WHITEHALL'S 'FRACKING' SCIENCE FAILURE

How The Government Has Misled Parliament And The Public On The Climate Change Impacts Of Shale Oil And Gas Development In Britain

A Report For Talk Fracking

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Executive Summary

How The Government Has Misled Parliament And The Public On The Climate Change Impacts Of Shale Oil And Gas Development In Britain

'With the right safeguards in place, the net effect on UK GHG emissions from shale gas production in the UK will be relatively small.' Mackay / Stone

What is science? It is a process for how we find, measure and then evaluate the real-world in order to identify 'how it works'. In that process how things are measured and analysed is as important as the results – because the mechanics of the process have a large influence on what those results will be.

The problem is, particularly for contentious debates in the media and politics, rarely does the process of science ever get discussed. Only the results. Seldom do we hear the 'confidence' we might have in those results, or their 'uncertainties'. Rarely is the method of how those results were produced ever discussed.

In such an environment it is easy to use 'results' in a way that has no validity to the context in which they were formed.

'Fracking' and Whitehall's energy policy

The Government in Whitehall (distinct from those in Edinburgh or Cardiff, who currently have moratoriums on development) has promoted onshore oil and gas not only as a source of energy, but as a means to meet climate change obligations. **Gas, as Ed Davey claimed in 2013, is a "bridge" to a low carbon economy.**

That claim rests on the results of one key report, written by the Department of Energy and Climate Change's (DECC) Chief Scientist, David Mackay, and the economist, Timothy Stone. The report, published in September 2013, states that, *We have gathered available information on the carbon footprint of shale gas to inform our estimate of the potential impacts of shale gas exploration, extraction and use in the UK on UK climate change objectives… With the right safeguards in place, the net effect on UK GHG emissions from shale gas production in the UK will be relatively small.*

However, as noted above, the results of the study are the end-point of a process. What is at question today is whether that process of evaluation was valid, even when the report was first published in 2013.

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'Bottom-up' versus 'Top-down'

How we measure and evaluate the pollution emitted by industrial processes is a compromise, between what is technically possible and realistically practicable. Reliably measuring gases emitted from equipment outdoors is difficult, so it requires some flexibility.

These historic difficulties mean that regulators have relied on a 'bottom-up' method to assess the leaks from oil and gas operations. Small parts of the equipment are tested, either in a laboratory or specially constructed test rigs, the leaks are measured or estimated, and the figures combined to produce a total.

When the climate impacts of oil and gas production were first assessed at the end of the 1990s the assumption, from these bottom-up evaluations, was that the effects were "insignificant".

What has happened since is that the monitoring technology has improved.

Today it is possible to equip aircraft or large ground vehicles as mobile gas monitoring laboratories. These are flown or driven around oil and gas fields to sniff the air. From that sampling it is possible to produce a 'top-down' estimate of how much gas is leaking in order to create the measured concentrations in the air.

In an ideal world the top-down and bottom-up measurements would, within a reasonable boundary of uncertainty, match. The difficulty is that they do not.

What consistent studies carried out over

the last decade or so have found is that the leakage detected from real-world, 'top-down' monitoring exceeds the 'bottom-up' measurement of emissions by at least two to four times.

Howarth and the significance of methane

The research paper which highlighted the significance of this debate was produced by Howarth, Santoro and Ingraffea in June 2011.

The 'Howarth' paper gained prominence because it claimed to show that shale gas was not only worse than conventional gas. Under certain circumstances it could be worse than coal-fired power generation.

The reason why the paper claimed such high climate impacts was due to two main factors:

Firstly, because it was using 'top-down' assessments of leakage from natural gas systems. As noted above, these have consistently produced much higher levels of leakage than 'bottom-up' data.

Secondly, they used a 20- rather than 100-year baseline for the impact of methane on climate change – which has gained prominence as a greenhouse gas because it has a far faster response in warming the climate than other gases; and because new sampling techniques have been finding far higher concentrations in the environment than were expected.

Both the industry and regulators dismissed the findings of the paper, precisely because they didn't match the leakage which traditional 'bottom-up' studies had found.

The Mackay-Stone review

In Britain, DECC commissioned Mackay and Stone to evaluate the climate impacts of shale gas – although if you read the report, it is clear that it is targeted squarely at the results of the Howarth study.

Very roughly, Mackay and Stone:

- took a figure for how much gas leaks from a gas well and then calculated the climate impact of those leaks;
- they added the impacts of the gas being burnt;
- then they divided the total figure for impacts by the amount of gas produced from each well to produce a figure for impacts per unit of energy;
- then they compared that to other available figures for conventional gas, coal-fired power and imported liquefied natural gas (LNG).

That is a fair assessment procedure in order to test the impacts of shale gas against other sources of natural gas for power generation. **The problem with Mackay and Stone's report is not the process, it is the data which they used in their calculations:**

- Their figures for gas leakage were predominantly from 'bottom-up' studies – which on the basis of a range of research studies have traditionally under-estimated emissions by two to four times;
- They deliberately excluded the figures in the Howarth study from their final calculations because they claimed they were a statistical 'outlier' which would skew their results; and
- The figures used for gas production per well were at least twice what is seen in US gas wells – and had no clear independent source.

Using a figure for leakage which was perhaps a half of what it should have been, and using a figure for gas production which was twice what it should have been, the level of impacts which their analysis found is arguably a quarter of what it should be.

Mackay and Stone, while rejecting Howarth's figures, also disregarded other US-government backed studies produced around that time, which had produced similar results to Howarth. Instead they promoted an as yet unpublished study, by Allen et al., which claimed that leakage rates could be minimized using what was called "reduced emissions completions" (REC).

The Allen study

The 2013 study by Allen et al. was part-funded by the US Environmental Defense Fund. It is a 'bottom'up' analysis of leakage from oil and gas operations, and claimed levels of leakage far lower than similar studies – due to the improved operational practice of RECs.

However, the study ran into problems from the start. The journal, PNAS, had to publish a correction because the authors had failed to declare their conflicting industry affiliations. More significantly, the study does not disclose which, and what type of sites were being tested. Most seriously though, the sites were not randomly selected for testing. Their industry partners selected which

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‘one of the most widely used sensors to measure methane concentrations – which had been used in the Allen study – routinely malfunctioned, under-reporting methane concentrations’

‘the sensor might be under-reporting methane levels by three to five times’

sites they were to test.

All these problems are accepted in the supporting information published alongside the Allen paper.

The real problem for the Allen study emerged in 2015. Research by Howard et al. highlighted that **one of the most widely used sensors to measure methane concentrations – which had been used in the Allen study – routinely malfunctioned, under-reporting methane concentrations.** The US Argonne National Laboratory, which co-ordinates the reporting of US carbon emissions, noted that **the sensor might be under-reporting methane levels by three to five times.**

In 2016 the Environmental Defense Fund, who had part-funded it, rejected the Allen study results.

Misleading Parliament and the public

From the date of its publication the Mackay-Stone report has been flawed – because of the approach taken to calculating the impacts of shale gas, particularly the selection of data used in the calculations.

DECC and its authors defended this by referencing the Allen study as proof that emissions could be reduced to levels where the impacts would be ‘small’.

Now that the Allen study has been shown to be flawed, the Mackay-Stone report has been definitively invalidated too. However, that has not stopped ministers and Parliamentarians quoting it to support the Government’s policies on oil and gas extraction.

Current serving ministers – such as Michael Fallon, Andrea Leadsom and Amber Rudd – have all quoted Mackay-Stone to defend government policy. Arguably this breaches the Ministerial Code as the ministers involved have given inaccurate information to MPs.

DECC was disbanded in 2016, but in January 2017 the new department – the Department of Business, Energy and Industrial Strategy (BEIS) – issued revised guidance on shale gas, once again echoing the results of the Mackay-Stone report.

