Natural Gas, Methane, and Climate Change after COP21

Robert Howarth
The David R. Atkinson Professor of Ecology & Environmental Biology
Cornell University

Fossil Fuel Lock-in: Why Gas is a False Solution
Conference in Brussels

26 September 2016
Outline of talk:

• COP21 target, tipping points in the climate system, and risk of runaway global warming

• Methane as a critically important greenhouse gas, and how we compare methane with CO2

• Shale gas revolution (in the US) as a driver of methane emissions, and research on methane emissions from natural gas
Global warming is caused by humans. Without greenhouse gas emissions, the planet would be cooling.
COP21: United Nations Conference of the Parties
Le Bourget, Paris -- December 2016
• COP21 Paris Accord target: “well below 2° C ”

• Clear recognition that warming beyond 1.5° C is dangerous
Shindell et al. 2012, *Science*
Ed Hawkins, Univ. of Reading: Spiralling Global Temperatures (May 9, 2016)

http://www.climate-lab-book.ac.uk/2016/spiralling-global-temperatures/...
Global warming over the next few decades may well be sufficient to push the Earth into a different climatic regime.

At that point, reducing greenhouse gas emissions may no longer reverse global warming, on the time scale of 10,000 years or more.

Runaway global warming, climate disruption, and sea-level rise at a scale never before experienced.
As temperature rises above 1.5° C, large and increasing risk of feedbacks leading to catastrophic change in the climate system.
Many possible tipping points to push Earth into new climate system – some examples:

- less uptake of CO2 by oceans and/or forests and grasslands
- change in ocean circulation (from less salty Atlantic Ocean)
- more thunderstorms in Arctic, leading to more fires
- melting of permafrost, and of methane hydrates
Global Carbon Project 2010; Updated from Le Quéré et al. 2009, Nature Geoscience; Canadel et al. 2007, PNAS
Although CO₂ emissions stable since 2013, CO₂ in atmosphere rose at fastest rate ever in 2015, reaching record high in February 2016.
Although CO$_2$ emissions stable since 2013, CO$_2$ in atmosphere rose at fastest rate ever in 2015, reaching record high in February 2016.

Feedback from global change, with slowing of net CO$_2$ uptake by oceans and terrestrial ecosystems?
April 2016  L-OTI( °C) Anomaly vs 1951-1980  1.11

http://data.giss.nasa.gov/gistemp/ (downloaded May 19, 2016)
Possible tipping points to push Earth into new climate system:

- less uptake of CO2 by oceans and/or forests and grasslands
- **change in ocean circulation (from less salty Atlantic Ocean)**
- more thunderstorms in Arctic, leading to more fires
- melting of permafrost, and of methane hydrates
Water sinks primarily in North Atlantic. **WHY?** More dense than surface waters elsewhere; Colder than most surface ocean waters, and saltier than North Pacific.
Great conveyor belt not only distributes heat (and therefore influences climates) …..

….. but helps mitigate global warming by taking CO2 out of the atmosphere
And the great conveyor belt may be slowing...

.... Caused by melting of Arctic ice and Greenland ice sheet, making North Atlantic less salty.
Possible tipping points to push Earth into new climate system:

- less uptake of CO2 by oceans and/or forests and grasslands
- change in ocean circulation (from less salty Atlantic Ocean)
- more thunderstorms in Arctic, leading to more fires
- melting of permafrost, and of methane hydrates
Tundra fire – North slope of Alaska (2007)

First burn of this tundra in 500 years....

Large flux of \( \text{CO}_2 \) to atmosphere. Tundra soils hold massive amounts of carbon.....
Possible tipping points to push Earth into new climate system:

- less uptake of CO2 by oceans and/or forests and grasslands
- change in ocean circulation (from less salty Atlantic Ocean)
- more thunderstorms in Arctic, leading to more fires
- melting of permafrost, and of methane hydrates
High potential for massive emissions of ancient CH$_4$ due to thawing permafrost and release of “frozen” methane (methane clathrates).

