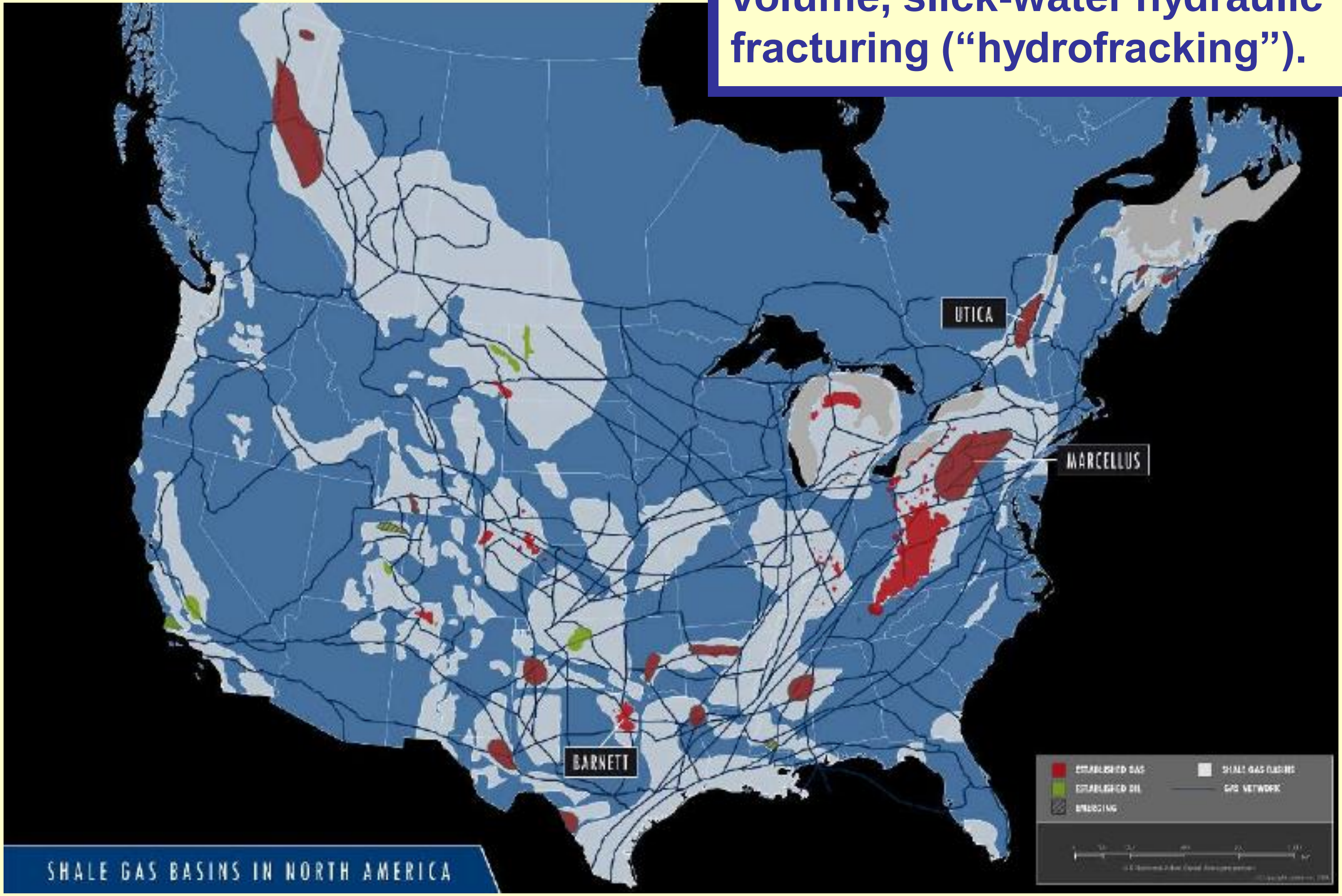
Bob Howarth
Cornell University

Scientific & Technical Advisory Committee
Chesapeake Bay Program
Annapolis, MD
June 8, 2011

Shales hold a lot of natural gas (methane), but very dispersed, not economical using traditional technology…… Within last 4-13 years, horizontal drilling and high-volume, slick-water hydraulic fracturing (“hydrofracking”).

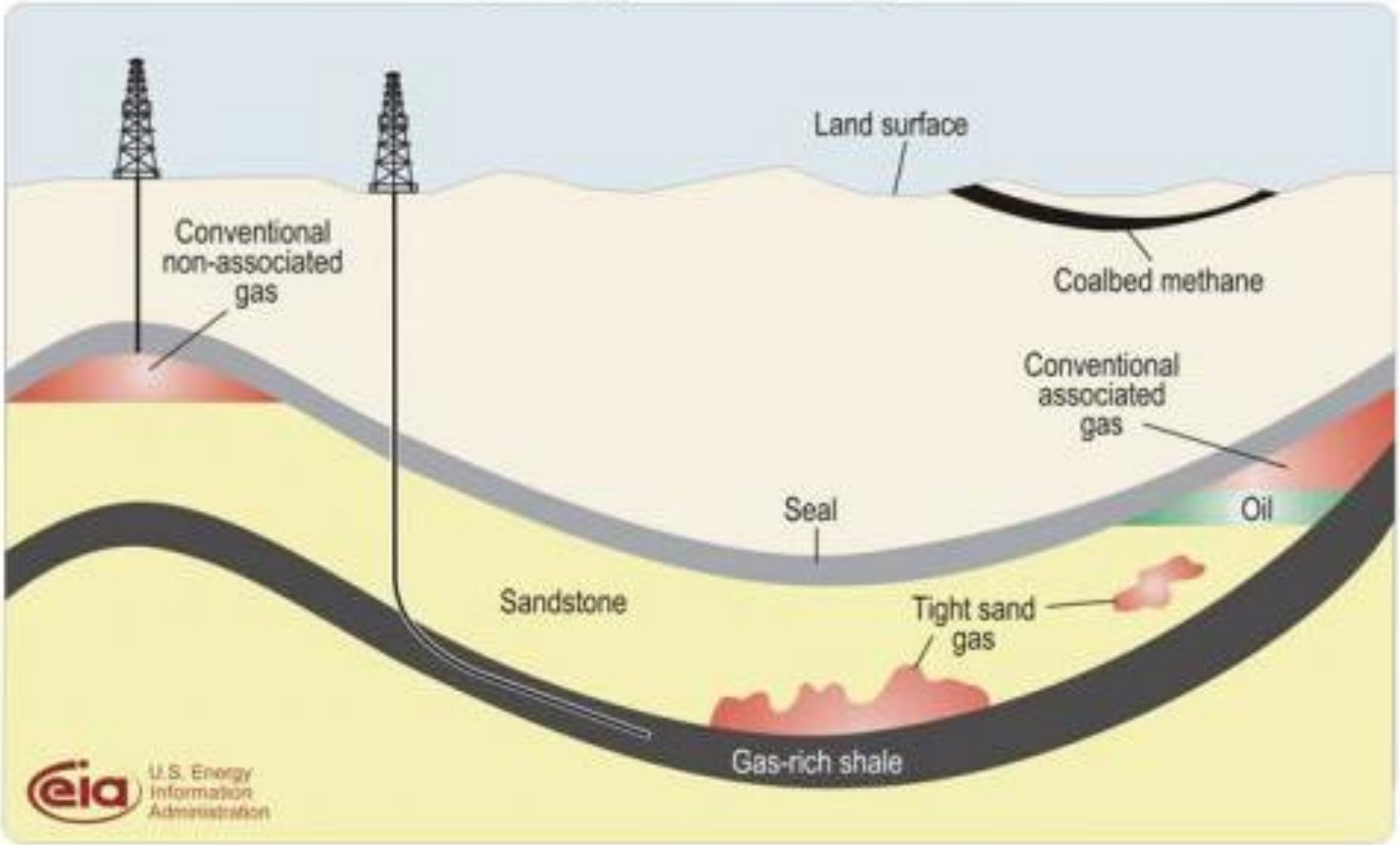


Source: JUNEX -- http://www.searchanddiscovery.com/documents/2009/80073marcil/ndx_marcil.pdf

Unconventional extraction of gas from shale formations is new, and is being promoted globally by U.S. government and industry

- Argentina
- Australia
- Canada
- China
- Denmark
- Germany
- India
- Poland
- South Africa

Schematic geology of natural gas resources



Hydraulic fracturing has been used to increase flows from conventional gas formations for decades….. But relatively small amounts of water used (< 300 m^3).

Hydraulic fracturing for shale gas is new: past 13 years in Texas, past 3-4 years in Pennsylvania.

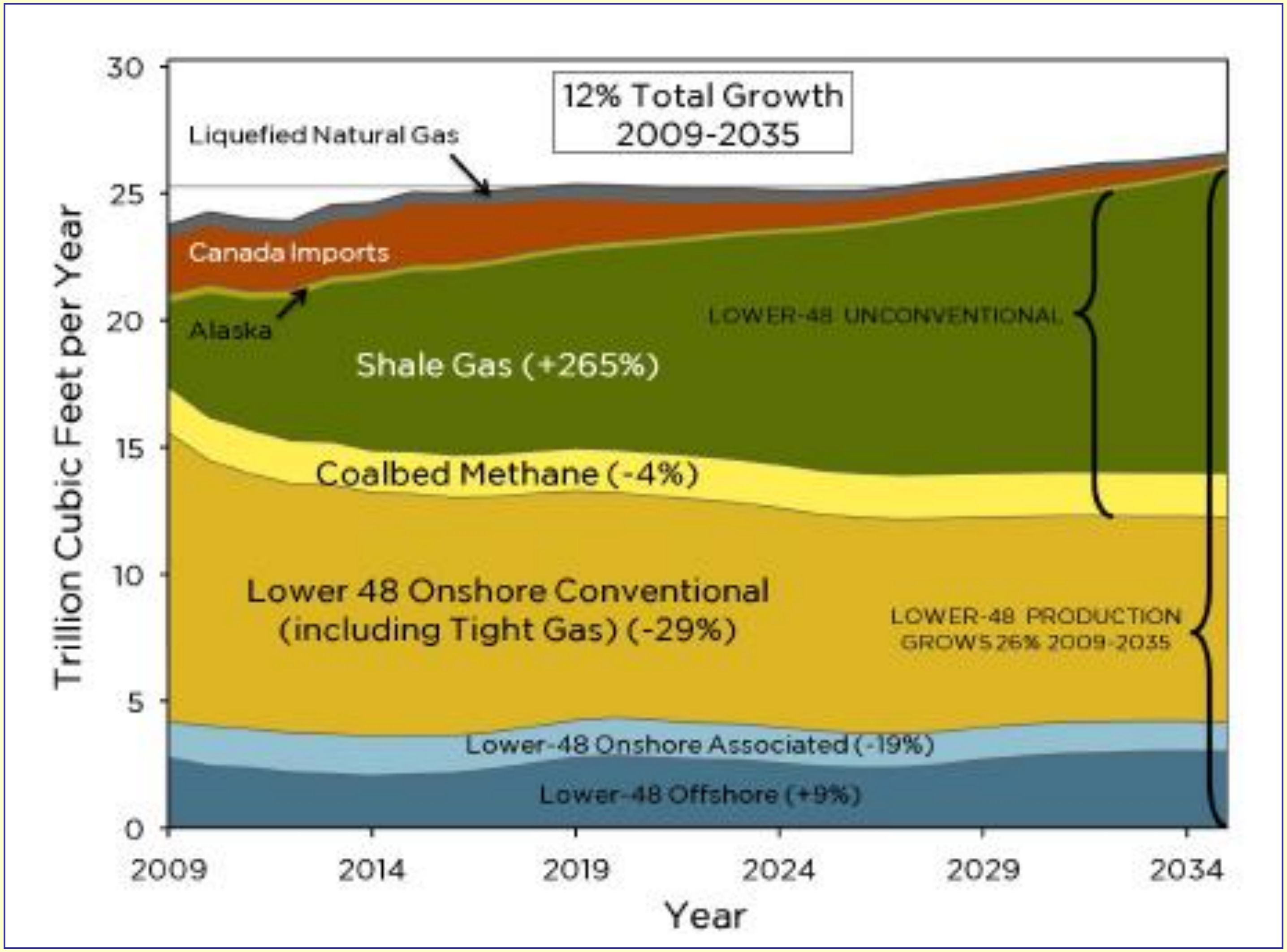
For hydraulic fracturing in shales, large volumes of fluid used for each well (60,000 m^3 and more).

Often have 6 to 16 lateral wells per each surface site (so up to 960,000 m^3 of fluid per site).

Large volume and long horizontal wells require additives to reduce friction of the water (slick water). Additives also added to prop fractures open ("sand," plastics), perforate well casing, prevent bacterial growth, and other purposes.

A large volume of hydrofracking fluids comes back to surface in first few weeks of drilling.