Recently the Committee on Climate Change (CCC) produced a report on onshore oil and gas production. **When Environment Secretary Andrea Leadsom reported this to Parliament she claimed that the CCC said that onshore oil and gas is compatible with the UK’s climate target. This is misleading Parliament as this is not within the context of their conclusions.**

As stated in the recent House of Commons Library briefing on Shale Gas, **the CCC concluded that ‘fracking’ must pass three tests to be acceptable. The third of those requires that we reduce emissions elsewhere in the economy to accommodate the emissions from onshore oil and gas. And, as Climate Change Secretary Nick Hurd stated in evidence to a Select Committee in January 2017, even finding the 50% of saving yet to be identified will be, ‘hard’.**

Whitehall’s fracking policies are completely flawed

The Mackay-Stone report, which was arguably flawed on the day of its publication, is today wholly discredited. No minister can quote its conclusions without demonstrably misleading MPs and the public as to the current state of the science related to ‘fracking’ and climate change.

Mackay-Stone report must be withdrawn, and a moratorium implemented on all ‘fracking’ operations, until we can state the impacts with certainty.

Whitehall's 'Fracking' Science Failure

How The Government Has Misled Parliament And The Public On The Climate Change Impacts Of Shale Oil And Gas Development In Britain

The representation of scientific research in the media and political debate primarily concentrates upon the results. That can easily be misleading.

What is often neglected in reporting is the process or method by which those results were generated, and how the data fed into calculations was sourced or measured (or, quite frequently, estimated).

Least of all do we find that the 'certainty' we might have in those results is explained as part of reporting, and why the results are uncertain.

Over recent years a debate has emerged within the environmental sciences over how the impacts of the oil and gas industry are measured and reported. Explaining why the differing sides in this debate produce such starkly differing results goes a long way to explaining why the debate exists – and what confidence we can have in those results.

In its recent promotion of unconventional oil and gas extraction in Britain, the Government in Whitehall (in contrast to Edinburgh or Cardiff) has always taken an industry-friendly stance. As a result the scientific reviews commissioned by Whitehall have failed to look at the whole range of research available on the ecological impacts of fracking. Consequently they fail to explain to the public why disagreements exist over the science of how we measure the impacts of 'fracking'.

This report seeks to explain how the debate over the gaseous emissions from 'fracking', and their impacts on climate change, has changed over the last few years – and precisely why that debate is critical to how the Whitehall Government has justified, and promoted, onshore oil and gas extraction in Britain.

Finally, this report covers just one facet of the 'fracking' issue in the UK – climate change. The information presented here also has a significant effect, for example, on how we assess the health impacts of gaseous emissions. Other similarly detailed studies could be written on critical issues such as waste management, landscape impacts, human and ecological health impacts, or energy policy.

What this issue has lacked, since the issuing of the first licences for exploration in 2008, is a full and transparent assessment of the Government's policy, taking into account the latest available research studies. Until such a review takes place, UK policy on on-shore oil and gas will remain demonstrably flawed, and an arguable danger to human health and the local/global environment.

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> **‘This assertion, that shale gas is a “bridge” to a clean energy future, has been repeated many times by Government ministers, industry figures and Parliamentarians since that date. Even the Church of England has thrown their support behind the climate benefits of shale gas using the same argument’**

> **‘Gas as the cleanest fossil fuel, is part of the answer to climate change, as a bridge in our transition to a green future, especially in our move away from coal’ Ed Davey**

The debate over ‘fracking’ and climate change in the UK

1. In September 2013, launching the Mackay-Stone review on the climate change impacts of shale gas in the UK, Energy Secretary Ed Davey stated [1],

Gas, as the cleanest fossil fuel, is part of the answer to climate change, as a bridge in our transition to a green future, especially in our move away from coal.

2. This assertion, that shale gas is a “bridge” to a clean energy future, has been repeated many times by Government ministers, industry figures and Parliamentarians since that date. Even the Church of England[2] has thrown their support behind the climate benefits of shale gas using the same argument.

3. The Government’s recent update[3] to their guidance on shale gas was produced by the Department for Business, Energy and Industrial Strategy (BEIS) on the 13th January 2017. In relation to the impacts upon climate change it states,

In September 2013 Professor David MacKay (then the Department of Energy and Climate Change’s Chief Scientist) and Dr Timothy Stone wrote a report on potential greenhouse gas emissions from UK produced shale gas. They concluded that the overall effect of UK shale gas production on national emissions is likely, with the right safeguards, to be relatively small. Indeed emissions from the production and transport of UK shale gas would be comparable to imported Liquefied Natural Gas (LNG), and much lower than coal, when both are used to generate electricity.

4. This updated report was the first detailed statement on shale oil and gas to be produced by the new BEIS department since its formation almost six months earlier – after the Department of Energy and Climate Change (DECC) was disbanded. However, the substance of that statement has not changed since DECC evolved the bulk of the UK’s policy on shale oil and gas between 2010 and 2014; and in relation to the emissions from shale gas, since Ed Davey launched the Mackay-Stone review in 2013.

5. The purpose of this report is to examine whether there any is evidence to back up these statements, and the quality of the research that current unconventional oil and gas policy is based upon.

6. The week before BEIS issued their updated shale guidance, the House of Commons Library had reissued their research briefing on Shale Gas and Fracking[4] for Members of Parliament. This report depicts a far less certain case, stating,

A report on this was published by the then Department for Energy and Climate Change in September 2013, in which shale gas emissions were said to be similar to those of conventional gas and lower than those of coal and LNG, leading the Secretary of State to describe shale gas as a ‘bridge’ to a low-carbon future. However, the Committee on Climate Change concluded in July 2016 that the implications of shale gas for greenhouse gas emissions are uncertain, and that shale gas exploitation on a significant scale will not be compatible with UK carbon budgets unless tests in relation to emissions, gas consumption, and carbon reductions elsewhere are satisfied.

7. At the heart of the Mackay-Stone review[5] – which provides the core climate justifications for UK shale oil and gas alongside scientific reviews from the Royal Society[6] and Public Health England[7] – is a calculation of the emissions from shale gas operations. The figures used in that calculation are based upon the findings of various studies of the emissions from shale oil and gas operations.

8. The problem for the Government’s case is that not only that new evidence casts doubt on some of the figures quoted in the Mackay-Stone review, the key study they cite – by Allen et al., which at the time of the Mackay-Stone review had not yet been published – has since been shown to be seriously flawed by more recent research studies.

The debate before the Mackay-Stone review

9. Before shale gas and ‘fracking’ provoked a scientific debate, which has shone a light on the issue of emissions from the oil and gas industry as a whole, very little was known about ‘fugitive emissions’ (the gases which leak or are vented as part of the everyday operation of an industrial

process) from oil and gas extraction. What was considered to be 'known' was in fact largely an assumption based upon limited data from the oil and gas industry.

10. For example, in January 2011, when the Tyndall Centre Manchester published its first review[8] of the potential climate impacts of shale gas, they considered the fugitive emissions from the process to be "insignificant". This conclusion followed-on from the conclusions of a New York State Department of Environment and Conservation (NYDEP) study[9], which in turn was based on US oil and gas industry studies carried out as far back as the 1980s.

11. This illustrates the low priority given to the climate impacts of oil and gas production prior to 2011 – in part because the focus on methane and other gases was primarily an issue of physical health and safety for workers and the public, not their climate impacts.

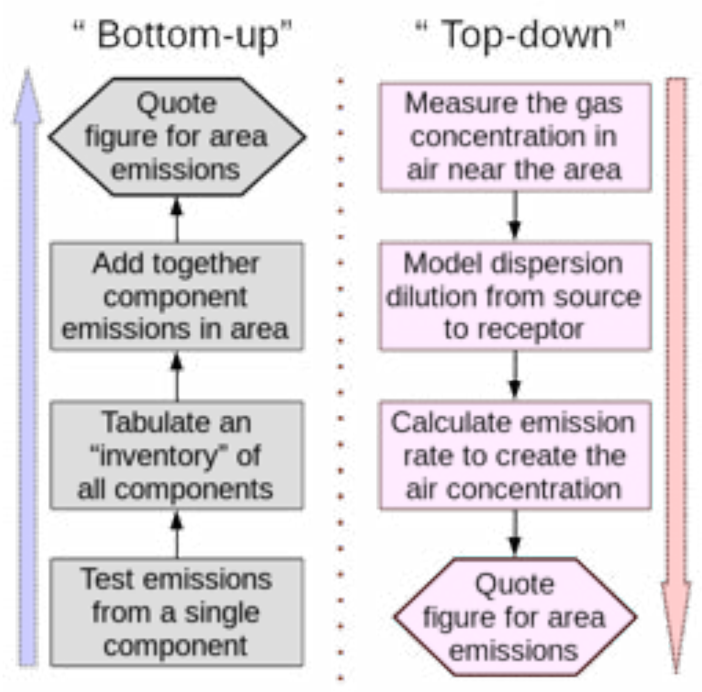
12. What has always limited the ability to measure the emissions from oil and gas infrastructure in the field has been the accuracy and reliability of mobile gas monitoring equipment. As a result two general forms of environmental sampling have arisen in order to produce an estimate of emissions from the industry: 'bottom-up' or 'inventory' analysis; and 'top-down' or 'instrumental' analysis.