Zimov et al. (2006) Science
Hansen et al. (2007) analyzed role of methane in past climates: critical threshold to avoid melting of methane clathrates at 1.8° C
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Carbon Dioxide
Methane
Carbon Dioxide
Methane
The two faces of Carbon

Carbon dioxide (CO2)

- Emissions today will influence climate for 100s of years
- Because of lags in climate system, reducing emissions now will have little influence during next 40 years

Methane (CH4)

- 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 immediately slows global warming
Methane and black carbon (BC) critical to slowing global warming to reach Paris COP21 target. The target cannot be reached through CO₂ reductions alone.

Shindell et al. 2012 Science
How do we currently account for methane relative to CO$_2$?
Global Warming Potential (GWP):

The integrated effect of radiative forcing of a greenhouse gas relative to carbon dioxide over a defined period of time.
Global anthropogenic emissions of CO2 and methane, weighted by global warming potentials
(redrawn from IPCC 2013)

Red = methane
Orange = CO2

Global warming potential applied

Pg CO2 equivalents per year

10 year  20 year  100 year
GWP values for methane:

<table>
<thead>
<tr>
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<th>20 year</th>
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<tr>
<td>IPCC 1996</td>
<td>56</td>
<td>21</td>
</tr>
<tr>
<td>IPCC 2007</td>
<td>72</td>
<td>25</td>
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<tr>
<td>IPCC 2013</td>
<td>86</td>
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These changes reflect improved science, including indirect effects of methane on global warming.
GWP values for methane:

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Most governments and almost all standard life-cycle assessments still use 21 or 25.
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.”
The 10- or 20-year GWP approach best captures the potential climate damage from methane in the context of the COP21 target.

A 100-year time period greatly discounts this potential for damage over coming decades.
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• Shale gas revolution (in the US) as a driver of methane emissions, and research on methane emissions from natural gas
How much methane is emitted from using natural gas?
EPA drastically underestimates methane released at drilling sites

Drilling operations at several natural gas wells in southwestern Pennsylvania released methane into the atmosphere at rates that were 100 to 1,000 times greater than federal regulators had estimated, new research shows.
US 'likely culprit' of global spike in methane emissions over last decade

Harvard study shows 30% rise across the country since 2002 with peaks coinciding with shale oil and gas boom, reports Climate Central
Methane emission estimates for **conventional natural gas** (ie, before shale gas began in 2009), listed chronologically (% of lifetime production of a well)

<table>
<thead>
<tr>
<th>Source</th>
<th>Upstream (well site)</th>
<th>Downstream (storage, distribution, etc.)</th>
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EPA has always relied on a bottom-up inventory approach.

An increasing number of top-down studies show much higher emissions.


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Critical update in 2015: measurement technique behind EPA bottom-up inventory called into question by patent holder on the EPA-approved instrument.

Bacharach High Flow Sampler (BHFS) is the only EPA approved instrument for methane emissions.

BHFS sampler subject to calibration issues, resulting in sometimes huge underestimation.

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Abstract
Quantification of leaks from natural gas (NG) infrastructure is a key step in reducing emissions of the greenhouse gas methane (CH4), particularly as NG becomes a larger component of domestic energy supply. The United States Environmental Protection Agency (USEPA) requires measurement and reporting of emissions of CH4 from NG transmission, storage, and processing facilities, and the high flow sampler (or high volume sampler) is one of the tools approved for this by the USEPA. The Bacharach Hi-Flow® Sampler (BHFS) is the only commercially available high flow instrument, and it is also used throughout the NG supply chain for directed inspection and maintenance, emission factor development, and greenhouse gas reduction programs. Here we document failure of the BHFS to transition from a catalytic oxidation sensor used to measure low NG (~5% or less) concentrations to a thermal conductivity sensor for higher concentrations (from ~5% to 100%), resulting in underestimation of NG emission rates. Our analysis includes both our own field testing as well as analysis of data from two other studies (Modrak et al., 2012; City of Ft Worth, 2011). Although this failure is not completely understood, and although we do not know if all BHFS models are similarly affected, sensor transition failure has been observed under one or more of these conditions: 1), calibration is more than ~2 weeks old; 2), firmware is out of date; or 3), the composition of the NG source is less than ~91% CH4. The extent to which this issue has affected recent emission studies is uncertain, but the analysis presented here suggests that the problem could be widespread. Furthermore, it is critical that this problem be resolved before the onset of regulations on CH4 emissions from the oil and gas industry, as the BHFS is a popular instrument for these measurements.