Predicted sources of natural gas for the United States

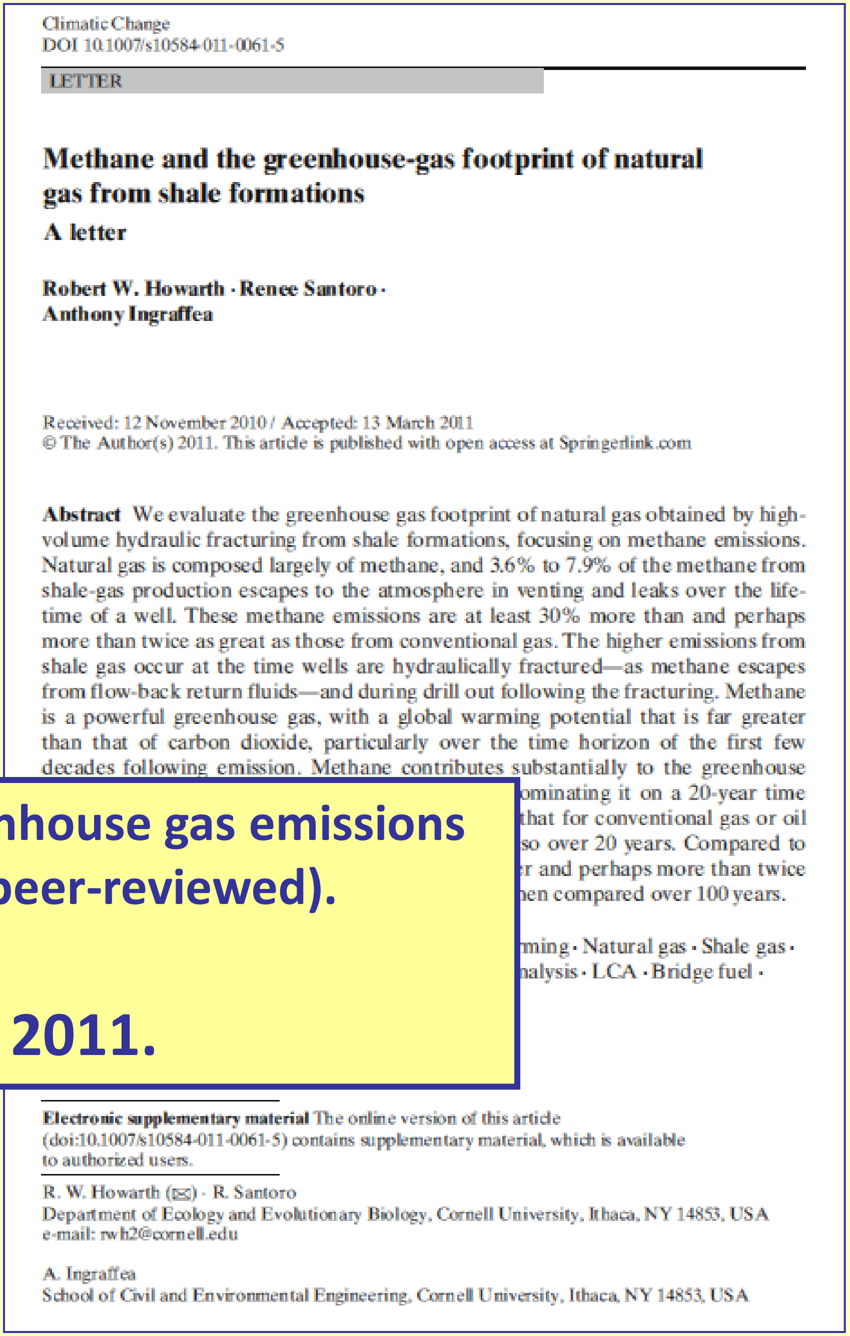


Hughes (2011), based on EIA/DOE annual energy outlook

“From a CO_2 emissions standpoint, [shale gas] is 60 percent cleaner than coal”

“60 Minutes” on CBS Television on November 14, 2010 made essentially same statement

Many others….


Climatic Change
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

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
ominating it on a 20-year time
that for conventional gas or oil
so over 20 years. Compared to
r and perhaps more than twice
hen compared over 100 years.

rming · Natural gas · Shale gas ·
nalysis · LCA · Bridge fuel ·

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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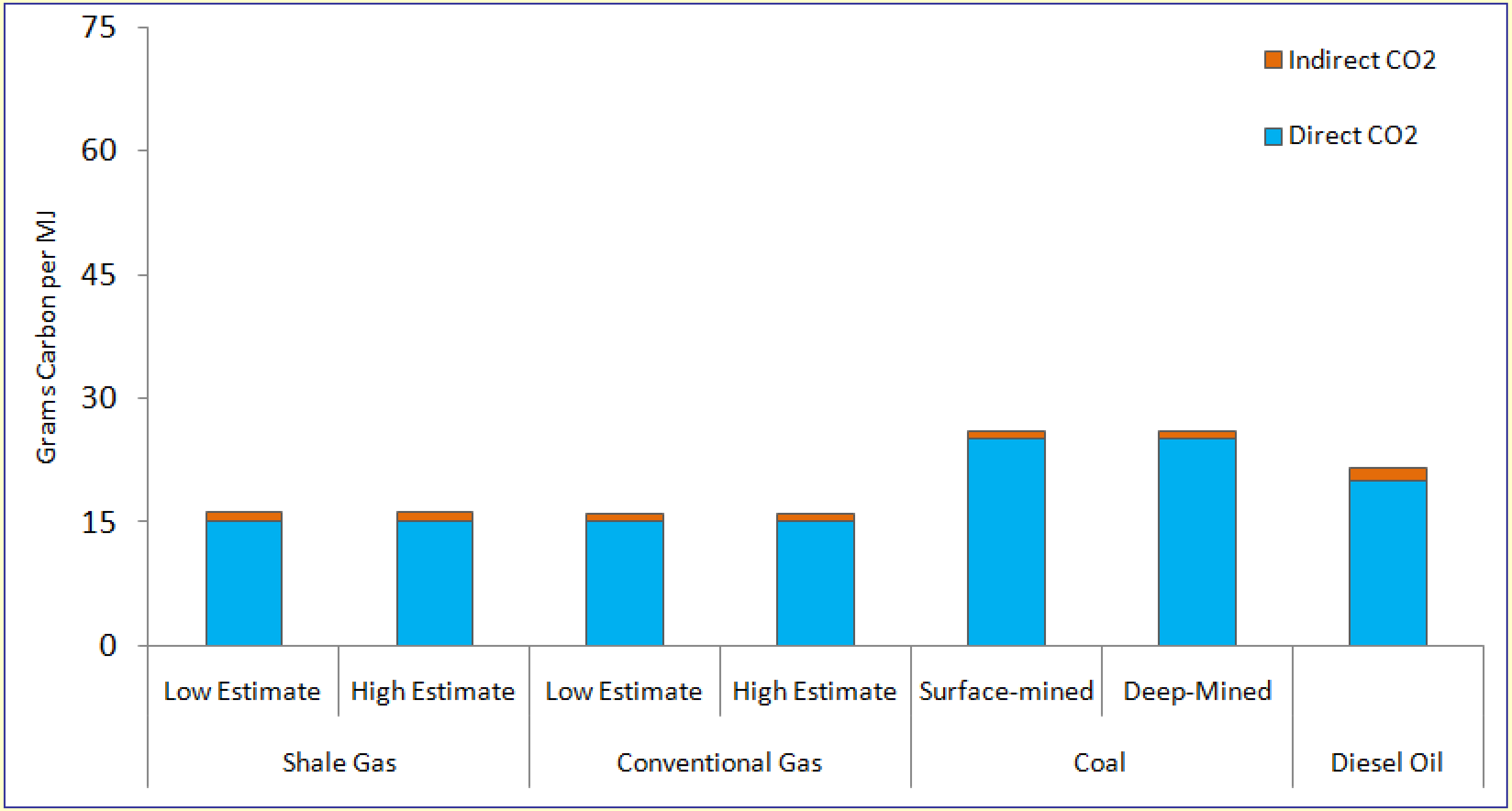
First comprehensive analysis of greenhouse gas emissions from shale gas (including non-peer-reviewed).

Published April 12, 2011.

Direct carbon dioxide emissions during combustion of fossil fuels plus indirect carbon dioxide emissions



Howarth et al. (2011)

Methane emissions – the Achilles' heel of shale gas

- Natural gas is mostly methane.

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

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

Methane is vented and leaked:

- during initial flow-back period
- routinely and continuously at the well site
- during liquid unloading
- during gas processing
- during transmission, storage, and distribution

We used the best available data to estimate methane venting and leaks:

- Peer-reviewed publications, when available.
- EPA report from November 30, 2010.
- GAO (2010) report.
- American Petroleum Institute (2009) report.
- archived PowerPoint presentations from EPA & industry, financial disclosure reports, etc.

Table 1. Methane emissions from flow-back fluids and initial production rates for 5 unconventional wells.

Basin	Methane emission during flow-back (10^3 m^3)	Methane emission per day during flow-back (10^3 m^3 d^{-1})	Initial gas production upon well completion (10^3 m^3 d^{-1})	Life-time production of well (10^6 m^3)	Flow-back emissions as % of life-time production
Haynesville (LA)	6,800	680	640	210	3.2%
Barnett (TX)	370	41	37	35	1.1%
Piceance (CO)	710	79	57	55	1.3%
Uinta (UT)	255	51	42	40	0.6%
Den-Jules (CO)	140	12	11	?	?

(Howarth et al. 2011)

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(Howarth et al. 2011)

Table 1. Methane emissions from flow-back fluids and initial production rates for 5 unconventional wells.

Limited data, poor documentation (Powerpoint slides from EPA workshops).

We have chosen to use the mean emission percentage of 1.6%

				on	Flow-back emissions as % of life-time production
					3.2%
Barnett (TX)	370	41	37	35	1.1%
Piceance (CO)	710	79	57	55	1.3%
Uinta (UT)	255	51	42	40	0.6%
Den-Jules (CO)	140	12	11	?	?

(Howarth et al. 2011)

Sources of methane leaks (as percentage of life-time total production):

	Conventional Gas	Shale Gas
Initial drilling & completion	0.01%	1.9%

1.6% from flow-back fluids, plus 0.3% from drill-out following hydraulic fracturing (0.6% equally likely, but we are being conservative).

Source: EPA (2010) plus numerous industry reports and presentation.

Sources of methane leaks (as percentage of life-time total production):

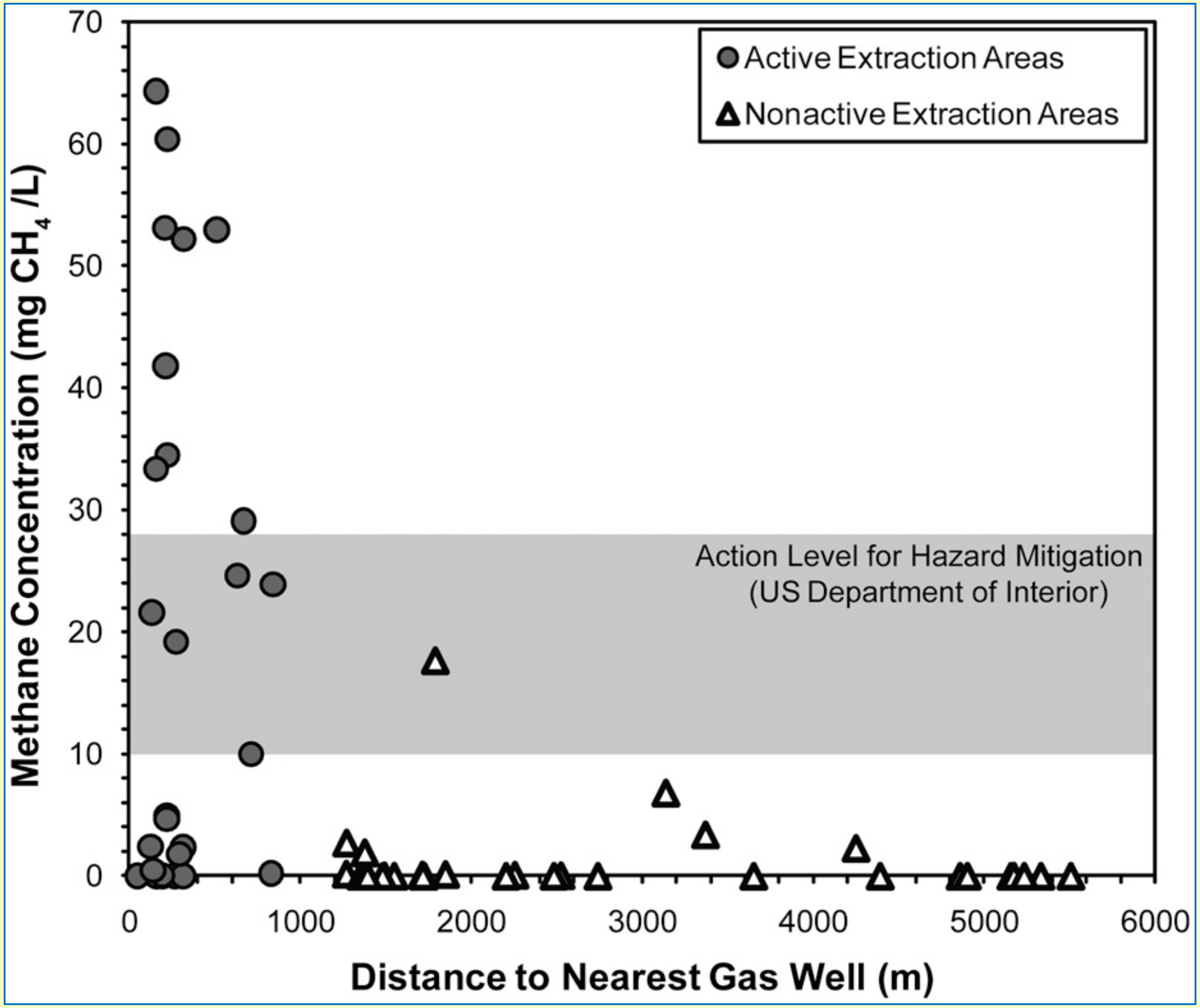
	Conventional Gas	Shale Gas
Initial drilling & completion	0.01%	1.9%
Routine leaks & emissions at well site	0.3 to 1.9%	0.3 to 1.9%