13. **The public debate on fugitive emissions has tended to be over the numerical results of individual studies, not the difference in numerical results which is the inevitable consequence of using two different analytical methods. Thus the 'quality' or 'accuracy' of each approach is ignored.**

'Bottom-up' analysis

14. 'Bottom-up' analysis is used not only in the oil and gas industry, but also in the chemicals industry and other large-scale polluting processes. It is described as "bottom-up" because it works from the level of emissions at each small part of the system, scaling-up to the total emissions from the whole system under test. It is synonymous with 'inventory analysis'.

15. In an 'inventory' analysis an industrial process is broken down into its component parts – valves, pipes, tanks, vents, etc. The emissions from each of



these components are then measured under test conditions, either under specially engineered conditions in the field or under laboratory simulation.

16. To assess the emissions from a single unit, or a large area or production field, an 'inventory' of all the component leaks/losses is created. The sum of the component losses then indicates the total level of emissions. The problem with the inventory approach is that components, or whole installations, can sometimes go missing from the calculation process – artificially lowering the results.

17. The main difficulty with inventory analysis, from a 'certainty' point of view, is that it often portrays emissions under idealized conditions.

18. To fit monitoring equipment to an industrial process requires that the facility be built or modified to include that equipment. For that reason the samples may not be representative of the 'normal' levels of construction quality and design, and may only reflect the emission standards of 'new' plants – not the level of emissions after a long period of use, wear and corrosion of the system.

'Top-down' analysis

19. 'Top-down' analysis involves taking a sample of pollution levels in the environment – either from air, water, or even from soil if studies of solid deposition are being used. Then the dilution of the

'This illustrates the low priority given to the climate impacts of oil and gas production prior to 2011'

sample as a result of its transport from the source to the monitoring (or 'receptor') point is calculated. This gives a measure of how much pollution was emitted at the source. Once other potential sources of pollution have been excluded – which can be a significant confounding factor in the process – it is possible to express the total emissions from a single site, or, with sufficient monitoring over a wide area, an entire field.

20. It is called "top down" because from a measure for the whole system the emissions from parts of it are broken down to their constituent parts.

21. It is only with the recent development of mobile, miniaturized and accurate sensors that reliable samples of environmental pollution can be carried out at low cost 'in the field'. Prior to this samples had to be physically collected and analysed under laboratory conditions, or large and highly specialized equipment had to be assembled in the field – which restricted the scope of its use.

22. The great benefit of top-down analysis is that it can give far better temporal resolution to the measurement of pollution. Older monitoring technologies (for example, diffusion tubes) are designed to assess the levels of pollution emitted over a periods of many hours, or days – meaning they are slow to respond to large, short-term changes in pollution levels. By taking almost instantaneous samples it is possible to find not only the level of pollution, but also the statistical range of emissions varying over time.

23. The principal draw-back with instrumental sampling is the ability to distinguish between different sources of the same pollutant which might be geographically near to each other. As analytical techniques improve, different ways have been found to discriminate between different sources of the same pollutant, usually through more elaborate forms of testing which differentiate a 'fingerprint' for the source of interest against background levels.

The 'top-down' versus 'bottom-up' contention over shale emissions

24. The oil and gas industry nearly always utilizes inventory-based, 'bottom-up' analyses when quoting their environment emissions. However, the use of this data is looking more doubtful for environmental regulation[10] as the emergence of more versatile methods of sampling over the last two decades, which question the accuracy of bottom-up analyses.

25. The problem is that the data itself – from either method – can be so variable that it's not possible, with reasonable confidence, to state a fixed answer. There can be so many factors involved that the quoted levels might vary over a wide range. This is, in part, why the public debate is so 'uncertain'; it allows the industry and regulators to exploit doubt[11] in order to argue against changing the regulatory status quo.

26. To address this uncertainty, in the USA the National Oceanographic and Atmospheric Administration (NOAA) has funded a long-term project[12] to measure levels of atmospheric gases around oil and gas facilities. This involves the use of aircraft, which are equipped with an array of gas monitoring equipment, which are flown back and forth across the area of interest. Other studies use trucks which can drive around production fields. In Australia, studies have used smaller land cruiser vehicles equipped as mobile gas laboratories which drive around gas production fields sampling a variety of gases[13] .

27. What the results of instrumental analysis have shown is that the accuracy of bottom-up/inventory analyses is far poorer than previously thought[14] . These assessments appear to always under-estimate the total level of emissions. The discrepancy in results between the two methods can be a factor of two to four times, or higher. Another study[15] of the use of the inventory method more generally, including other sectors such as agriculture, also found that it significantly under-estimated measured levels of emissions.

28. What is more interesting is that, as a result of safety valves or flare stacks operating, emission levels can change enormously from moment to moment for short periods. This creates what is statistically called a 'heavy-' or 'fat-tailed' distribution, where many sites produce a relatively similar level of pollution, but a subset – often called 'super-emitters' – will produce far more[16] .

29. **While the wide swings in pollution levels have significance for climate change impacts, it is far more relevant to the assessment of public health impacts[17] . The assessment of pollution on public health has also, historically, relied on inventory assessments of gaseous emissions. Any large under-estimate of emissions under the current regulatory regime potentially has a high impact on public health. For this reason there has been an apparent official reluctance to discuss the implications of recent top-down studies.**

Government shale gas policy and the Howarth study

30. The Government began their push for 'unconventional' oil and gas in Britain in 2008, as part of DECC's 13th Landward Oil and Gas Licensing Round[18] . The licences issued by the Government in 2008 are the ones which are current being drilled for shale gas, shale/tight oil and coalbed methane. Those issued more recently will be actively explored within the next few years.

31. In 2010, as part of the 14th Licensing Round[19] , greater emphasis was put on opening up Britain to hydraulic fracturing for oil and gas. That round should have been completed in 2012 but, due to the controversy created, the final licences were not awarded until mid-2016.

32. **The contention of the Government has been that unconventional oil and gas production is broadly equivalent to conventional oil and gas production. The flaws in that assumption can be clearly seen if you compare the Government's first strategic environmental appraisal[20] (SEA) report for the 14th Licensing Round in 2010 – which had to be withdrawn in 2012 due to its evidential flaws – with the second SEA report[21] produced in December 2013. The second report indicated far higher levels of environmental impacts compared to the first.**

33. As evidence from the US, Canada and Australia has accumulated over the last decade or so, the Government's assertion of 'equivalence' has become increasingly strained. That includes both the economic impacts of shale gas, its environmental impacts, and its implications for climate change.

34. The greatest challenge to the Government's assertion of 'equivalence' came with the publication of a study[22] by Howarth, Santoro and Ingraffea in June 2011. **The study not only said that shale gas was significantly worse than conventional gas, but also potentially worse than coal. This conclusion challenged the Government's key claim that shale gas could be a "bridge" to a low carbon economy.**

35. The reasons why the Howarth study produced such a different result to other industry studies are complex. It is not just an issue about the 'bottom-up' versus 'top-down' methodology outlined earlier. It also encompasses a debate over the relative importance of different gases to climate change, and how this is assessed, and over what period of time, as part of the analytical process within the study.

36. The Howarth study utilizes data from a wider range of sources, including top-down analyses. What is also significant are the time-weighted 'global warming potential' (GWP) figures, used to assess the impacts of methane. This included an assessment over 20 years rather than 100 years. This gives a far higher impact in the short-term due to the enhanced effect of methane on climate change compared to carbon dioxide.