Implications
An instrument commonly used to measure leaks in natural gas infrastructure has a critical sensor transition failure issue that results in underestimation of leaks, with implications for greenhouse gas emissions estimates as well as safety.
University of Texas study underestimates national methane emissions at natural gas production sites due to instrument sensor failure

Touché Howard
Indaco Air Quality Services, Inc., Durham, North Carolina

Abstract
The University of Texas reported on a campaign to measure methane (CH₄) emissions from United States natural gas (NG) production sites as part of an improved national inventory. Unfortunately, their study appears to have systematically underestimated emissions. They used the Bacharach Hi-Flow® Sampler (BHFS) which in previous studies has been shown to exhibit sensor failures leading to underreporting of NG emissions. The data reported by the University of Texas study suggest their measurements exhibit this sensor failure, as shown by the paucity of high-emitting observations when the wellhead gas composition was less than 91% CH₄ where sensor failures are most likely; during follow-up testing, the BHFS used in that study indeed exhibited sensor failure consistent with under-reporting of these high emitters. Tracer ratio measurements made by the University of Texas at a subset of sites with low CH₄ content further indicate that the BHFS measurements at these sites were too low by factors of three to five. Over 98% of the CH₄ inventory calculated from their own data and 41% of their compiled national inventory may be affected by this measurement failure. Their data also indicate that this sensor failure could occur at NG compositions as high as 97% CH₄, possibly affecting other BHFS measurement programs throughout the entire NG supply chain, including at transmission sites where the BHFS is used to report greenhouse gas emissions to the United States Environmental Protection Agency Greenhouse Gas Reporting Program (USEPA GHGRP, U.S. 40 CFR Part 98, Subpart W). The presence of such an obvious problem in this high profile, landmark study highlights the need for increased quality assurance in all greenhouse gas measurement programs.
Emission measurement methods
(measurements of gas entering and/or leaving the controller)

Supply line measurements
(primary measurement)

Exhaust measurements
(secondary/QC measurement)
Emission measurement
(measurements of gas emissions)

Supply line measurement
(primary measurement)
**Global methane sources (Tg/yr) as of 2000 (pre-shale gas)**

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td><strong>Total</strong></td>
<td>553</td>
</tr>
<tr>
<td><strong>Total natural</strong></td>
<td>218</td>
</tr>
<tr>
<td>Geological seeps</td>
<td>24</td>
</tr>
<tr>
<td>Wetlands</td>
<td>175</td>
</tr>
<tr>
<td>Other biogenic</td>
<td>19</td>
</tr>
<tr>
<td><strong>Total anthropogenic</strong></td>
<td>335</td>
</tr>
<tr>
<td>Natural gas</td>
<td>91</td>
</tr>
<tr>
<td>Coal</td>
<td>33</td>
</tr>
<tr>
<td>Oil</td>
<td>18</td>
</tr>
<tr>
<td>Animal agriculture</td>
<td>73</td>
</tr>
<tr>
<td>Rice</td>
<td>29</td>
</tr>
<tr>
<td>Landfills &amp; sewage</td>
<td>61</td>
</tr>
<tr>
<td>Biomass burning</td>
<td>30</td>
</tr>
</tbody>
</table>

Red = C14 dead  
Blue = recent  

Modified from Begon et al. 2014
Methane emissions from shale gas are much higher than from conventional natural gas, according to most (but not all) recent top-down measurements.

Perhaps 3-fold higher?

Shale gas development is new, so measurements on methane emissions from shale gas are new....
Schematic geology of natural gas resources

- Conventional non-associated gas
- Coalbed methane
- Conventional associated gas
- Tight sand gas
- Gas-rich shale
- Sandstone
- Seal
- Oil
- Land surface
Natural Gas Production in the United States
EIA 2015 Outlook data and mean reference projections

Howarth 2015 Energy Emissions & Control Technologies
Is natural gas a “bridge fuel?”