0.3% reflects use of best technology

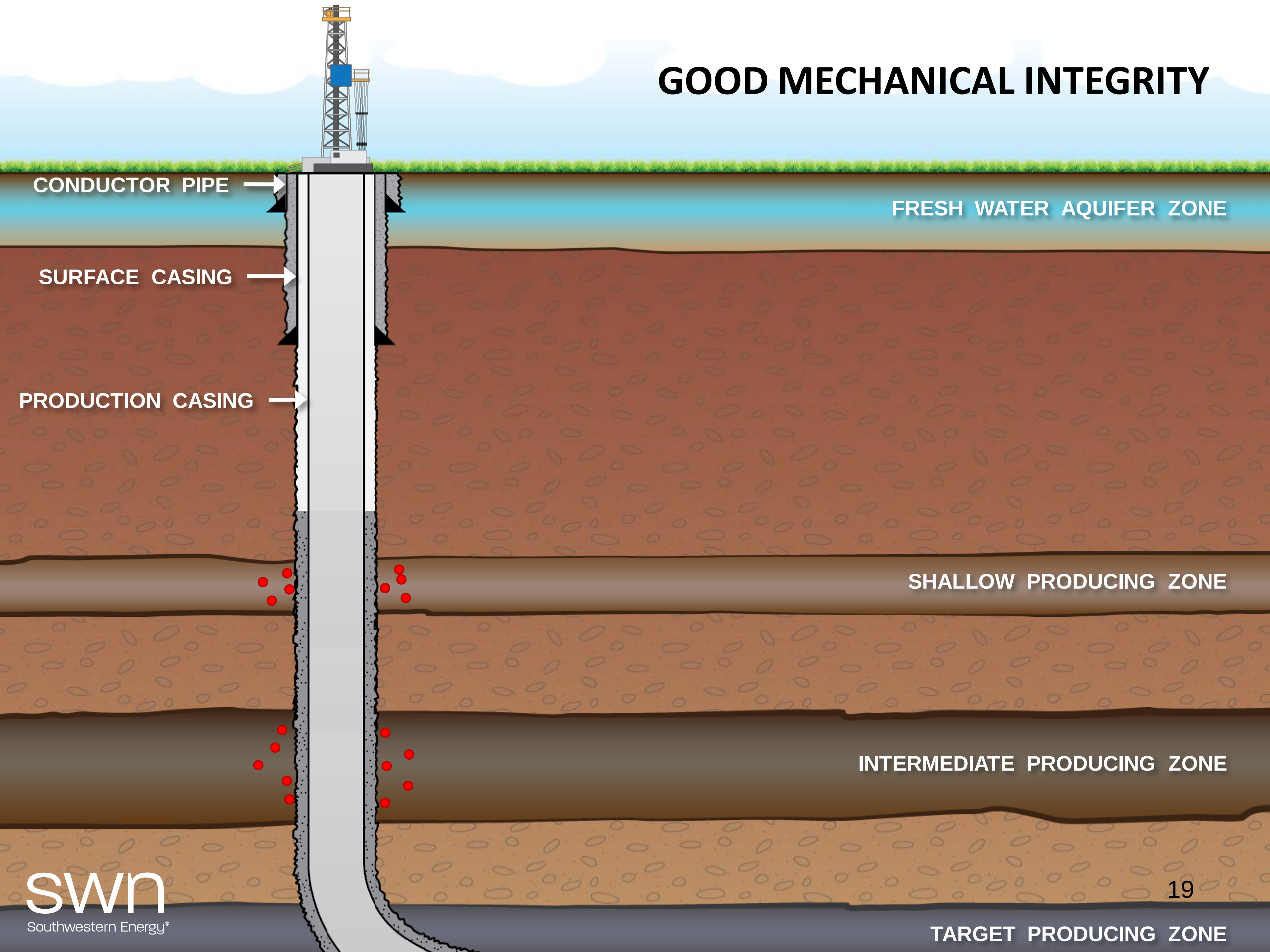
Note that routine leaks and emissions occur continuously over 7-10 year life-time of the well, contrasting with the initial drilling and completion leaks that occur in just a few weeks.

Source for routine leaks and emissions at well = GAO (2010)

Osborn et al. (2011) – widespread methane contamination in drinking water wells near gaswells in Marcellus shale



GOOD MECHANICAL INTEGRITY



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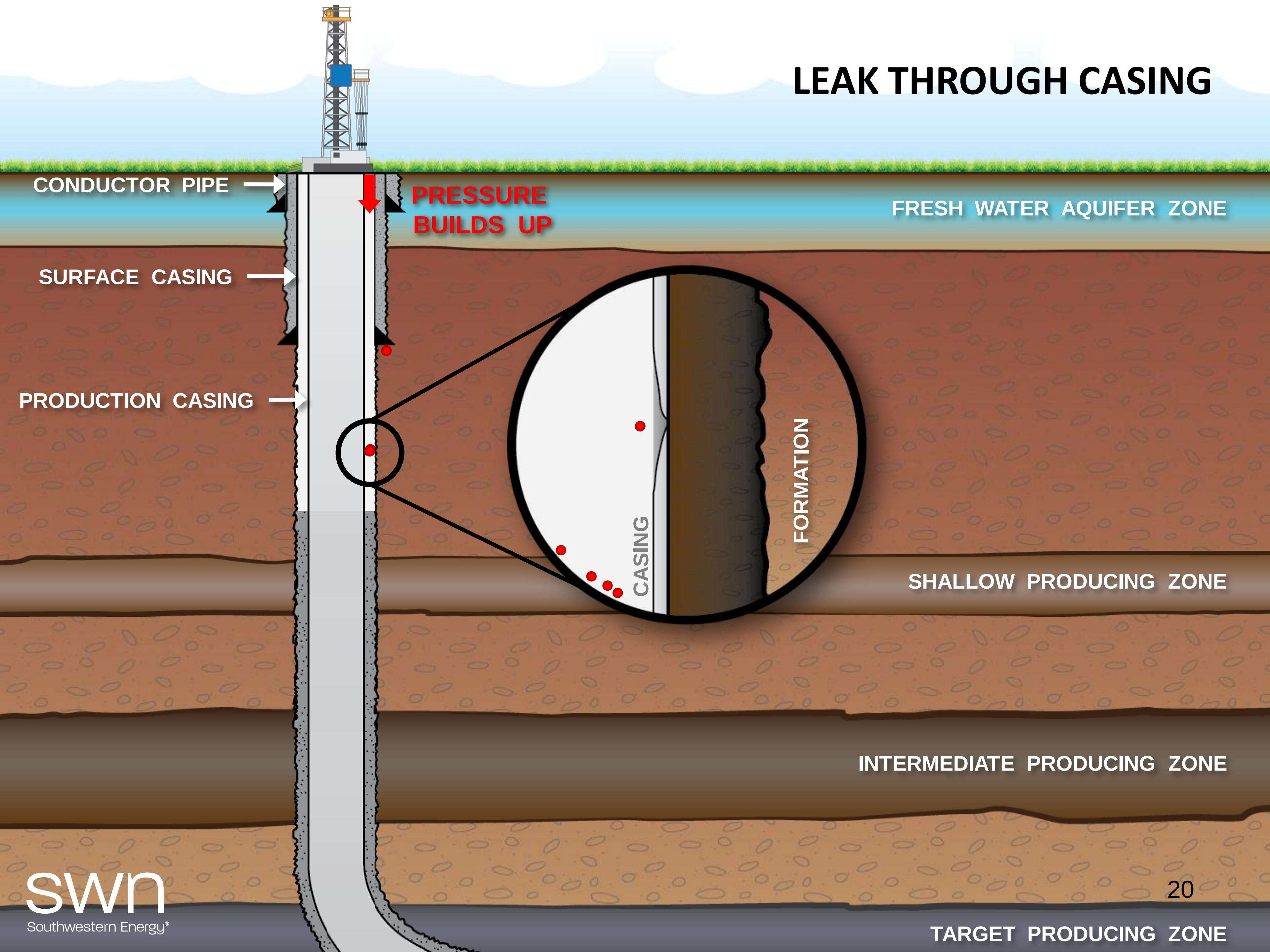
LEAK THROUGH CASING



swn
Southwestern Energy®

Sources of methane leaks (as percentage of life-time total production):

	Conventional Gas	Shale Gas
Initial drilling & completion	0.01%	1.9%
Routine leaks & emissions at well site	0.3 to 1.9%	0.3 to 1.9%
Venting during liquid unloading	0 to 0.26%	0 to 0.26%
Emissions during gas processing	0 to 0.19%	0 to 0.19%
TOTAL FOR PRODUCTION & PROCESSING	**0.31 to 2.4%**	**2.2 to 4.3%**

1.8- to 7-fold more methane leakage from shale gas during development and processing

Sources of methane leaks (as percentage of life-time total production):

	Conventional Gas	Shale Gas
Initial drilling & completion	0.01%	1.9%
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TOTAL FOR PRODUCTION & PROCESSING	**0.31 to 2.4%**	**2.2 to 4.3%**

But, this is only part of the story, as the gas has to be delivered stored, transported, and distributed.

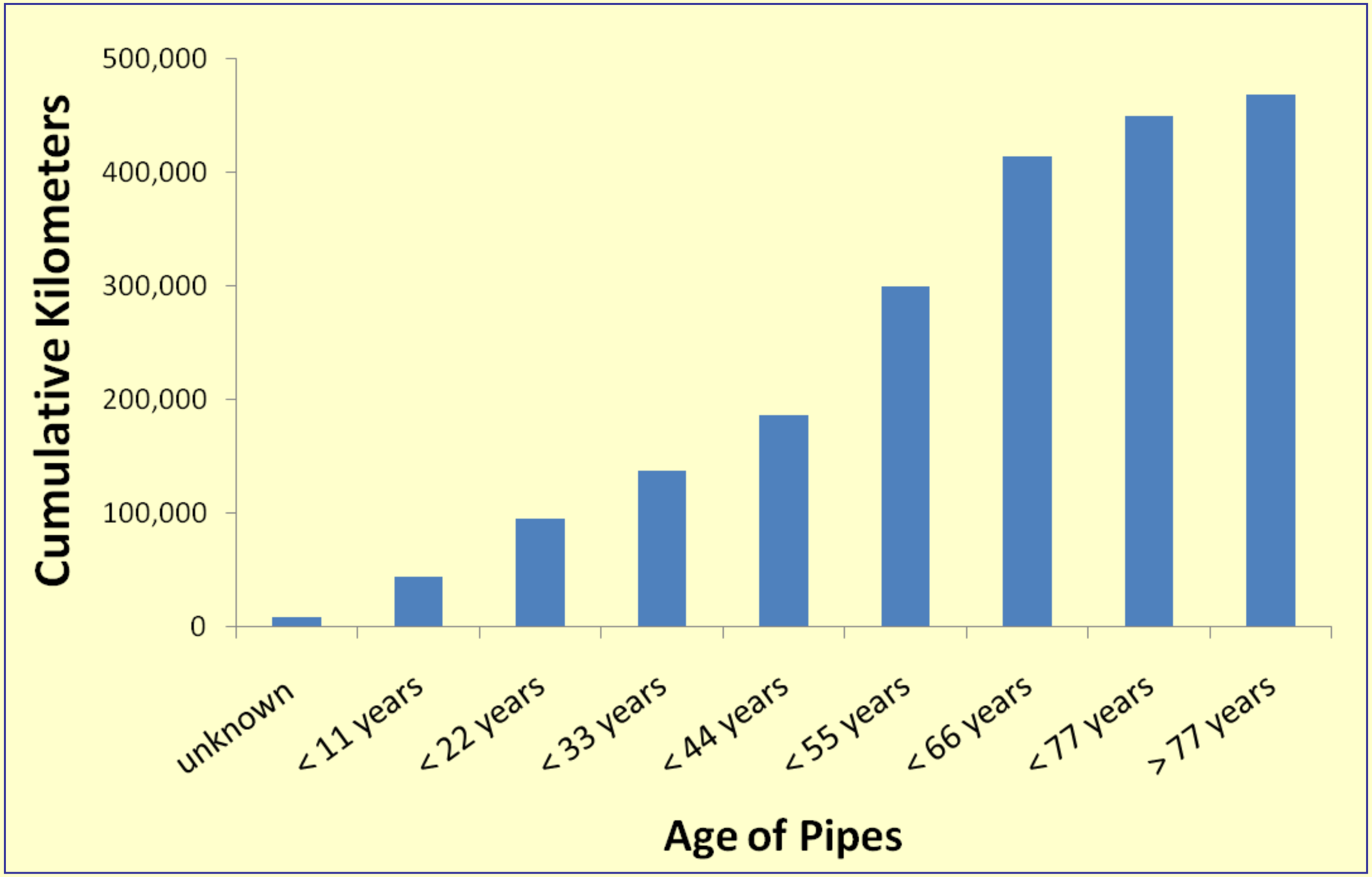
Methane (natural gas) leaks from tanks, pipelines, compressors, etc.