'The study not only said that shale gas was significantly worse than conventional gas, but also potentially worse than coal. This conclusion challenged the Government's key claim that shale gas could be a "bridge" to a low carbon economy'

‘The method of calculation used in the Mackay-Stone report is acceptable. The issue which is the subject of debate is the selection of the data fed into those calculations’

37. The justification for this, subsequently backed by the IPCC[23] , is that the uncertainty regarding climate tipping points[24] requires that we consider short-term impacts as well as those operating over a century.

38. There was a critique of the Howarth study from Cathales et al[25]. , published in January 2012. It was critical of the data sources used by the Howarth study – as they were not representative of the inventory-based estimates used by the industry and US Environmental Protection Agency – and the use of short- rather than long-term GWP figures for methane. Howarth's response to this paper[26] , published in July 2012, highlighted the failure of Cathales to model the whole gas system (their paper had only considered power generation), and included updated leakage information showing that their original paper had used representative data.

The Mackay-Stone review of shale gas emissions

39. The controversy over the climate emissions from shale gas led DECC to commission a detailed report from their Chief Scientific Adviser, David Mackay, and economist, Timothy Stone. Their report was commissioned as a general assessment of the climate change impacts of shale gas, but when reading the report, it is clear that one of the key aims was to deflect any criticisms of Government policy as a result of the Howarth study.

40. The Mackay-Stone review concluded:

We have used these US studies to estimate the potential for fugitive emissions from shale gas in the UK, with the understanding that actual emissions will vary according to local circumstances and that we must be cautious when extrapolating results. We have gathered available information on the carbon footprint of shale gas to inform our estimate of the potential impacts of shale gas exploration, extraction and use in the UK on UK climate change objectives.

With the right safeguards in place, the net effect on UK GHG [greenhouse gas] emissions from shale gas production in the UK will be relatively small.

41. The method of calculation used in the Mackay-Stone report is acceptable. The issue which is the subject of debate is the selection of the data fed into those calculations.

42. In order to compare different energy sources, such as natural gas and coal, their impacts must be converted into a standard unit for comparison. This also requires that the differing impacts of the greenhouse gases produced – such as carbon dioxide and methane – also be converted to a common value.

43. Studies such as the Mackay-Stone report express values as ‘equivalent’ greenhouse gas emissions per unit of energy produced. Producing these figures requires that certain values are known precisely in order to calculate those equivalent figures:

- The amount of ‘fugitive’ leaks and system losses must be accurately known in order to take account of the greenhouse gas emissions lost from the process;
- The amount of energy produced by a gas/oil well over its operating life must be known to get a figure for the energy produced; and
- There must be a standard approach to assessing the impacts of different greenhouse gases, using ‘global warming potentials’ (GWPs), to produced a harmonized measure of climate impacts over time.

44. **On all of these points the Mackay-Stone report fails to adequately represent the range of available data correctly. More critically, because they failed to address the uncertainties involved in producing the data, using different methodologies, the way they express their results tends to improve the case for shale gas relative to other fossil fuel sources.**

Fugitive emission estimates

45. To evaluate the range of figures for fugitive emissions of gas, the Mackay-Stone study takes various figures for emissions and then produces a statistically weighted figure for the level of emissions. However the figures from the Howarth study were specifically excluded from the results quoted in the final conclusion of the report (see paragraphs 50/51, pages 21/22, and paragraph 72, page 26, of their report).

46. The results from the Howarth study were classed as an "outlier" to the other data, and were excluded to prevent them skewing the report's final results.

47. **Though new research studies results were available at the time their report was compiled, and although these results were consistent with the range of the results in the Howarth study, these results were not included in the Mackay-Stone calculations either.**

48. **To justify this Mackay and Stone referenced an as yet, at that time, unpublished study from the University of Texas – the Allen study[27]** . This was believed to provide an authoritative response to the Howarth and the other top-down studies as it demonstrated that low levels of fugitive emissions could be achieved with 'reduced emissions completions' (RECs).

49. **What this means is that the data upon which Mackay and Stone base their estimates of emissions are predominantly bottom-up 'inventory studies' – rather than the direct measurement of emissions in shale production areas produced by top-down studies. There is growing concern about the accuracy of inventory-based statistics[28], since in-field sampling has demonstrated that using inventory-based data routinely under-report emissions[29] .**

Estimates of gas production per well

50. The figures for gas production used by Mackay and Stone are listed in paragraph 68 of their report. They assumed that gas production per well ranges from 2 billion cubic feet (bcf) to 5bcf, with a 'central' estimate of 3bcf. There is no clear, independent source for this data,

51. The report acknowledges that data from the US indicates a much lower range of gas production – **0.04 to 2.6bcf per well [30]. In paragraph 35 of their report, Mackay and Stone argue that "economic factors" will determine the level of gas produced from a well rather than geophysics – an assertion which is not substantiated by independent evidence.**

52. The difficulty for Mackay and Stone is that the emissions data they use is based upon wells operating at a lower range of production. Higher levels of gas production per well – for example, due to higher gas pressure/flows, or the result of more intensive hydraulic fracturing – would lead to greater levels of fugitive emissions. Consequently using a higher gas production figure with existing emissions data is likely to lead to an under-estimate of fugitive emissions.

53. Getting the correct figures for production is essential. Recent research [31] highlights that the overall level of oil or gas production (the 'estimated ultimate recovery', or EUR) is a sensitive variable in life-cycle models. Small variations have a significant impact upon results.

54. **Therefore, even if we accept Mackay and Stone's arguments in relation to the amount of gas production per well, that argument also requires that we must scale-up the level of impacts in order to reflect the greater gas flow, and thus leakage**.

55. **More importantly, the use of an excessively high EUR figure in their calculations would lead to a significant under-estimate of the climate change impacts of unconventional oil and gas. It would artificially lower the impacts reported in their results**.

Global warming potentials (GWPs)

56. **As outlined in paragraph 65 of their report, Mackay and Stone assume that methane is 25 times more potent a greenhouse gas than carbon dioxide over a 100 year period (abbreviated, 'GWP100'). This is not the approach taken within Howarth's calculations, which considers both 20-year ('GWP20') and 100-year 'global warming potentials' (GWPs).**

57. **Methane is significant in the short-term because it has a greater effect upon warming than carbon dioxide. As we approach critical tipping points[32] in the climate system, though the long-term prognosis[33] will be dominated by carbon dioxide, the short-term impacts of methane could exacerbate the progress of climate change. Therefore we must avoid large changes in the emission of critical greenhouse gases such as methane[34] .**

> **"economic factors" will determine the level of gas produced from a well rather than geophysics – an assertion which is not substantiated by independent evidence**

‘This also has implications for the level of acceptable leakage which is permissible by regulators’

58. This is why Howarth uses a ‘GWP20’ figure in his 2011 and subsequent papers.

59. In his 2014 update[35] of the original research paper, Robert Howarth outlined how the case for higher methane emissions had become more certain as a result of further ‘top-down’ environmental sampling. He also considered new research from the Intergovernmental Panel on Climate Change (IPCC) which had made the case that studies should use the GWP20 figure in assessments, as well as GWP100, to reflect the time-sensitive impact of emissions.

60. The IPCC’s 2013 review[36] of the science states that:
There is no scientific argument for selecting 100 years compared with other choices. The choice of time horizon is a value judgement because it depends on the relative weight assigned to effects at different times. Other important choices include the background atmosphere on which the GWP calculations are superimposed, and the way indirect effects and feedbacks are included.

61. Mackay and Stone’s failure to consider the short-term impacts of methane emissions is questionable since methane emissions have become a significant concern in our attempts to limit climate change.

62. GWPs are also significant because they affect the point at which leakage eliminates the climate benefits of using gas for power generation. For example, a recent modelling study by Sanchez and Mays[37] indicates that, compared to coal, while over 9% of gas could leak at GWP100 before its climate benefits are negated, less than 4% need leak for its benefits to be eliminated at GWP20 – which again is an issue which the Mackay-Stone report failed to elucidate.