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

<table>
<thead>
<tr>
<th>Fuel</th>
<th>g C of CO$_2$ MJ$^{-1}$ of energy</th>
</tr>
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<tbody>
<tr>
<td>Natural gas</td>
<td>15</td>
</tr>
<tr>
<td>Diesel oil</td>
<td>20</td>
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<td>Coal</td>
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(Hayhoe et al. 2002)
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
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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 lifetime of a well. These methane emissions are at least 30% more than and perhaps more than double those from conventional gas. The higher emissions from

- Natural gas is mostly methane
- Small leaks and emissions matter
- Shale gas emits more than conventional gas
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.
Other “People who Mattered” in 2011:

Osama bin Laden, Muammar Gaddafi, Barack Obama, Bill McKibben, Adele, Vladimir Putin, Benjamin Netanyahu, Rupert Murdoch, Mitt Romney, Newt Gingrich, Joe Paterno...
One of our major conclusions in Howarth et al. (2011): pertinent data for shale gas were extremely limited, and poorly documented.

Great need for better data on shale gas, conducted by researchers free of industry control and influence.
Toward a better understanding and quantification of methane emissions from shale gas development

Dana R. Caulton, Paul B. Shapson, Renee L. Santoro, Jed P. Sparks, Robert W. Howarth, Anthony R. Ingraffea, Maria O. L. Cambaliza, Colm Sweeney, Anna Karion, Kenneth J. Davis, Brian H. Stirm, Stephen A. Montzka, and Ben R. Miller

Departments of Chemistry, EEarth, Atmospheric and Planetary Science, and Aviation Technology, Purdue University, West Lafayette, IN 47907; Physicians, Scientists, and Engineers for Healthy Energy, Ithaca, NY 14851; Departments of Ecology and Evolutionary Biology and Civil and Environmental Engineering, Cornell University, Ithaca, NY 14853; National Oceanic and Atmospheric Administration, Boulder, CO 80305; Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO 80309; and Department of Meteorology, The Pennsylvania State University, University Park, PA 16802
Schneising et al. (2014) – “Remote sensing of fugitive methane emissions from oil and gas production in North American tight geologic formations.” *Earth’s Future* 2: 548-558

Prof. Oliver Schneising, Inst. of Env. Physics, Univ. of Bremen, Germany

**United States**
Upstream methane emissions from shale and other unconventional gas operations (upstream only, % of production)
Upstream methane emissions shale and other unconventional gas
Methane emissions from unconventional gas operations (upstream only, % of production)
Upstream methane emissions from unconventional gas operations (upstream only, % of production)

Best estimate? .... based on longest time series of data
Greenhouse gas footprints, CO₂ plus methane (averaged for 20 years after emission)

Howarth 2015 *Energy Emissions & Control Technologies*

- **Total emissions**: (with best accounting for methane, 20-yr GWP from 2013)
- **EPA estimate for total emissions**: (100-yr GWP from 2007)
- **Just CO₂**

Howarth 2015 *Energy Emissions & Control Technologies*
Methane emissions from shale gas are much higher than from conventional natural gas, according to most (but not all) recent top-down measurements.

Perhaps 3-fold higher?

Shale gas development is new, so measurements on methane emissions from shale gas are new....

**Why are emissions higher?** Imperfect knowledge, with some surprises already, making it difficult to regulate reductions.

Methane emissions from shale gas & oil development in US probably are major driver behind global increase in atmospheric methane over past decade.
Policy makers in US are beginning to pay attention to methane problem from natural gas:

Howarth presentation to the Office of Science & Technology Policy, Executive Office of the White House, on May 27, 2016
What is the European situation?

Natural gas comes largely from conventional sources; methane emissions very likely in range of 3.6%

LNG imported from US likely to come at least in part from shale gas (maybe largely?), with emissions in range of 12%
Greenhouse gas footprints, CO$_2$ plus methane (averaged for 20 years after emission)

Howarth 2015 *Energy Emissions & Control Technologies*
Portugal received first European LNG cargo from US earlier this year
Portugal received first European LNG cargo from US earlier this year.

How much methane is vented during filling, transit, and unloading?