Naked eye

Infra-red (42)

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

Half of the natural gas transmission pipelines in the US are more than half a century old



Sources: PHMSA 2009 Transmission Annual Data

Two approaches for estimating leakage during transmission, storage, and distribution

1) Direct measurements, based on measurements on Russian pipeline during last 10-15 years (Lelieveld et al. 2005), with extrapolations from EPA (1996) study = 1.4%

Two approaches for estimating leakage during transmission, storage, and distribution

1) Direct measurements, based on measurements on Russian pipeline during last 10-15 years (Lelieveld et al. 2005), with extrapolations from EPA (1996) study = 1.4%

2) “missing and unaccounted for gas,” based on range of values in Texas over past decade (Percival 2010) = mean value of 3.6%

Sources of methane leaks (as percentage of life-time total production):

	Conventional Gas	Shale Gas
Initial drilling & completion	0.01%	1.9%
Routine leaks & emissions at well site	0.3 to 1.9%	0.3 to 1.9%
Venting during liquid unloading	0 to 0.26%	0 to 0.26%
Emissions during gas processing	0 to 0.19%	0 to 0.19%
Transmission, storage, and distribution	1.4 to 3.6%	1.4 to 3.6%
Total	**1.7 to 6.0%**	**3.6 to 7.9%**

Urban infrastructure is old…. In Philadelphia, gas distribution pipes are 100 years old, made of un-welded iron pipe.

Gas leakage within the city is ~ 3%.

Chris Kimmerle, Executive Director, Philadelphia Gas Commission, pers. comm, April 19, 2011

How do our methane emission estimates compare with others from the peer-reviewed literature?

How do our methane emission estimates compare with others from the peer-reviewed literature?

1) There are no other peer-reviewed papers on methane emissions from shale gas….

   The only current and credible report, from EPA on November 30, 2010, was not peer-reviewed. Our estimates are broadly consistent with this EPA report.

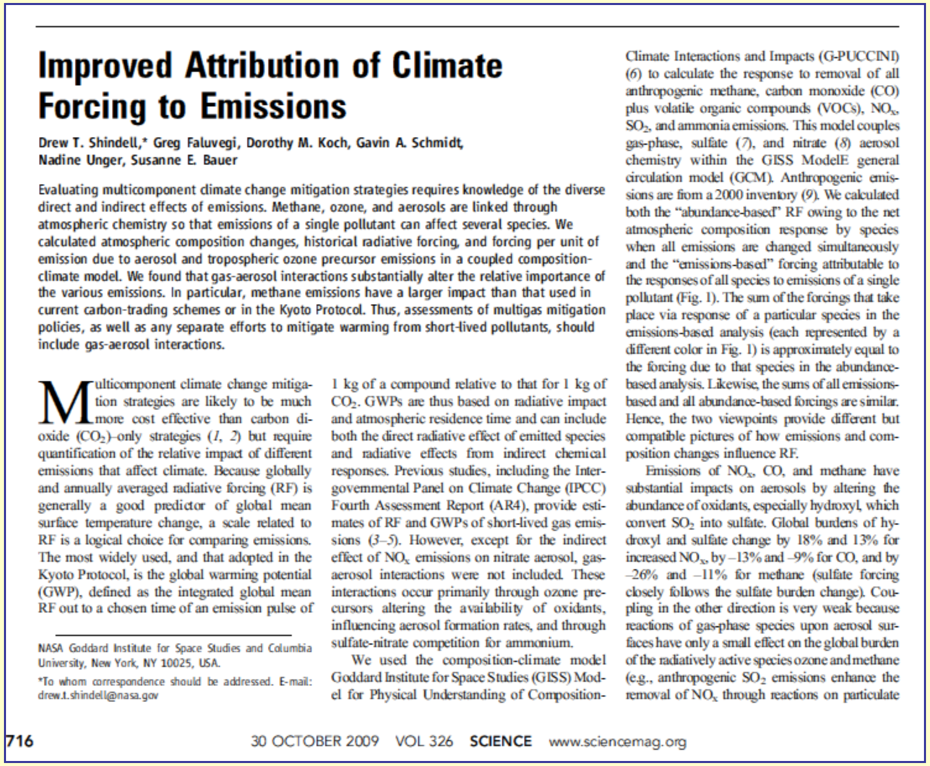
How do our methane emission estimates compare with others from the peer-reviewed literature?

2) We can compare our estimates for <u>conventional gas</u> with 2 other peer-reviewed papers

- Howarth et al. (2011) = 1.7% to 6%
- Hayhoe et al. (2002), "best estimate" = 3%
  (range of 0.7% to 10%)
- Jamarillo et al. (2007) = 1.1%
  (based entirely on EPA 1996 report; in 2010, EPA greatly increased these estimates)

Methane is far greater in its global warming potential than is carbon dioxide

- **105-fold, compared over 20-year period following emission.**
- **33-fold, compared over 100-year period following emission.**



Improved Attribution of Climate Forcing to Emissions

Drew T. Shindell,* Greg Faluvegi, Dorothy M. Koch, Gavin A. Schmidt,
Nadine Unger, Susanne E. Bauer

Evaluating multicomponent climate change mitigation strategies requires knowledge of the diverse direct and indirect effects of emissions. Methane, ozone, and aerosols are linked through atmospheric chemistry so that emissions of a single pollutant can affect several species. We calculated atmospheric composition changes, historical radiative forcing, and forcing per unit of emission due to aerosol and tropospheric ozone precursor emissions in a coupled composition-climate model. We found that gas-aerosol interactions substantially alter the relative importance of the various emissions. In particular, methane emissions have a larger impact than that used in current carbon-trading schemes or in the Kyoto Protocol. Thus, assessments of multigas mitigation policies, as well as any separate efforts to mitigate warming from short-lived pollutants, should include gas-aerosol interactions.

Multicomponent climate change mitigation strategies are likely to be much more cost effective than carbon dioxide (CO_2)–only strategies (*1*, *2*) but require quantification of the relative impact of different emissions that affect climate. Because globally and annually averaged radiative forcing (RF) is generally a good predictor of global mean surface temperature change, a scale related to RF is a logical choice for comparing emissions. The most widely used, and that adopted in the Kyoto Protocol, is the global warming potential (GWP), defined as the integrated global mean RF out to a chosen time of an emission pulse of 1 kg of a compound relative to that for 1 kg of CO_2. GWPs are thus based on radiative impact and atmospheric residence time and can include both the direct radiative effect of emitted species and radiative effects from indirect chemical responses. Previous studies, including the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4), provide estimates of RF and GWPs of short-lived gas emissions (*3*–*5*). However, except for the indirect effect of NO_x emissions on nitrate aerosol, gas-aerosol interactions were not included. These interactions occur primarily through ozone precursors altering the availability of oxidants, influencing aerosol formation rates, and through sulfate-nitrate competition for ammonium.

We used the composition-climate model Goddard Institute for Space Studies (GISS) Model for Physical Understanding of Composition-Climate Interactions and Impacts (G-PUCCINI) (*6*) to calculate the response to removal of all anthropogenic methane, carbon monoxide (CO) plus volatile organic compounds (VOCs), NO_x, SO_2, and ammonia emissions. This model couples gas-phase, sulfate (*7*), and nitrate (*8*) aerosol chemistry within the GISS ModelE general circulation model (GCM). Anthropogenic emissions are from a 2000 inventory (*9*). We calculated both the "abundance-based" RF owing to the net atmospheric composition response by species when all emissions are changed simultaneously and the "emissions-based" forcing attributable to the responses of all species to emissions of a single pollutant (Fig. 1). The sum of the forcings that take place via response of a particular species in the emissions-based analysis (each represented by a different color in Fig. 1) is approximately equal to the forcing due to that species in the abundance-based analysis. Likewise, the sums of all emissions-based and all abundance-based forcings are similar. Hence, the two viewpoints provide different but compatible pictures of how emissions and composition changes influence RF.

Emissions of NO_x, CO, and methane have substantial impacts on aerosols by altering the abundance of oxidants, especially hydroxyl, which convert SO_2 into sulfate. Global burdens of hydroxyl and sulfate change by 18% and 13% for increased NO_x, by –13% and –9% for CO, and by –26% and –11% for methane (sulfate forcing closely follows the sulfate burden change). Coupling in the other direction is very weak because reactions of gas-phase species upon aerosol surfaces have only a small effect on the global burden of the radiatively active species ozone and methane (e.g., anthropogenic SO_2 emissions enhance the removal of NO_x through reactions on particulate

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*To whom correspondence should be addressed. E-mail: drew.t.shindell@nasa.gov

Converting methane to global warming potential equivalents, in terms of CO_2

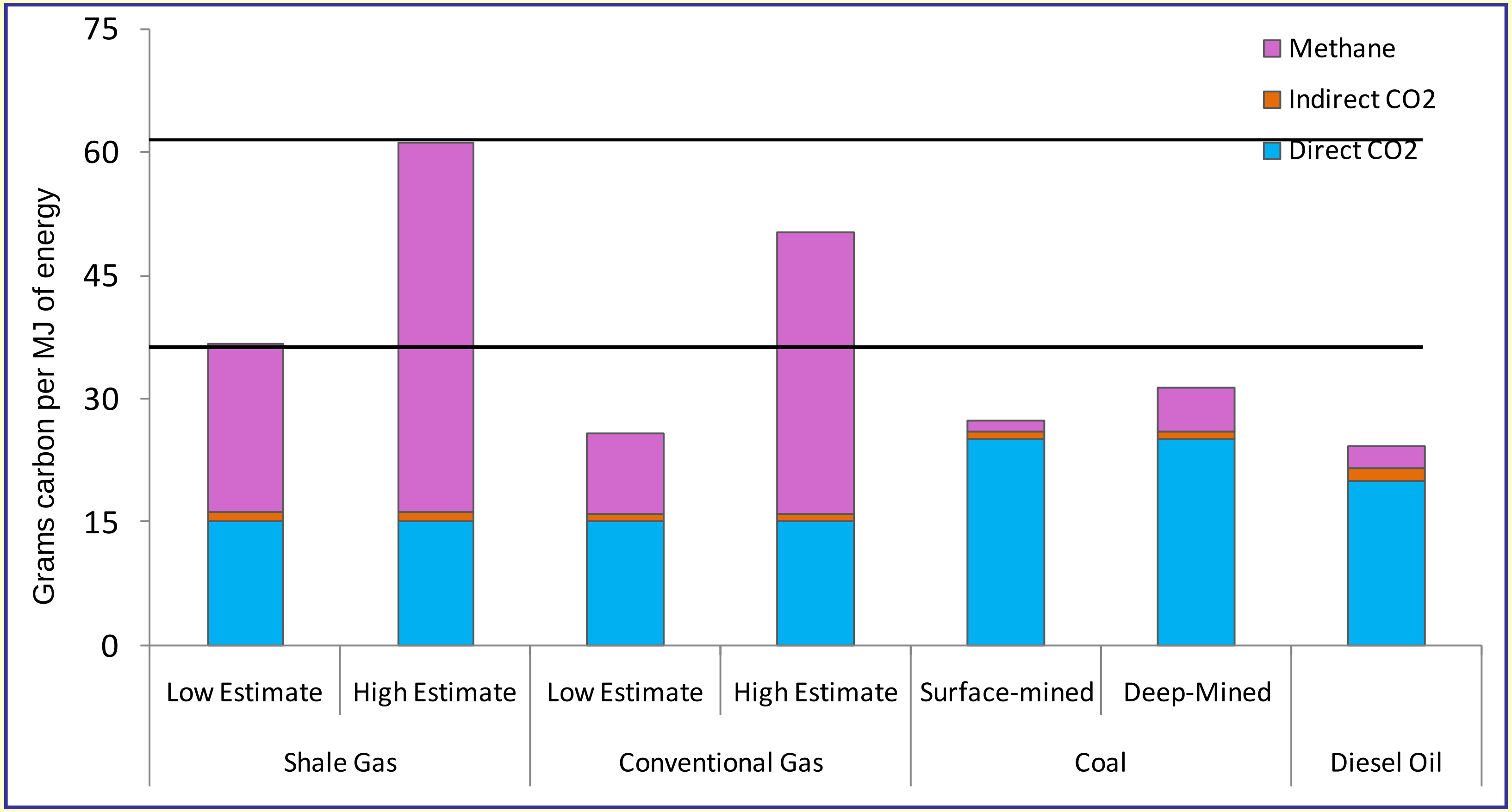
- IPCC (1995) considered only 100-year time frame;
  GWP = 21
  (used in all previous peer-reviewed studies, although Hayhoe et al. 2002 and Lelieveld et al. 2005 emphasized need for shorter horizons).