63. Given the dominant greenhouse gas footprint of methane, Mackay and Stone should have used a 20-year GWP to properly assess the contribution of additional methane releases. This also has implications for the level of acceptable leakage which is permissible by regulators.

The impact of Mackay and Stone’s decisions on their results

64. The effect of the decisions over data selection and analysis taken by Mackay and Stone have very clear impacts on the results presented in the report:

- Selecting predominantly ‘inventory-based’ measures of fugitive emissions gives a lower result – it has been known for some time that inventory analyses under-estimate emissions;
- Excluding, as ‘outliers’, the data from instrumental sampling in the field – from the studies by Howarth, Pétron[38] and Karion[39] – significantly reduced the statistical range of the results produced, especially with regard to the comparison with liquefied natural gas (LNG);
- Using a very large figure for gas production, when the figures for fugitive emissions are based on much lower well production figures, artificially reduced the impacts of shale gas; and
- Using only a GWP100 figure, rather than the GWP20 used by Howarth and others, will also produce a lower result as it excludes the short-term effects of methane upon warming.

65. The result of Mackay and Stone’s decisions on their use of data is to improve the case for shale gas over other energy sources. In general, “back of the envelope” terms:

- The figures used for emissions are perhaps half, or less, of what is being observed in the field from actual shale gas/oil operations;
- The figures used for gas production are roughly twice that found in the USA; and therefore
- If we divide half by two, we can roughly say that Mackay and Stone’s results under-estimated the impacts of shale gas production by a factor of four.

66. In reality the band of potential results is very broad, depending upon the assumptions made in the data. It’s this uncertainty in results which fuels the confusion of impacts within the current debate on emissions.

67. **For example, recent evidence suggests is that a large proportion of the methane leakage from shale gas production comes not only from the well site, but also from the gas compressor stations[40] where the raw gas is cleaned and standardized for injection into the gas network – a source not properly evaluated in Mackay and Stone's calculations.**

68. **The appendices of the Mackay-Stone report contained tables produced from a spreadsheet. That spreadsheet was not made available for further analysis by DECC when they released the report. As part of my own analysis of the Mackay-Stone report I replicated this spreadsheet[41]**, initially to reproduce the calculated results presented in the tables of the report. Having established the baseline results presented in the report, I was able to vary the data fed into the model (as outlined in Appendix A of the report written to document[42] that analysis) **in order to study the sensitivity of Mackay and Stone's assumptions.**

69. **Remedying the perceived problems in the data used by Mackay and Stone, the results presented in their report increased by around 250%. That, contrary to the claims of their report, means that shale gas is less favourable than imported piped gas or LNG.**

70. It is difficult to modify the model to implement the 20-year GWP due to the conditions under which the data fed into the model was collected. As a rough approximation, using a 20-year GWP produces results which are not significantly lower than Howarth's 2011 study. **In fact, the use of Mackay and Stone's results to criticise the case as to why 'shale was worse than coal', given the distinct analytical assumptions between each study, is of itself misleading. If you use a 20-year GWP, like Howarth's study, the case for natural gas versus coal will almost inevitably disappear.**

71. The failures in data selection and analysis within Mackay and Stone's report creates questionable results. This was clearly foreseeable in late 2013 as a result of the emerging research then available, and their failure to highlight these uncertainties in their report, and reflect this in their advice, is a serious omission. Their selection of data, in particular the figures for gas production, are highly suspect, given that each decision has the effect of enhancing the case in support of shale gas. Consequently we can have little faith in the accuracy of their results.

Subsequent research on unconventional oil & gas impacts The Allen/ University of Texas study

72. As stated by Mackay and Stone, a few weeks after their report was published the Allen study[43] was published in the Proceedings of the National Academy of Sciences (PNAS). Almost immediately it ran into problems.

73. The first problem emerged only a few weeks after its initial release. The authors had declared no conflict of interest at the time of publication. A few weeks later PNAS had to publish a correction to note the various connections between certain authors of the study and the oil and gas industry.

74. The most significant criticisms emerged in the months following publication when other researchers had a chance to study the data. These criticisms not only call the results of this study into question, but by their reliance upon it to justify excluding Howarth's data, it negates the conclusions drawn by Mackay and Stone in their report too.

75. Allen's research was an 'inventory-based' study. What's equally significant is the number and type of oil and gas facilities involved. It states,

Emission measurements were performed for 27 well completion flowbacks, 9 liquids unloadings, 4 well workovers, and 150 production sites with 489 hydraulically fractured wells. Data are summarized here for the well completion flowbacks, liquids unloading, and production site emissions.

76. In reality, no general trend can be drawn from the evidence in this paper since the sites under investigation were not properly identified. It is not stated whether these operations were carried out at shale gas, coalbed methane, tight gas or associated oil and gas production sites –

'The authors had declared no conflict of interest at the time of publication. A few weeks later PNAS had to publish a correction to note the various connections between the authors of the study and the oil and gas industry'

'The figures used for emissions are perhaps half, or less, of what is being observed in the field from actual shale gas/oil operations'

even though the authors' own secondary measurements made by the downwind tracer ratio technique confirmed the BHFS sensor failure. That such an obvious problem could escape notice in this high profile, landmark study highlights the need for increased vigilance in all aspects of quality assurance for all CH4 emission rate measurement programs

or a combination of all of these. Different types of source rock produce different rates of flowback. Without more detailed information on the precise source, type and location it is not possible to integrate these results with other studies – and certainly not with the situation in the UK.

77. For example, all that the supplementary information appendix for the paper states is that,
Of the 27 completions sampled in this work, five were in the Appalachian region, seven in the Gulf Coast region, five in the Mid-Continent region, and ten in the Rocky Mountain region.

78. One of the significant flaws of this study is that the sites selected do not represent a randomized sample. The sites were selected by their industry partners, who were not identified in the study. What is more, the sites sampled represent only 0.1% of the on-shore conventional and unconventional wells in the USA.

79. Therefore we must question whether such a small and non-randomized sample of the total population of on-shore wells can be considered statistically significant – or whether these results are applicable even to the national US emissions profile, let alone that of other states such as the UK.

80. As is stated in the Allen study,
The uncertainty estimate does not include factors such as uncertainty in national counts of wells or equipment and the issue of whether the companies that provided sampling sites are representative of the national population.

81. This point is outlined further in the supporting information for the study,
The nine companies that participated in this study included mid-size and large companies. While there are thousands of oil and gas companies in the U.S., and small companies were not part of the participants, the participants do represent a sizable sample of overall U.S. production and well count... Representativeness cannot be completely assured, however, since companies volunteered, and were not randomly selected.

82. **It is entirely possible that all the sites selected by the industry for inclusion the Allen study were sites with the highest likelihood of achieving low emissions, due to the characteristics of the site, or because the operators took special care to minimise emissions during the tests.**

Discrepancy between inventory- and instrumental-based surveys

83. The studies recently carried out by the NOAA of US facilities[44] – not just oil and gas sites but also landfills and intensive agricultural operations – are enabling a far more accurate analysis of greenhouse gas emissions to be carried out. What these studies show is that 'bottom up' inventory-based studies tend to significantly under-estimate the level of emissions as compared to 'top down' environmental sampling.

84. The significance of this debate for the Mackay-Stone review is that their data is based almost entirely on bottom-up inventory studies. Recent top down sampling studies – such as those produced by Howarth – were left out of the calculations upon which the report's final conclusions were based. This means that the true value of emissions is likely to be be much greater than those described by Mackay and Stone.

85. At the time the Mackay-Stone review was compiled (July/August 2013) there were already a number of research studies[45] which indicated that there were problems with inventory-based estimates of emissions. The Mackay-Stone report did not use this data to form the main conclusions of the report. Instead they referenced the as yet unpublished, bottom-up inventory study by Allen in order to justify their exclusion of these other research studies.

86. Mackay and Stone also omitted the study by Peischl[46] , published in May 2013. This demonstrated that inventory-based studies did not correlate to the levels of atmospheric pollution observed from environmental sampling. Using an aircraft-based analysis of particular trace gases they were able to break-down the emissions by source, demonstrating that one large source of methane was likely to be the oil and gas industry (in addition to landfills and agriculture).