No publicly available data....
Underway, the LNG cargo starts to convert from liquid to gas. Typically, between 0.1 – 0.25% of the cargo converts the gas each day, so on a 20 day voyage anywhere between 2 to 6% of the liquid boils way into gas. Unless the gas is vented, the pressure in the tanks will build and burst the tanks. Older LNG tankers use steam turbines for propulsion, using boilers that run on a combination of methane and oil. As the liquid in the tank begins to boil off, the vaporized gases routed to the boilers create steam. As vessel operators converted ships to slow-speed diesel engines, the vessels had to be equipped with reliquefaction plants to help control the gas loss. Some vessels now use long-stroke engines designed to burn natural gas, again using the cargo to fuel the vessel.

http://www.wearethepractitioners.com/library/thepractitioner/2014/12/22/floating-the-boats
Well past time to apply the precautionary principle:

Methane emissions are probably high, although exact magnitude still debated.

Invest in infrastructure (pipelines, LNG facilities, storage) for a bridge fuel? Might have made sense 30 years ago, but not now....

Need to cut methane; need to be free of fossil fuels in 35 years.

Put resources into heat pumps, smart grids, mass transit, energy efficiency, wind, solar, etc.
• COP21 Paris Accord target: “well below 2° C ”
• Clear recognition that warming beyond 1.5° C is dangerous
• Carbon targets approved at COP21 will lead to 3.5° to 4° C
• To reach COP21 target will require the world to be largely free of fossil fuels by 2050
• Methane reductions are critical; cannot reach COP21 target with CO2 reductions alone
So what should our energy future be?

Natural gas.... A bridge to nowhere

Yesterday’s fuel
Powering New York State with Wind, Water, and the Sun to Address Global Warming, Air Pollution, & Energy Security

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

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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 ~1/3.
- 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 ($23 billion/yr or 2% of NYS GDP).

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 70% onshore wind (40GW 5 MW turbines), 40% offshore wind (12,700 5 MW turbines), 10% concentrated solar (977 100 MW plants), 10% solar PV
Our Energy Plan for New York State

Greenhouse gas footprint for heating domestic hot water

- Natural gas (shale gas)
- Heat pump (coal-generated Electricity)
- Heat pump (renewable electricity)

g Carbon Dioxide Equivalents per MJ

Hong and Howarth 2016
Howarth-Marino home (1890’s farm house) is 100% carbon neutral, with geothermal heating and renewable electricity.

Half of our driving is by electric car.
Changes in Horse and Automobile Transportation, United States, early 20th Century

Data from Geels 2005
The science message from Paris: We need to move very aggressively away from fossil fuels, including not only coal but also natural gas (particularly from shale).
Figure: NASA GISS/Gavin Schmidt
Turner et al. 2016
Methane emissions from unconventional gas operations (upstream only, % of production)

- Peischl et al. (2015)
  - NE Marcellus
  - Fayetteville
  - Western Arkoma
  - Haynesville

- Schneising et al. (2014)
  - Bakken & Eagle Ford

- Petron et al. (2012)
  - Denver-Julesburg

- Karion et al. (2013)
  - Uinta

- Allen et al. (2013)
  - US Average

- Petron et al. (2014)
  - Denver-Julesburg

- Caulton et al. (2014)
  - SW Marcellus

- Howarth et al. (2011)

- EPA (2011)

- EPA (2013)

- Karion et al. (2013)

- Allen et al. (2013)

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Denver-Julesburg
Caulton et al. (2014)
SW Marcellus
Schneising et al. (2014)
Bakken & Eagle Ford
Haynesville
Western Arkoma
Fayetteville
Peischl et al. (2015)
NE Marcellus

Methane emissions from unconventional gas operations (upstream only, % of production)
Peischl et al. (2015) attribute their lower fluxes for the NE Marcellus compared to our Caulton et al. (2014) estimates for SW Marcellus to dry gas vs. wet gas: much higher emissions from wet gas.

Another possibility: non-steady state situation, with much lower drilling and fracking activity at the time of their study (July 2013) compared to that of Caulton et al. (June 2012). Emissions are normalized to production, which was still reasonably high in 2013, but based on drilling and fracking at a previous time.