- IPCC (2007); GWP for 100-year horizon = 25
  GWP for 20-year horizon = 72

- Shindell et al. (2009), Science: GWP for 100-year = 33
  GWP for 20-year = 105

Greenhouse gas footprint of shale gas and other fossil fuels

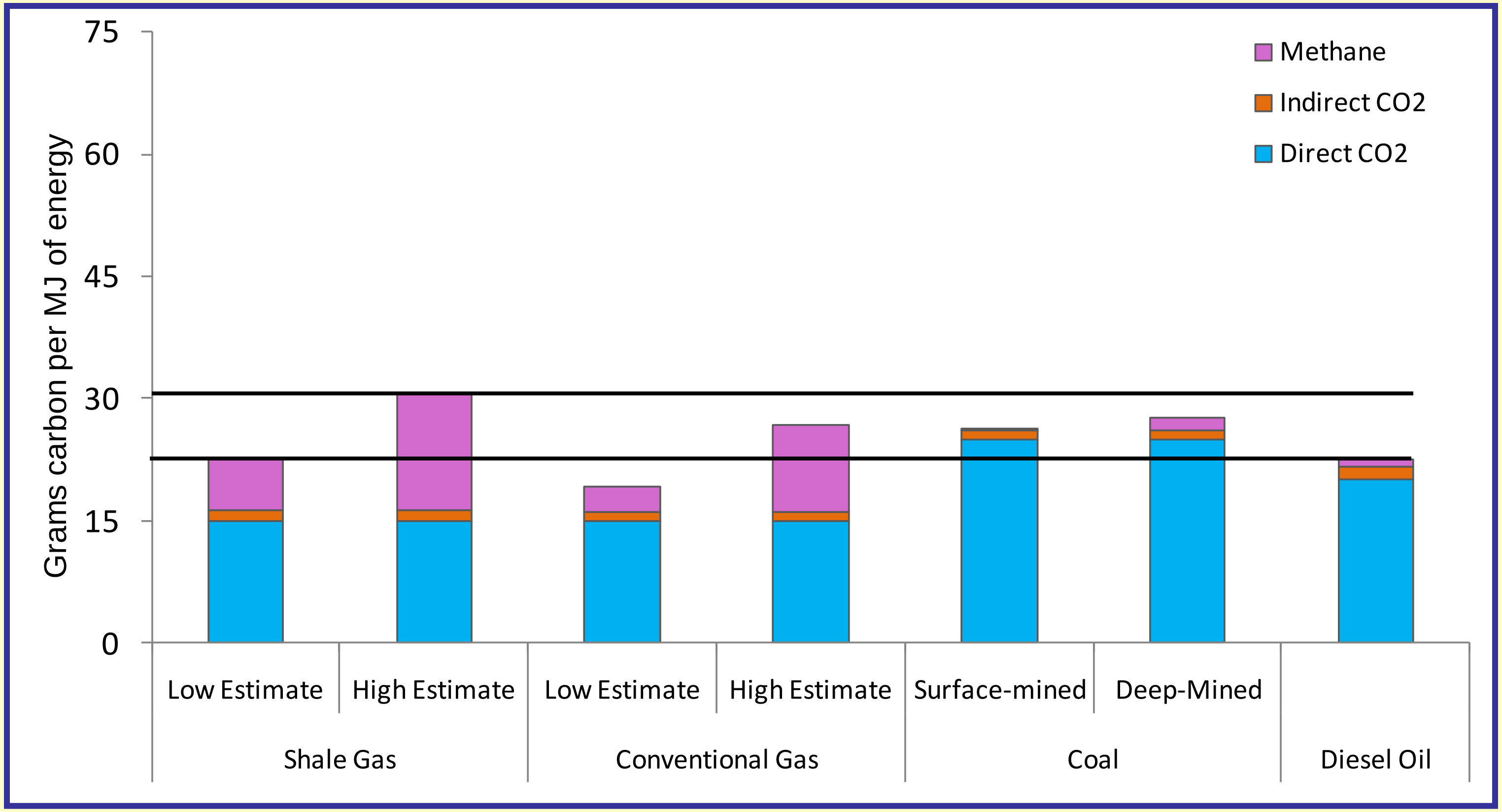
(20-year analysis; methane given in CO2 equivalents, assuming Global warming Potential = 105)



(Howarth et al. 2011)

Greenhouse gas footprint of shale gas and other fossil fuels

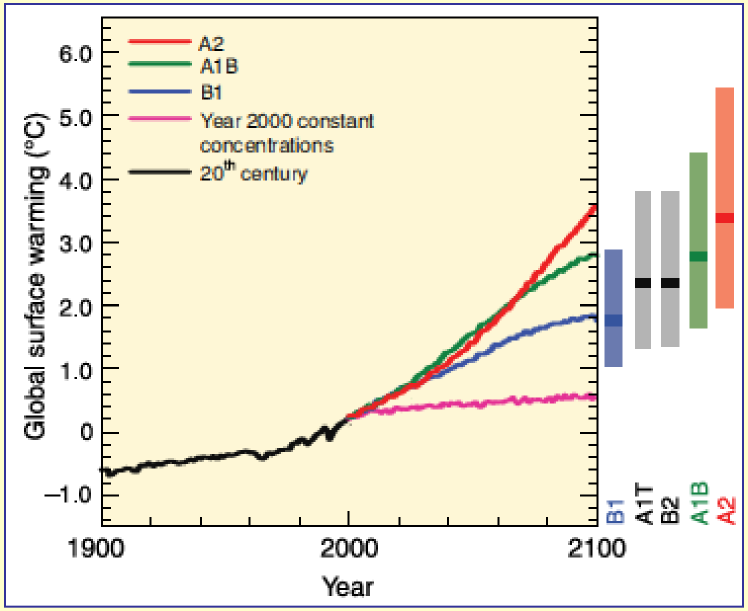
(100-year analysis; methane given in CO2 equivalents, assuming Global warming Potential = 33)

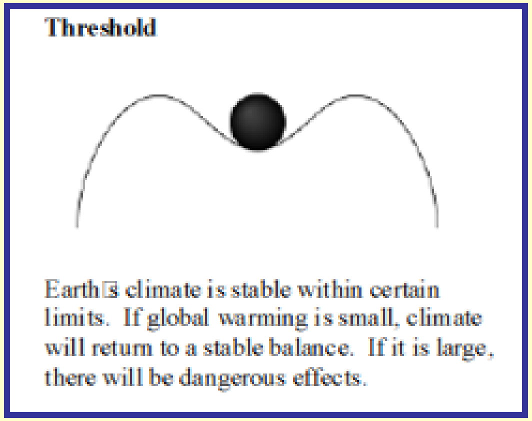


(Howarth et al. 2011)

Existing models for global warming potential (GWP) of methane only support analysis at 20-year and 100-year integrated time scales.

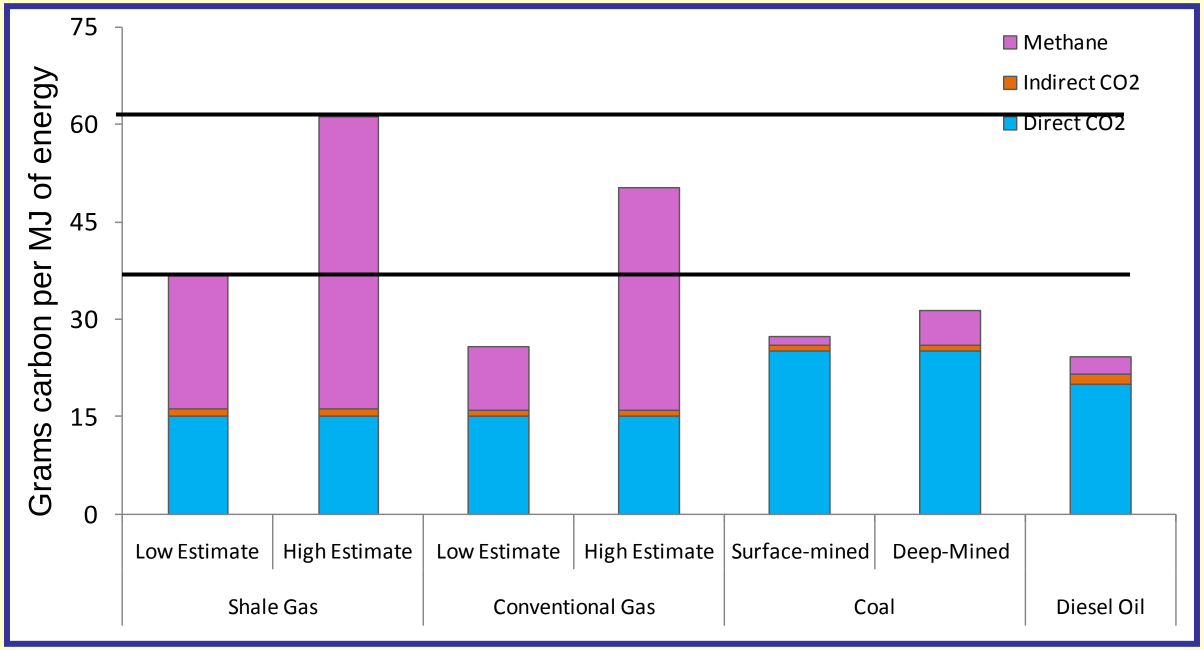
Both are important. But shorter time focus critical to minimize likelihood of surpassing tipping points and moving climate system to some new, undesirable state.



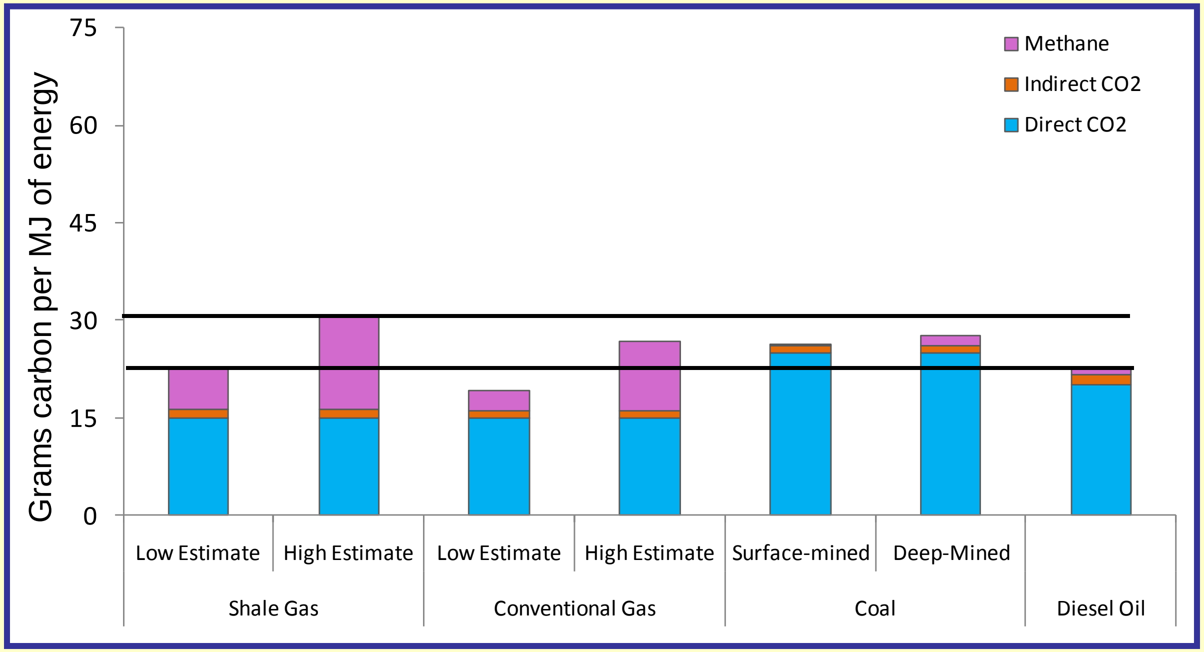

Threshold

Earth's climate is stable within certain limits. If global warming is small, climate will return to a stable balance. If it is large, there will be dangerous effects.