87. A study published shortly after Mackay and Stone's report by Miller[47] indicated the scale of the problem. In its analysis of methane emissions in the US,

it estimated the discrepancy between actual versus inventory based emissions to be 4.9 ± 2.6 times larger than the USEPA's most comprehensive global methane inventory. Again, that large '±2.6' uncertainty illustrates the problem of assessing the true impacts.

88. Since 2011, when Howarth et al. published their study, there have been many papers published which challenge the accuracy of inventory-based studies. These are listed, together with an extract of their significant findings, in Table 1 – reproduced at the end of this report.

89. Taken together, what these studies are beginning to show is that inventory-based methods are systematically under-estimating the true level of emissions. How great that discrepancy is varies across different industrial sectors, and across sites within each sector. For example, due to the geophysical variations in the oil and gas basins within the USA, environmental sampling shows that the emissions from each shale oil/gas production region vary significantly.

90. **Irrespective of the precise level of the variation, the problem for the Mackay-Stone review, and for the UK Government in general, is that the benefits claimed in the report cannot be supported when we look at the latest research on the emissions from shale oil and gas production. Those benefits were uncertain in 2013, when the Mackay-Stone report was produced. Today it is not possible to claim any validity for the findings of the report now there is extensive sampling to show that inventory-based emissions estimates are significantly understated.**

Flaws in sensors and their implication for emissions estimates

91. The final blow for the Allen study, and thus for the results of the Mackay-Stone report, came in late 2015/early 2016. Allen, and other inventory studies, use methane sensors installed within the system under test in order to quantify the levels of methane present in the system. Those levels inform the level of emissions, using flow analysis to calculate the levels of methane which leak to atmosphere.

92. In the Summer of 2015 a paper published by Howard[48] highlighted the failure of a commonly used methane sensor under certain test conditions – and the implications this had for monitoring and emissions inventories in the natural gas industry. In a subsequent paper[49] in September, Howard outlines how the Allen study had used these sensors to collect data, and how the data presented in the paper demonstrated that the methane measurements were influenced by the failure of the sensor.

93. As a result the data stated in the Allen study – irrespective of the issues with inventory analyses in general – were likely to understate the true level of emissions from the equipment under test.

94. Howard's second, September 2015 paper concluded:

Sensor transition failure is clearly apparent in the BHFS [Bacharach high flow sensor] measurements made in the UT study by Allen et al., as evidenced by the rare occurrence of high emitters at sites with lower CH4 (<91%) content in the well-head gas. The occurrence of this sensor transition failure was corroborated by field tests of the UT BHFS during which it exhibited this sensor failure, as well as by tracer ratio measurements made at a subset of sites with lower well-head gas CH4 concentrations...

Finally, it is important to note that the BHFS sensor failure in the UT study went undetected in spite of the clear artefact that it created in the emission rate trend as a function of well-head gas CH4 content and even though the authors' own secondary measurements made by the downwind tracer ratio technique confirmed the BHFS sensor failure. That such an obvious problem could escape notice in this high profile, landmark study highlights the need for increased vigilance in all aspects of quality assurance for all CH4 emission rate measurement programs.

95. These two papers, in addition to the other research outlined above, have caused a significant shift in the approach to both emissions sampling and inventory analysis.

96. In October 2015, in an update[50] to the US national greenhouse gas emission model, the Argonne National Laboratory

'The final blow for the Allen study, and thus for the results of the Mackay-Stone report, came in late 2015/early 2016'

'the data presented in the paper demonstrated that the methane measurements were influenced by the failure of the sensor'

'Given the weight of available evidence, BEIS, and Parliament, can have no confidence in the reliability of Mackay and Stone's conclusions'

'There are numerous examples of where ministers have quoted the Mackay-Stone report, and have attributed to it a level of certainty which cannot be supported if we look at the available body of evidence on emissions'

'emissions from the US oil and gas industry have been significantly underestimated'

noted the growing discrepancy between the inventory-based model they used, and the available real-world sampling. On the evidence presented by the Howard studies the report noted,
Howard (2015) published a study indicating that the high-flow sampling equipment used in the University of Texas studies had a sensor failure that caused a systematic underestimation of CH4 emissions. The key evidence was the lack of high emitting observations in those studies at gas compositions where the sensor is known to fail. Separate tracer measurements done by Allen et al. at some of the well sites suggest the high-flow measurements were a factor ranging from three to five too low.

97. The implication is that emissions from the US oil and gas industry have been significantly underestimated. That in turn has affected the models created to assess the emissions as part of the USA's monitoring of national emissions, which are then reported to the United Nations Climate Change Convention.

98. **At the beginning of February 2016 a paper by Turner[51] highlighted the growth in global methane emissions measured by satellite observations. It also postulated that US unconventional oil and gas production could be a factor in the increased global methane footprint.**

99. **This finding is also backed up by recent research[52] published by the Environmental Defense Fund (EDF). EDF were the backers of the Allen study in 2013. Their 2016 publication contradicted that research, having found that methane emissions are significantly greater than anticipated under inventory-based studies.**

100. **Recent research suggests that confidence in the Allen study is misplaced, not only because of its uncertainties regarding sample selection, but also because the data it presents is demonstrably wrong. As a result, the reliance of Mackay and Stone upon the Allen study, to justify their exclusion of environmental sampling-based studies from unconventional oil and gas sites, has also failed. Given the weight of available evidence, BEIS, and Parliament, can have no confidence in the reliability of Mackay and Stone's conclusions.**

How the Mackay-Stone report has misled the debate on 'fracking'

101. The Department of Energy and Climate Change (DECC) commissioned the Mackay-Stone review to promote their shale gas policy – and to support their "low carbon" claims in relation to shale gas against the research published by Howarth and others between 2011 and 2013.

102. Subsequent research on shale emissions – culminating in Howard's research looking at flaws in the Allen paper, on which the Mackay-Stone review relies in order to dismiss recent research findings as "outliers" – demonstrates that the data presented in the Mackay-Stone review is flawed.

103. Despite this, and though myself and others have pointed out the flaws in Whitehall's policy on shale gas and climate change, there has been no review of the findings of the Mackay-Stone report.

Parliamentary debates and the Mackay-Stone report

104. Arguably DECC, and more recently the new Department of Business, Energy and Industrial Strategy (BEIS), have actively misled the public over the likely emissions from shale oil and gas. There are numerous examples of where ministers have quoted the Mackay-Stone report, and have attributed to it a level of certainty which cannot be supported if we look at the available body of evidence on emissions.

105. For example:

- In October 2013, then Minister of State for Climate Change, Greg Barker, stated in response to a Parliamentary question[53] , and citing the Mackay-Stone report, that shale gas was compatible with the Government's climate change commitments;
- In March 2014, during a debate in the House of Lords[54] , DECC Parliamentary Under-Secretary of

State, Baroness Verma, stated that the Mackay-Stone report concluded that the carbon footprint of UK-produced shale gas would be lower than imported gas;

- In June 2014, in response to a question[55] , the Minister of State for Energy, Michael Fallon, stated that the Mackay-Stone review concluded that emissions from shale gas production in the UK would be relatively small;
- In September 2015, Parliamentary Under-secretary of State for Climate Change, Amber Rudd, misled Parliament when she made a statement to the House[56] , saying 'studies have shown that the carbon footprint of electricity from UK shale gas would be likely to be significantly less than unabated coal and also lower than imported liquefied natural gas.';
- In January 2015, Amber Rudd also gave a similar statement[57] to the Public Bills Committee as part of the debate over the Infrastructure Bill – which created a legal imperative to maximize the production of the UK's oil and gas resources;
- In January 2016, the Minister of State at the Department of Energy and Climate Change, Andrea Leadsom, stated in two Parliamentary questions[58] that the carbon footprint of shale gas extraction and use is likely to be comparable to conventional sources of gas and lower than imported liquefied natural gas.

106. The significance of the Mackay-Stone report in deflecting criticism can be illustrated when we look at instances when Parliamentarians have considered a wider range of evidence.