20 year

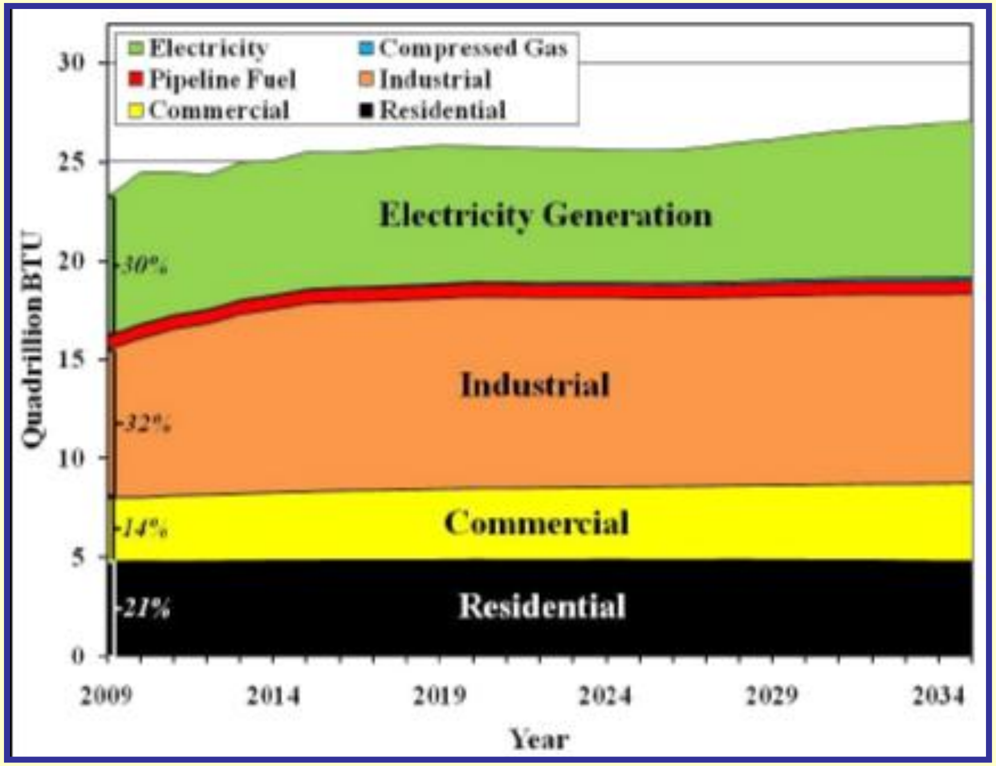


100 year

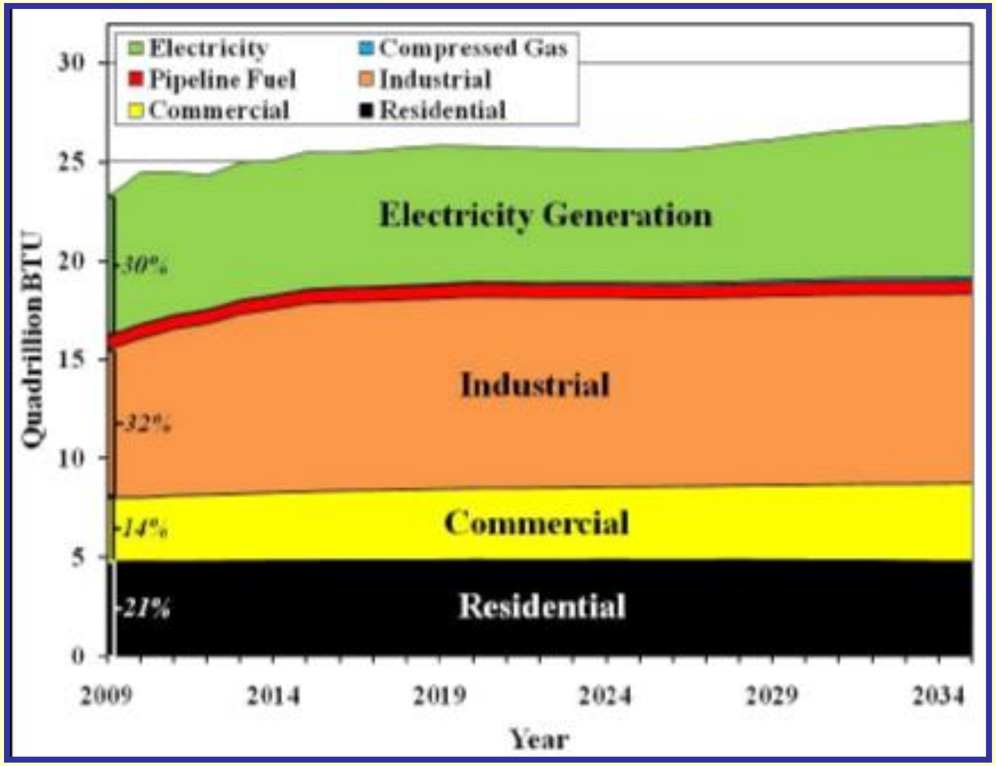


(Howarth et al. 2011)

Only 30% of natural gas in the U.S. is used to generate electricity….



http://www.eia.doe.gov/forecasts/aeo/excel/aeotab_2.xls



Efficiency of use of natural gas for most uses (including transportation) is very similar to that of oil or coal.

For electricity, natural gas gains some efficiency over coal….

But even for electricity, GHG footprint for shale gas is similar to or worse than that for coal.

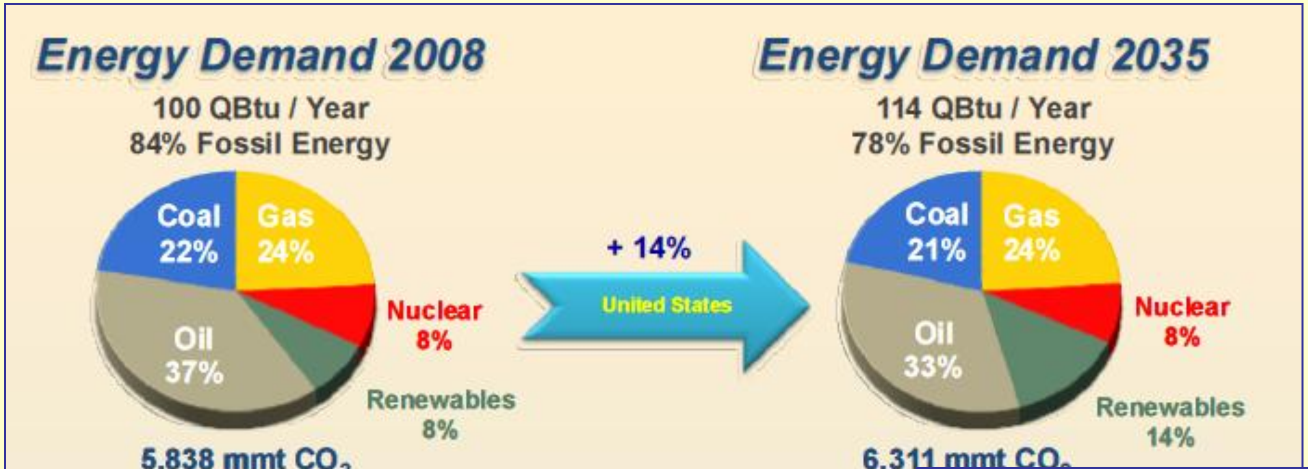
Emissions from generating electricity

(g C-CO_2 equivalents/kWatt-hr, 20-year integration)

	Current average plant	Best technology
Coal	**280**	**220**
Shale gas	**320-560**	**270-460**

(Hughes 2011)

Very modest growth in use of both coal and natural gas predicted…. NOT replacement of coal by natural gas.



Energy Demand 2008

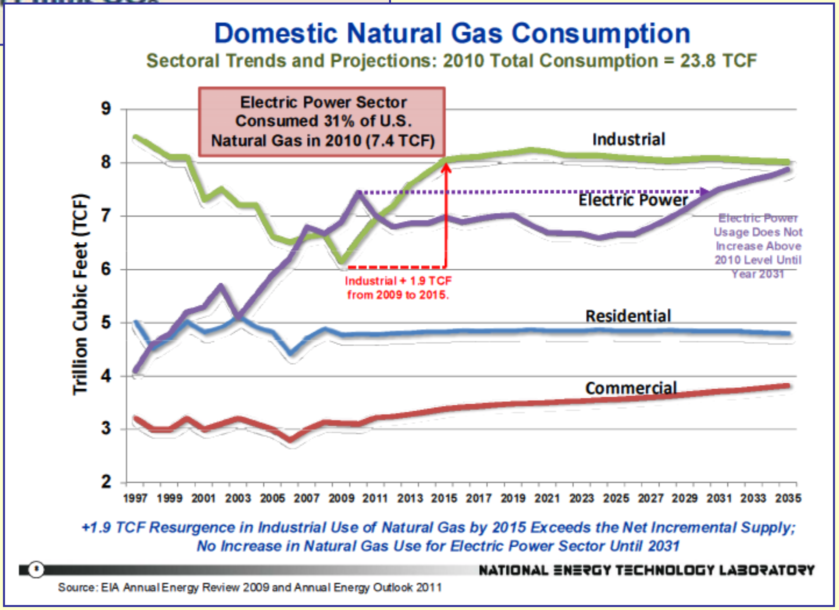
100 QBtu / Year
84% Fossil Energy

5,838 mmt CO_2

Energy Demand 2035

114 QBtu / Year
78% Fossil Energy

6,311 mmt CO_2



Domestic Natural Gas Consumption

Sectoral Trends and Projections: 2010 Total Consumption = 23.8 TCF

Electric Power Sector Consumed 31% of U.S. Natural Gas in 2010 (7.4 TCF)

Industrial + 1.9 TCF from 2009 to 2015.

Electric Power Usage Does Not Increase Above 2010 Level Until Year 2031

+1.9 TCF Resurgence in Industrial Use of Natural Gas by 2015 Exceeds the Net Incremental Supply; No Increase in Natural Gas Use for Electric Power Sector Until 2031

NATIONAL ENERGY TECHNOLOGY LABORATORY

Source: EIA Annual Energy Review 2009 and Annual Energy Outlook 2011

Annual Energy Outlook (2011) , Energy Information Agency, U.S. Department of Energy

How does natural gas fit into the national greenhouse gas inventory?

Update by US EPA on methane emissions from gas (Nov. 30, 2010):

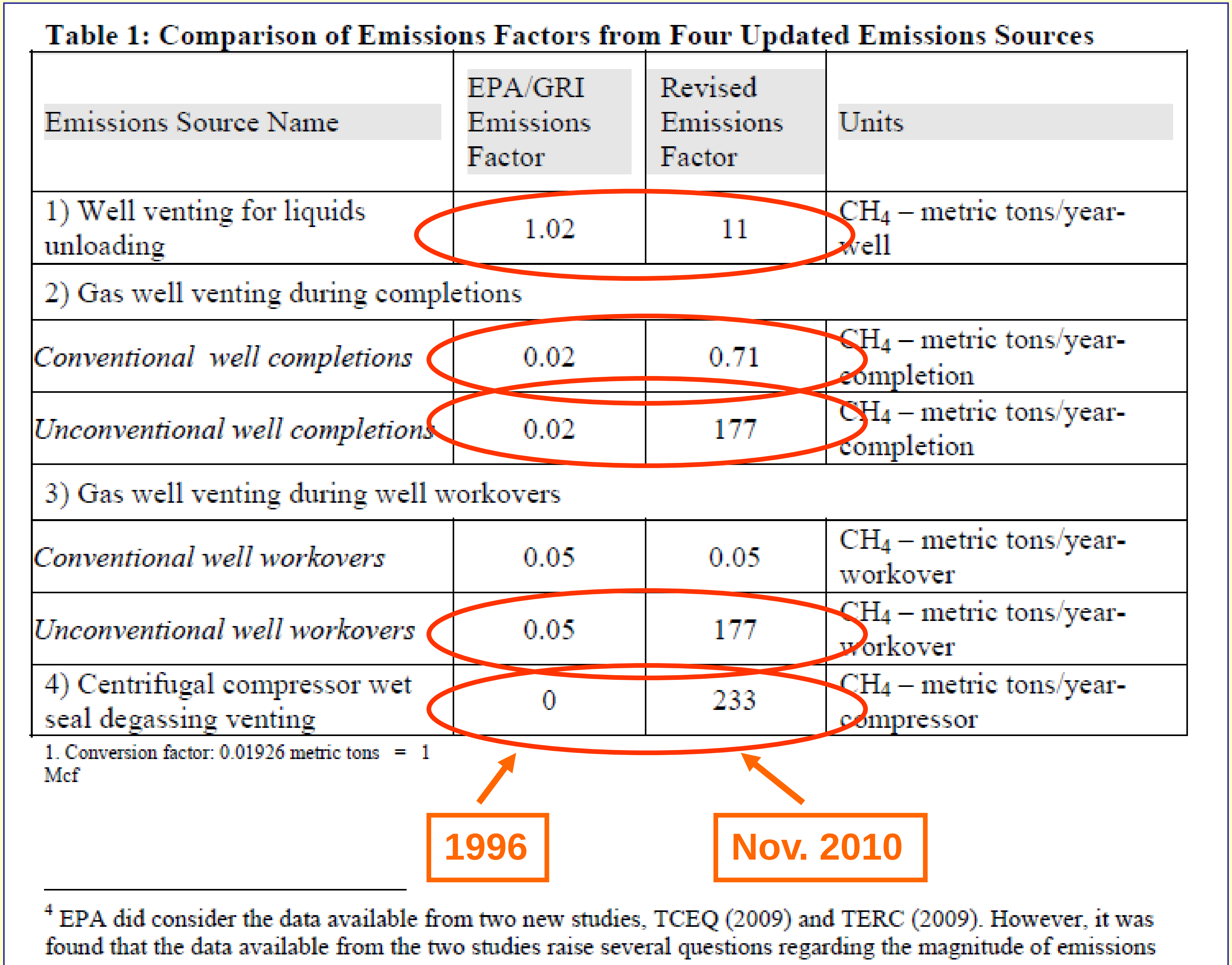


Table 1: Comparison of Emissions Factors from Four Updated Emissions Sources

Emissions Source Name	EPA/GRI Emissions Factor	Revised Emissions Factor	Units
1) Well venting for liquids unloading	1.02	11	CH_4 – metric tons/year-well
2) Gas well venting during completions			
Conventional well completions	0.02	0.71	CH_4 – metric tons/year-completion
Unconventional well completions	0.02	177	CH_4 – metric tons/year-completion
3) Gas well venting during well workovers			
Conventional well workovers	0.05	0.05	CH_4 – metric tons/year-workover
Unconventional well workovers	0.05	177	CH_4 – metric tons/year-workover
4) Centrifugal compressor wet seal degassing venting	0	233	CH_4 – metric tons/year-compressor

1. Conversion factor: 0.01926 metric tons = 1 Mcf

1996

Nov. 2010

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[4] EPA did consider the data available from two new studies, TCEQ (2009) and TERC (2009). However, it was found that the data available from the two studies raise several questions regarding the magnitude of emissions

U.S. Greenhouse gas inventory
(Tg CO_2 equivalents per year, 2008 base year)

	Old estimate (2010 analysis)	New estimate (2011 analysis)
Total net GHG emissions	5,916	6,020
Methane emissions (percent of total)	568 (9.6%)	677 (11%)
Methane from natural gas (percent of total)	97 (1.6%)	212 (3.5%)

Based on EPA (2011), using methane global warming potential = 21

Data from: http://www.epa.gov/climatechange/emissions/usinventoryreport.html

U.S. Greenhouse gas inventory

(Tg CO2 equivalents per year, 2008 base year)

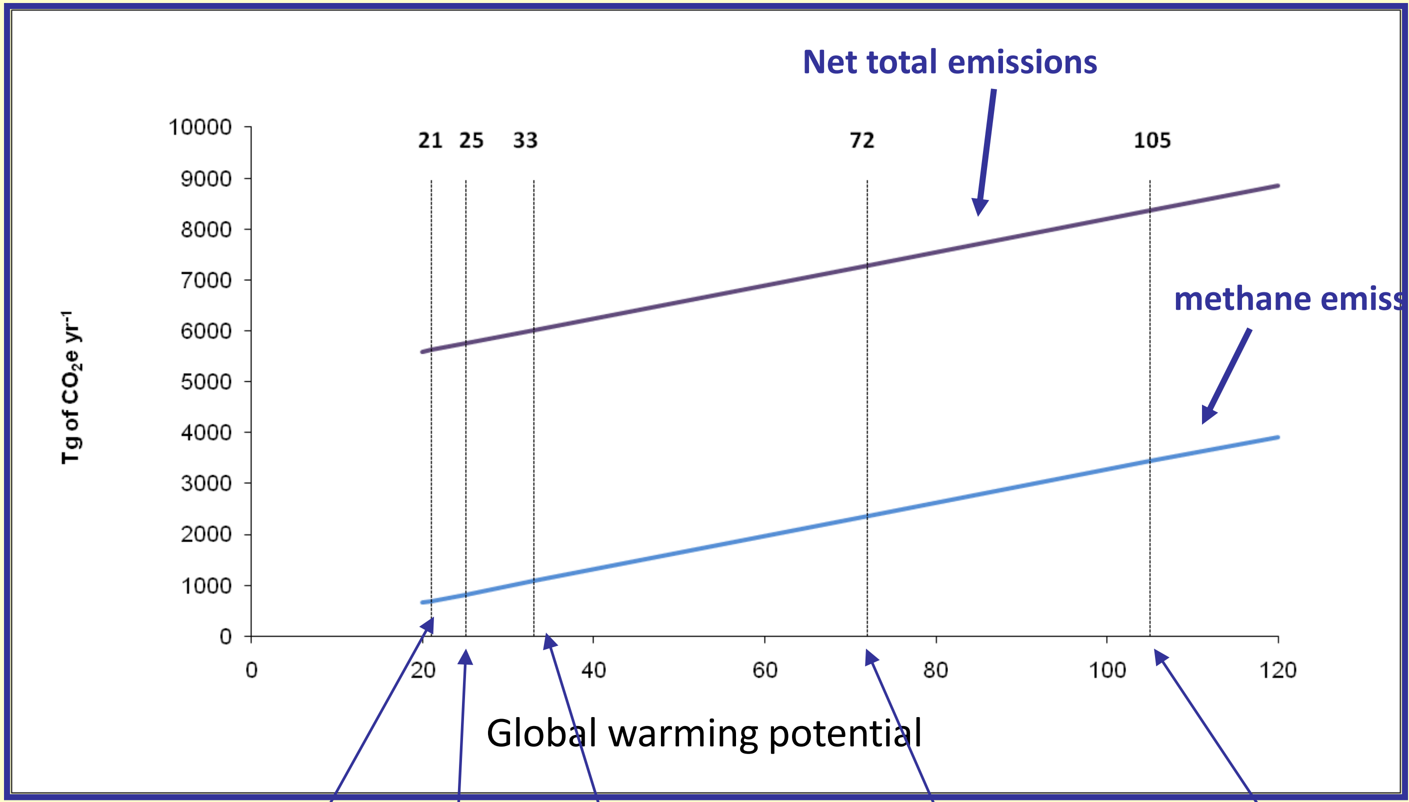
Equal to 3.1% leakage of all natural gas production, well within our range of 1.7% to 6% for conventional gas

	Old estimate	New estimate (2011 analysis)
[illegible]	[illegible]	6,020
Methane emissions	568	677
Methane from natural gas	97	212

Based on EPA (2011), using methane global warming potential = 21

Data from: http://www.epa.gov/climatechange/emissions/usinventoryreport.html

Influence of Global Warming Potential (GWP) on U.S. estimation of net emissions of all greenhouse gases and methane emissions



IPCC (1996), 100-year, used by EPA (2011)

IPCC (2007), 100-year

Shindell et al. (2009), 100-year

IPCC (2007), 20-year

Shindell et al. (2009), 20-year

Emissions data from EPA (2011)

The greenhouse gas footprint of natural gas will increase as conventional gas is further replaced by shale gas and other unconventional gas….

Using DOE (2011) projections for shale gas development and 20-year integrated GWP, the increased use of shale gas will increase the entire greenhouse gas footprint for the US by up to 9% by 2035 (with no increase in available gas or energy).

Cornell University
College of Agriculture and Life Sciences

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Thanks to my co-authors, Renee Santoro and Tony Ingraffea.


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LETTER

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

A letter

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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

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The Long-Lost Siblings of OUR SUN

page 40

A Plan for a Sustainable Future

How to get all energy from wind, water and solar power by 2030

Jacobson and Delucchi 2009

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May 4, 2010

We represent the leadership of over 1.4 million scientists in over 150 scientific disciplines.

The acceleration of greenhouse gas (GHG) emissions from human activity is increasingly leading to harmful climate change and ocean acidification. Societies must act urgently to reduce these emissions to protect the life-sustaining biophysical systems of the Earth. As noted by DoE Secretary Steven Chu in his Apri 28, 2010 testimony to the Senate Subcommittee on Energy and Water Development, the necessary transition "will require nothing short of a new industrial revolution." We agree with this assessment of the scale of response needed. We need to work aggressively to conserve energy and increase the efficiency of energy use, and we need rapidly to develop less polluting energy systems. Objective science has a critical role to play, and we urge that the nation fully use and incorporate the best available science in designing and implementing th energy and environmental policies necessary to guide the revolution.

America should move ahead quickly to develop a comprehensive energy policy to greatly reduce our GHG emissions. We urge that any potential approach be first evaluated in terms of the net benefits on environmental integrity, including a full analysis of GHG emissions, recognized by the Supreme Court as air pollutants, as well as other environmental concerns. The analysis of GHG emissions should include indirect land use effects and emissions of methane and nitrous oxide as well as carbon dioxide. No policy should be implemented without a full understanding of the consequences on the environment. Uncertainties will remain, which points to the necessity of also having the ability to reverse a policy action if unintended consequences are discovered.

Some energy bridges that are currently encouraged in the transition away from GHG-emitting fossil energy systems have received inadequate scientific analysis before implementation, and these may have greater GHG emissions and environmental costs than often appreciated. We find that their environmental impact studies and EPA determinations necessary to proceed are absent or inadequate. These include the production of ethanol from corn, where recent, more inclusive research concludes this is a poor option. As scientists we are concerned about the impact of the ethanol scale-up on water supply and quality, land use, GHG emissions, and net energy gain. In 2007, the nation used 27% of its corn harvest to produce 1.3% of total liquid fuels. One unintended result is greater nutrient flows down the Mississippi River, aggravating the ecological disaster underway in the Gulf of Mexico. Other biomass fedstocks produce more energy from less land, with less environmental harm. A recent report from the National Academy of Sciences lists many topics that deserve further scientific scrutiny before the nation further expands the role of ethanol as a fuel.

The production of natural gas (methane)from shales represents a major new domestic energy resource that can reduce reliance on imported crude oil. However, the development of methane from shale formations is another example where policy has preceeded adequate scientific study. Economic recovery of methane from shales requires the drilling of long-reach horizontal wells and the high-pressure injection of millions of gallons of water with chemical additives to release the gas through a process called hydrofracking. Despite the utilization of millions of gallons of water and the flow back to the surface of these injected fluids, hydrofracking is exempted from the Clean Water Act. Exploitation of the Marcellus Shale Formation in the Appalachian basin, recognized as the largest shale-gas reserve in the U.S., could occur across a five-state region. Prior, thorough science-based studies are required to evaluate the impact of massive shale development on rural land uses, water supply and quality, and full-life-cycle greenhouse gas emissions.

Sincerely,

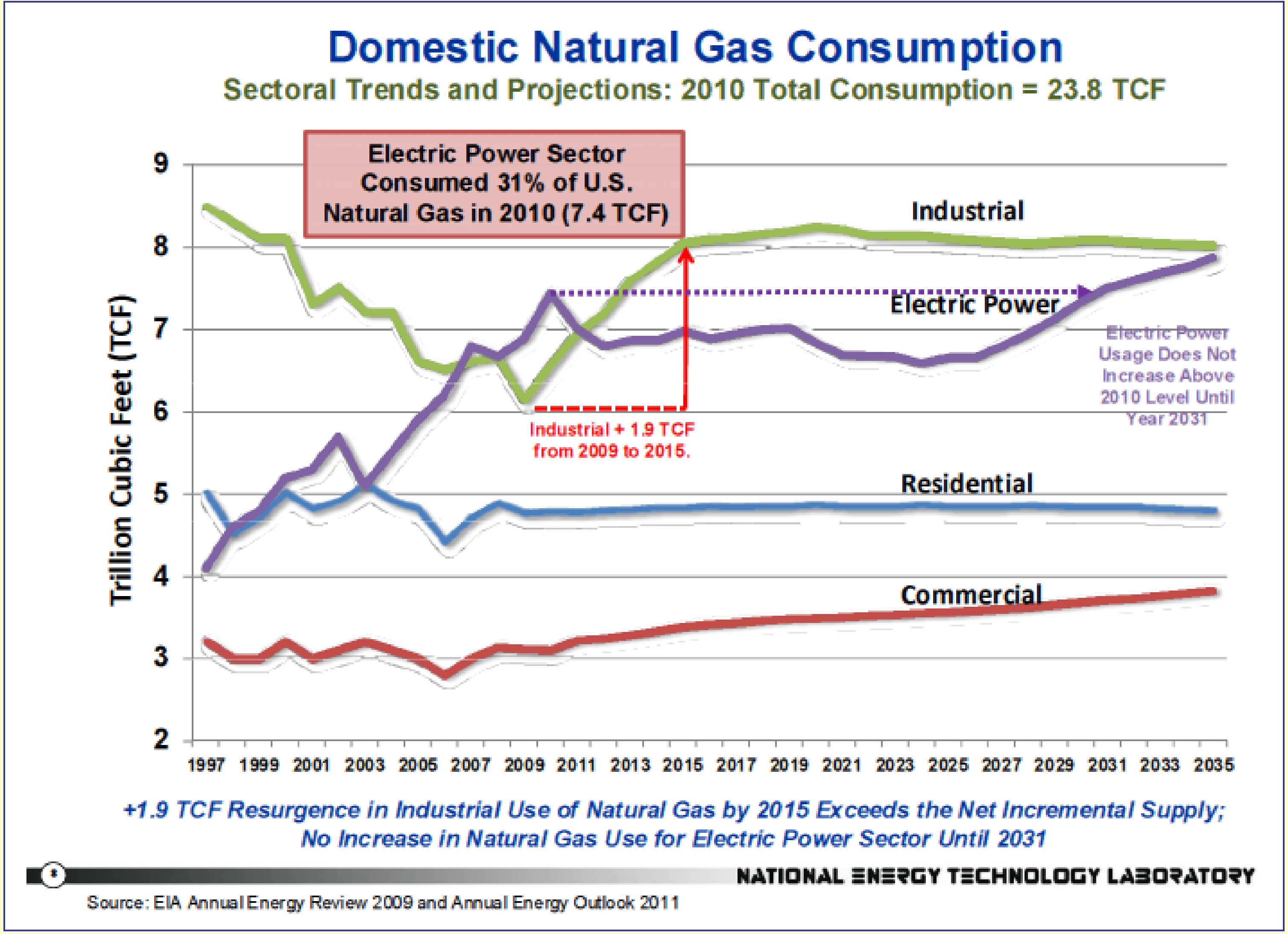
"The acceleration of greenhouse gas (GHG) emissions from human activity is increasingly leading to harmful climate change and ocean acidification. Societies must act urgently to reduce these emissions to protect the life-sustaining biophysical systems of the Earth."

"……the necessary transitions will require nothing short of a new industrial revolution."

"……..some energy bridges that are currently encouraged in the transition away from GHG-emitting fossil energy systems have received inadequate scientific analysis before implementation, and these **may have greater GHG emissions and environmental costs than often appreciated."**

"…. …**the development of methane from shale formations is another example where policy has preceeded adequate scientific study."**

Only 30% of natural gas in the U.S. is used to generate electricity….