107. For example, in advance of the debate on amendment to the Infrastructure Bill, the Commons Environmental Audit Select Committee conducted an inquiry into the Environmental Risks of Fracking. Various respondents, including myself[59] , gave evidence on the shortcomings of the analysis of the Mackay-Stone review. In their final report[60] the Committee referenced my evidence (para. 81 of their report), and on the issue of the uncertainties in the science concluded that,

We called in Part 2 for a moratorium on fracking because it cannot be accommodated within our climate change obligations. A halt is also needed on environmental grounds, and it is essential that further independent studies into the impacts of fracking in the UK are completed to help resolve the environmental risk uncertainties. It is vital that the precautionary principle is applied. Until uncertainties are fully resolved, and the required regulatory and monitoring system improvements we identify are introduced, there should also be a moratorium on the extraction of unconventional gas through fracking on environmental grounds.

108. That call for a moratorium was ignored in the Parliamentary debate on the Infrastructure Bill which followed. In part, once again, to the misleading conclusions of the Mackay-Stone cited by senior Parliamentarians during that debate.

109. For example, in an exchange between[61] the chairman of the Commons Energy and Climate Change Committee, Tim Yeo, and the then Parliamentary Under-secretary of State for Climate Change, Amber Rudd, the Mackay-Stone report was quoted directly in support of the Government's policies on shale gas.

110. **Objectively the assurances given by ministers in relation to shale gas and climate change are meaningless. No such certainty existed in late 2013, and today the use of the Mackay-Stone report is wholly unsupported by the whole range of research evidence now available. The Mackay-Stone report has been used by ministers at DECC/BEIS and DEFRA to misled members of Parliament and Parliamentary committees into accepting shale gas exploration. In quoting the report, especially after the shortcomings of the report were repeated expressed by other bodies from early 2014 onwards, ministers have misled Parliament and arguably breached the Ministerial Code[62].**

'That call for a moratorium was ignored in the Parliamentary debate on the Infrastructure Bill'

The Committee on Climate Change's onshore petroleum assessment

111. The Committee Climate Change (CCC) was set up under the Climate Change Act 2008 with the statutory duty to advise the Government on climate change issues.

112. In March 2016 the CCC produced a report[63] on the compatibility of onshore petroleum production with the UK's

‘The CCC’s report concluded “Our assessment is therefore that onshore petroleum extraction on a significant scale is NOT compatible with UK climate targets unless three tests are met”

‘Test 3. reduction (in fossil fuel) consumption elsewhere in the economy to make space for shale gas production’

Given our currently available knowledge of the scale on emissions, we must be extremely sceptical of the Government’s ability to meet ‘test 3’

climate change commitments. That report was not released by the Government[64] until 7th July, as part of the general dumping of information at the end of the Parliamentary session.

113. In a statement to the House[65], Andrea Leadsom, Minister of State, Department of Energy and Climate Change stated:
The CCC’s report mainly focuses on shale gas extraction. The Government welcome the CCC’s conclusion that shale gas is compatible with carbon budgets if certain conditions are met. We believe that our strong regulatory regime and determination to meet our carbon budgets mean those conditions can and will be met.

114. That is not a fair representation of what the CCC’s report concluded.

115. Page 69 of the CCC’s report lists their conclusions and their three ‘tests’. Without strict limits on emissions (test 1), reductions in fossil fuel use over time (test 2), and reduction consumption elsewhere in the economy to ‘make space’ for shale gas production (test 3), what the CCC’s report actually concluded was (my emphasis in bold):
Our assessment is therefore that onshore petroleum extraction on a significant scale is **NOT** compatible with UK climate targets unless three tests are met.

116. Here it is possible to see why the Parliamentary briefing on Shale Gas, cited at the beginning of the report (para.6), differs markedly in its interpretation from the statement by Andrea Leadsom.

117. In their formal response[66] to the CCC’s report, the Government acknowledge the need to make allowance for the additional emissions from shale production, but they identify no mechanism or process to do this. They blindly assume that it can and will be done without any evidence to demonstrate the possibility of compliance with ‘test 3’.

118. Therefore there is no proof that they can meet the CCC’s tests, and thus on a precautionary basis the policy on unconventional oil and gas should not be implemented.

119. For example, in his recent evidence to[67] the Commons Business, Energy and Industrial Strategy Committee, Nick Hurd, Minister of State for Climate Change and Industry, made it clear that only half of the necessary savings to meeting the UK’s climate change commitments had been identified – and that the remaining options for reduction were, in his words, “hard”.

120. Given our currently available knowledge of the scale on emissions, we must be extremely sceptical of the Government’s ability to meet ‘test 3’.

The CCC’s report and emissions estimates

121. What is significant is that at no point has the CCC evaluated the flaws in the Mackay-Stone review – and therefore whether their current advice on emissions, despite their sceptical stance, is valid. Not only the issues related to ‘bottom-up’ versus ‘top down’ emission estimates, and the large under-estimate of emissions which appears to be extant under many inventory-based studies; but also the flaws of the Allen study, and the use of faulty gas monitoring equipment identified by Howard, which affects the overall reliability of the evidence presented in the Mackay-Stone report.

122. The CCC’s uncritical use of data is not restricted to the Mackay-Stone review alone. As part of their report on onshore petroleum, the CCC draw heavily upon a report produced by the Sustainable Gas Institute[68] (SGI) – an industry-funded research organisation based at Imperial College London. That report not only fails to discuss the flaws identified within the Allen study. They largely dismiss the recent top-down studies of fugitive emissions in a similar manner to Mackay and Stone (see section 4.4.2 of the SGI’s report). Compared to contemporary reviews of this issue, which have sought to reconcile the divergent results[69], their rejection appears to be biased towards the use of the lower, bottom-up estimates of emissions.

123. **As many of the information sources the CCC rely upon are inventory-based studies, the CCC should review their use of this information in general – in particular, the disparity between bottom-up and top-down emissions estimates. More specifically, they must address the identified flaws within the Allen study, and the effect this has upon the reliability of the Mackay-Stone report.**

Conclusion and recommendations

124. The purpose of this report has been to examine the validity of the Department of Energy and Climate Change's (DECC) Mackay-Stone report. This analysis has examined the events which led to its commissioning, the validity of its conclusions at the time of its release, and how those conclusions have stood-up within this fast-moving field of research.

125. Arguably, at the time of its publication, the Mackay-Stone report was flawed. Written primarily as a response to the Howarth study, the report failed to examine fully why Howarth came to such different conclusions. The way Mackay and Stone selected certain data, while excluding other data, and then assumed the value of other figures – such as the gas production per well – added to their failure to show why Howarth's results were so different to previous studies.

126. Today, with over three years hindsight, it is possible to say that the claims made in their report are demonstrably incorrect. Recent research shows that not only was their faith in inventory-based emissions assessments misplaced, but the figures they excluded as 'outliers' have been shown by other research studies to have been broadly correct (given the wide variance of results all these studies embody).

127. In their defence, Mackay and Stone – later supported by DECC – cited the Allen study as a justification for their selection of certain data, and the exclusion of other results. At the time of its publication the Allen study, on its own terms, was statistically flawed. More recently, as shown in the recent papers by Howard, it has become apparent that the equipment the Allen study used was faulty, and significantly under-reported the true level of methane emissions by up to three to five times.

128. In the case of the Mackay-Stone report, the uncertainty of its conclusions was reasonably foreseeable at the time of its publication. They should have understood and communicated the limitations of their results, and the uncertainty they contained. Arguably then, DECC/BEIS and DEFRA ministers have misled Parliament when repeating facts about shale gas which cannot be objectively substantiated.

129. As outlined in this report, over the past three years ministers at DECC/BEIS have consistently misled Parliament, the media and the public in their quoting of Mackay-Stone's conclusions. It is not simply that more recent research has invalidated the report. At the time of its publication it was not possible to state the conclusions of that report with such certainty – and at no point did DECC ministers properly communicate those uncertainties when making their statements.

130. It should also be noted that the two other major reports on the safety of shale gas production produced for DECC – by the Royal Society (2012) and Public Health England (2013/14) – also suffer from similar evidential flaws to the Mackay-Stone report. Their findings have been overtaken by the results of more recent research, which invalidates their use in policy-making.