Domestic Natural Gas Consumption

Sectoral Trends and Projections: 2010 Total Consumption = 23.8 TCF

+1.9 TCF Resurgence in Industrial Use of Natural Gas by 2015 Exceeds the Net Incremental Supply; No Increase in Natural Gas Use for Electric Power Sector Until 2031

NATIONAL ENERGY TECHNOLOGY LABORATORY

Source: EIA Annual Energy Review 2009 and Annual Energy Outlook 2011

U.S. Department of Energy (2011)

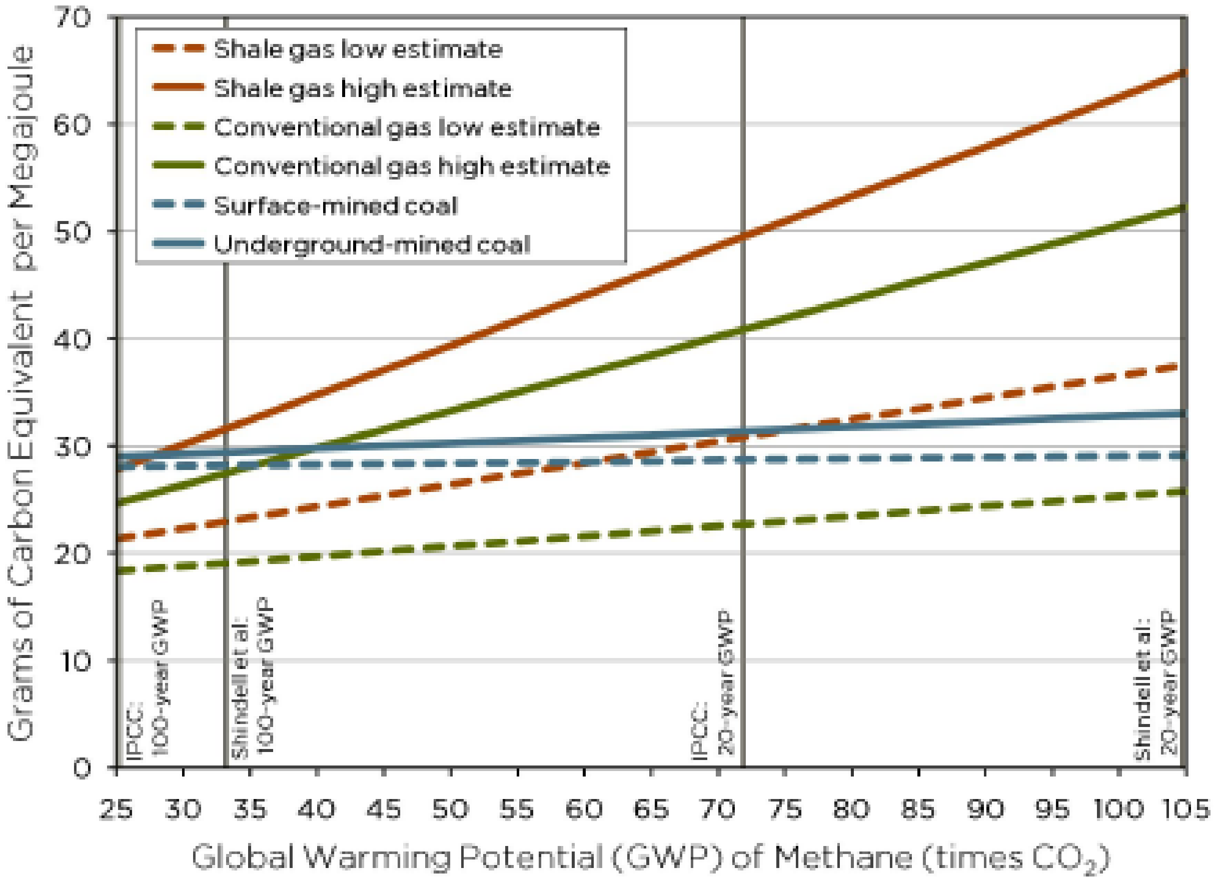


Figure 22. Comparison of Howarth et al.[94] estimates for shale gas, conventional gas and coal in terms of carbon emissions per unit of heat versus Global Warming Potential (GWP) using the estimates of the IPCC[95] and Shindell et al.[96] on 20- and 100-year timeframes.

Hughes (2011)

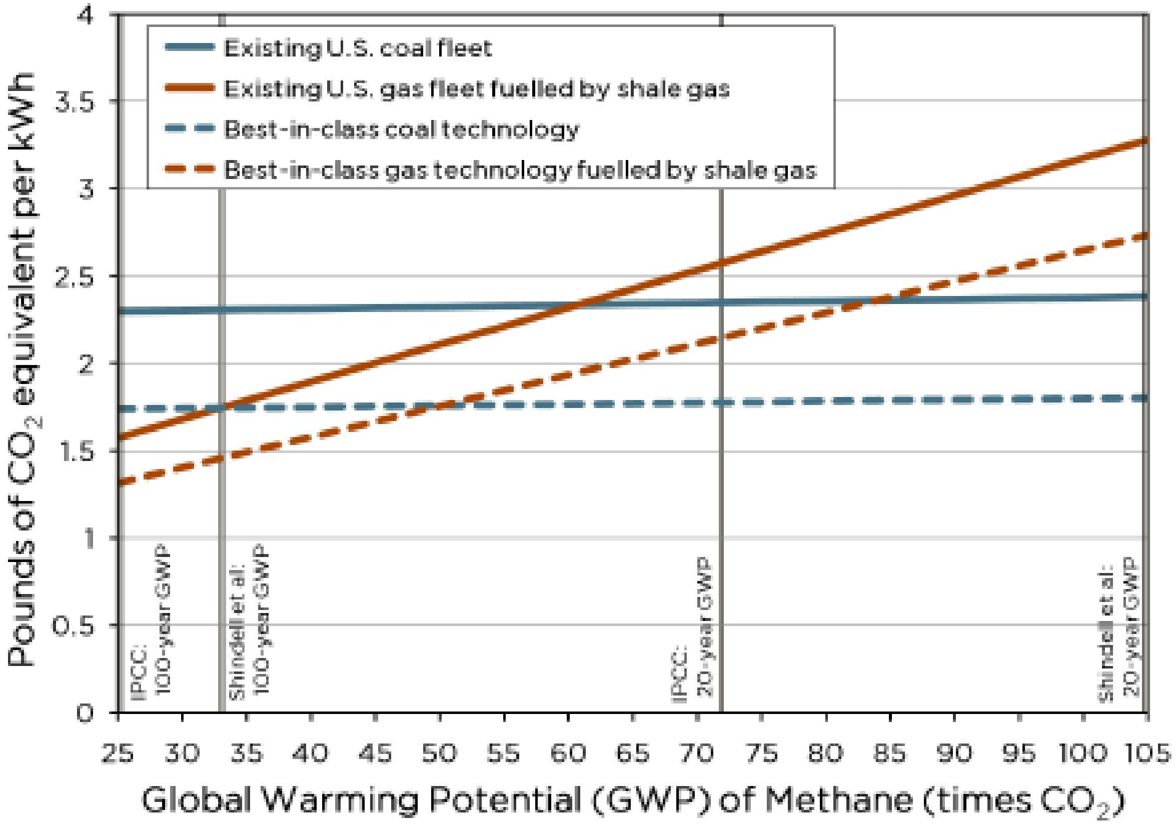


Figure 23. Comparison of CO_2 equivalent emissions per kilowatt-hour for the mean shale gas emission estimate of Howarth et al.[112] compared to surface-mined coal for both the existing coal and gas electricity generation fleet and best-technology coal and gas. This comparison covers the range of Global Warming Potential (GWP) highlighting the estimates of the IPCC[113] and Shindell et al.[114] on 20- and 100-year timeframes.

Hughes (2011)

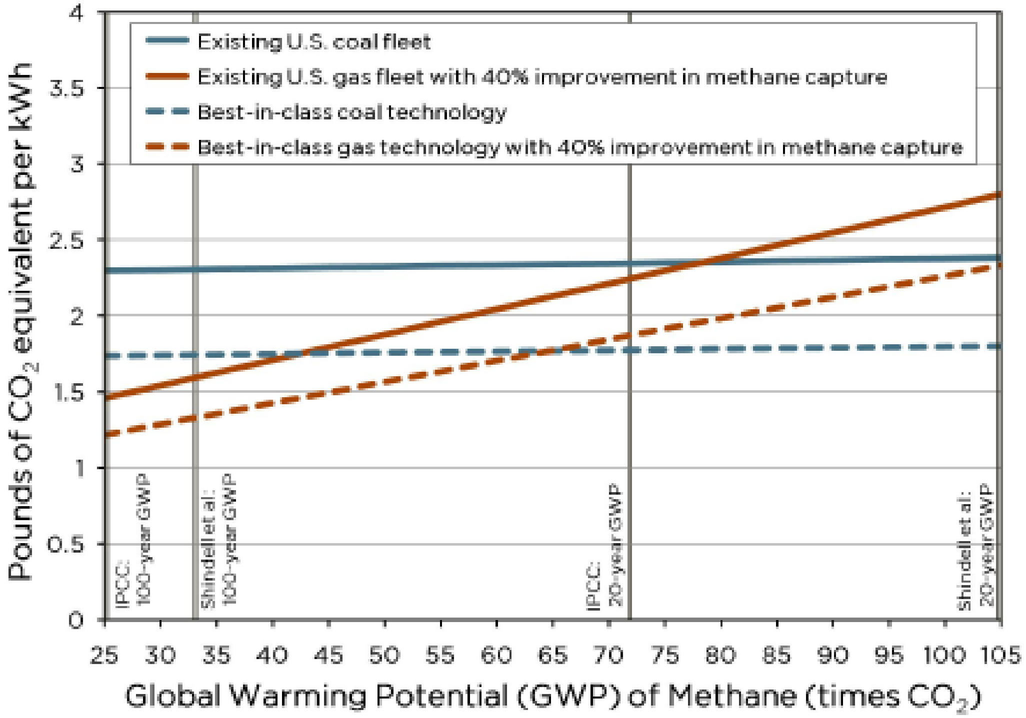
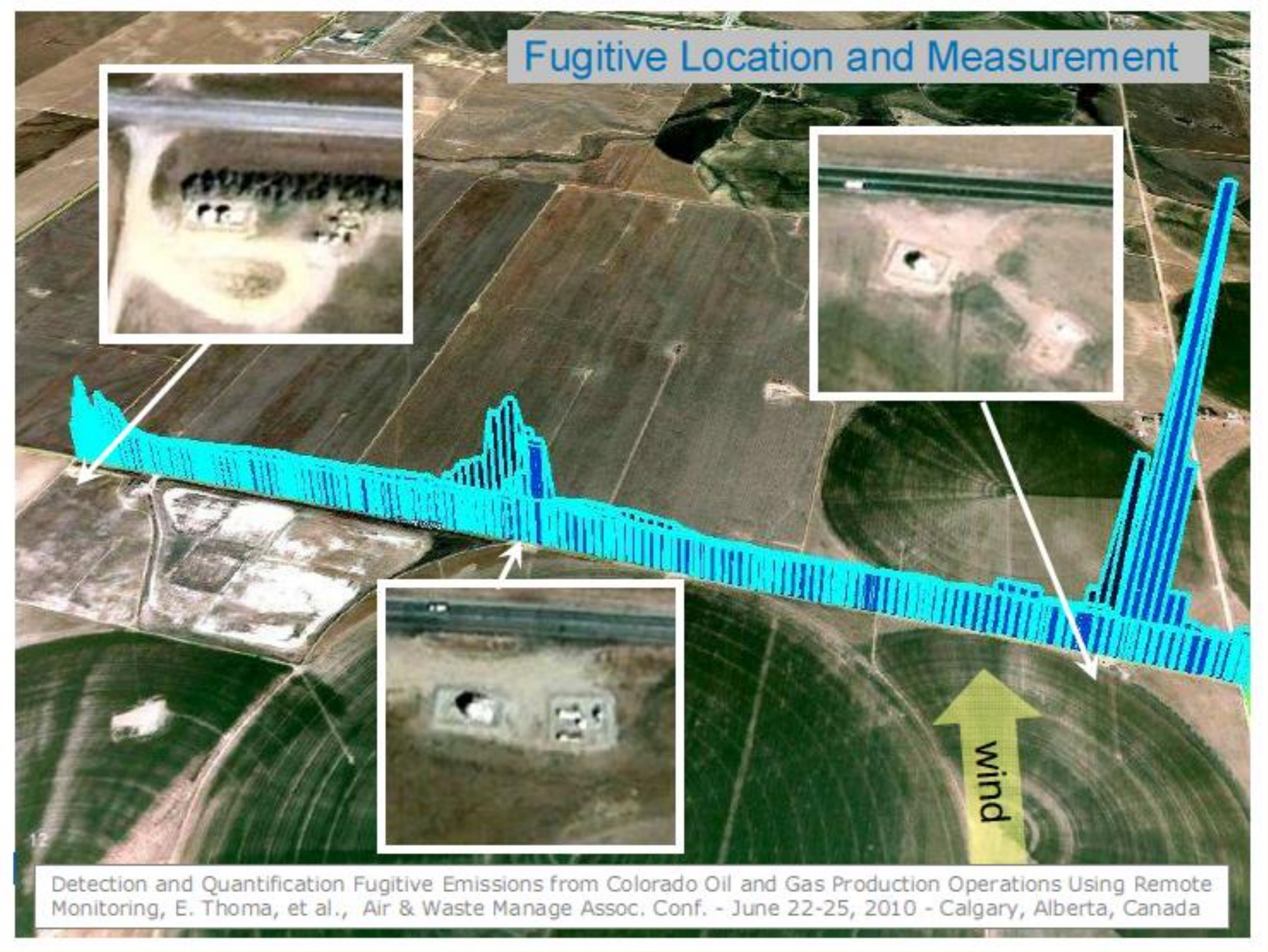


Figure 24. Comparison of future CO_2 equivalent emissions per kWh, if a 40% reduction is achieved in current methane emissions, for the mean shale gas emission estimate of Howarth et al.[120] compared to surface-mined coal for both the existing coal and gas electricity generation fleet and best-technology coal and gas. This comparison covers the range of Global Warming Potential (GWP) highlighting the estimates of the IPCC[121] and Shindell et al.[122] on 20- and 100-year timeframes.

Hughes (2011)



Fugitive Location and Measurement

Detection and Quantification Fugitive Emissions from Colorado Oil and Gas Production Operations Using Remote Monitoring, E. Thoma, et al., Air & Waste Manage Assoc. Conf. - June 22-25, 2010 - Calgary, Alberta, Canada

Eben Thoma, March 2010, EPA workshop presentation

I am not advocating for more coal or oil, but rather to recognize full environmental costs of all fossil fuels, and to move to a truly green, renewable future as quickly as possible.