131. In any case, there is a wider debate[70] at present as to whether the whole notion of a natural gas 'bridge' is valid. The IPCC in its 2014 review of the science[71] (chapter 7, section 7.5.1, page 527), commenting on the rise of hydraulic fracturing, notes that,

Empirical research is required to reduce uncertainties and to better understand the variability of fugitive gas emissions as well as to provide a more-global perspective. Recent empirical research has not yet resolved these uncertainties.

132. What research studies find when they test this assumption is that displacing coal with shale gas[72] does not significantly reduce emissions[73], in part due to the uncertainties of the fugitive methane leaks issue[74]. Only real-terms reductions in all fossil fuel use, demand reduction, and the fast transition to near-zero carbon energy sources, can achieve significant cuts[75] in global carbon emissions.

133. The evidence produced by DECC/BEIS to support its policies on unconventional oil and gas is no longer valid. The conclusions of those reports – not just Mackay-Stone, but also the Royal Society/RAE and Public Health England reports – have been invalidated by subsequent research. However in the case of the Mackay-Stone review its conclusions were never certain – and were thrown into doubt only a few weeks after its publication when the Allen study failed to provide a sound statistical case for the 'low carbon' credentials of shale oil and gas extraction.

134. In conclusion: the Government must immediately put in place a moratorium on shale gas and oilextraction and order a review of policy on unconventional gas and oil, taking account of all available research; and Parliament must review the use of Mackay-Stone report when making recent decisions on energy policy, and how the report has misinformed recent decisions over oil and gas extraction policy. In particular:

- The Commons Business, Energy and Industrial Strategy Committee must address the demonstrable flaws in the Mackay-Stone report with the BEIS department, and undertake a similar review in relation to the two other key reports published by DECC – by the Royal Society/Royal Academy of Engineering and Public Health England;
- The Commons Environmental Audit Committee should undertake a full review of the Government's oil and gas policies, promised after their limited review published in January 2015; and,
- All Parliamentarians need to scrutinize the statements made by ministers in relation to on-shore oil and gas development and climate change, and demand a full account of why the Government has failed to consider recent research which calls many of those claims into question.

Table 1. Recent research on the fugitive emissions from unconventional oil & gas production

(in chronological order by publication date)

PAPER	EXTRACT
Methane and the greenhouse-gas footprint of natural gas from shale formations, Howarth et al., Climatic Change, vol.106 no.4 pp.679-690, June 2011	*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. 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.*
Life cycle greenhouse gas emissions of Marcellus shale gas, Jiang et al., Environmental Research Letters, vol.6 no.034014, 5th August 2011	*This study estimates the life cycle greenhouse gas (GHG) emissions from the production of Marcellus shale natural gas and compares its emissions with national average US natural gas emissions produced in the year 2008, prior to any significant Marcellus shale development. We estimate that the development and completion of a typical Marcellus shale well results in roughly 5500t of carbon dioxide equivalent emissions or about 1.8gCO2e/MJ of gas produced, assuming conservative estimates of the production lifetime of a typical well. This represents an 11% increase in GHG emissions relative to average domestic gas (excluding combustion) and a 3% increase relative to the life cycle emissions when combustion is included. There is significant uncertainty in our Marcellus shale GHG emission estimates due to eventual production volumes and variability in flaring, construction and transportation.*
Coal to gas: the influence of methane leakage, Tom Wigley, Climatic Change, vol.108 pp.601-608, 26th August 2011	*Carbon dioxide (CO2) emissions from fossil fuel combustion may be reduced by using natural gas rather than coal to produce energy. Gas produces approximately half the amount of CO2 per unit of primary energy compared with coal. Here we consider a scenario where a fraction of coal usage is replaced by natural gas (i.e., methane, CH4) over a given time period, and where a percentage of the gas production is assumed to leak into the atmosphere. The additional CH 4 from leakage adds to the radiative forcing of the climate system, offsetting the reduction in CO2 forcing that accompanies the transition from coal to gas. We also consider the effects of: methane leakage from coal mining; changes in radiative forcing due to changes in the emissions of sulfur dioxide and carbonaceous aerosols; and differences in the efficiency of electricity production between coal- and gas-fired power generation.*
A commentary on 'The greenhouse-gas footprint of natural gas in shale formations' by R.W. Howarth, R. Santoro, and Anthony Ingraffea, Cathales et al., Geochemistry-Geophysics-Geosystems (G3), vol.13 no.6, 03/01/2012	*Natural gas is widely considered to be an environmentally cleaner fuel than coal because it does not produce detrimental by-products such as sulfur, mercury, ash and particulates and because it provides twice the energy per unit of weight with half the carbon footprint during combustion. These points are not in dispute. However, in their recent publication in Climatic Change Letters, Howarth et al. (2011) report that their life-cycle evaluation of shale gas drilling suggests that shale gas has a larger GHG footprint than coal and that this larger footprint "undercuts the logic of its use as a bridging fuel over the coming decades". We argue here that their analysis is seriously flawed in that they significantly overestimate the fugitive emissions associated with unconventional gas extraction, undervalue the contribution of "green technologies" to reducing those emissions to a level approaching that of conventional gas, base their comparison between gas and coal on heat rather than electricity generation (almost the sole use of coal), and assume a time interval over which to compute the relative climate impact of gas compared to coal that does not capture the contrast between the long residence time of CO2 and the short residence time of methane in the atmosphere.*
Air sampling reveals high emissions from gas field, Jeff Tollefson, Nature, vol.482 pp.139-140, 9th February 2012	*Methane leaks during production may offset climate benefits of natural gas*

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Hydrocarbon emissions characterization in the Colorado Front Range: A pilot study, Pétron et al., Journal Of Geophysical Research, vol.117 no.D4, 21st February 2012	*The multispecies analysis of daily air samples collected at the NOAA Boulder Atmospheric Observatory (BAO) in Weld County in northeastern Colorado since 2007 shows highly correlated alkane enhancements caused by a regionally distributed mix of sources in the Denver-Julesburg Basin. To further characterize the emissions of methane and non-methane hydrocarbons (propane, n-butane, i-pentane, n-pentane and benzene) around BAO, a pilot study involving automobile-based surveys was carried out during the summer of 2008. Our analysis suggests that the emissions of the species we measured are most likely underestimated in current inventories and that the uncertainties attached to these estimates can be as high as a factor of two.*
Assessing the greenhouse impact of natural gas, L.M. Cathales, Geochemistry-Geophysics-Geosystems (G3), vol.13 no.6, 19th June 2012	*The global warming impact of substituting natural gas for coal and oil is currently in debate. We address this question here by comparing the reduction of greenhouse warming that would result from substituting gas for coal and some oil to the reduction which could be achieved by instead substituting zero carbon energy sources. We show that substitution of natural gas reduces global warming by 40% of that which could be attained by the substitution of zero carbon energy sources. At methane leakage rates that are ~1% of production, which is similar to today's probable leakage rate of ~1.5% of production, the 40% benefit is realized as gas substitution occurs.*
Venting and Leaking of Methane from Shale Gas Development: Response to Cathles et al., Howarth et al., Climatic Change, vol.113 no.2 pp.537-549, July 2012	*In April 2011, we published the first comprehensive analysis of greenhouse gas (GHG) emissions from shale gas obtained by hydraulic fracturing, with a focus on methane emissions. Our analysis was challenged by Cathles et al. (2012). Here, we respond to those criticisms. We stand by our approach and findings. The latest EPA estimate for methane emissions from shale gas falls within the range of our estimates but not those of Cathles et al. which are substantially lower. Cathles et al. believe the focus should be just on electricity generation, and the global warming potential of methane should be considered only on a 100-year time scale. We reiterate our conclusion from our April 2011 paper that shale gas is not a suitable bridge fuel for the 21st Century.*
Shale gas production: potential versus actual greenhouse gas emissions, O'Sullivan & Paltsev, Environmental Research Letters, vol.7, 26th November 2012	*Estimates of greenhouse gas (GHG) emissions from shale gas production and use are controversial. Here we assess the level of GHG emissions from shale gas well hydraulic fracturing operations in the United States during 2010. Data from each of the approximately 4000 horizontal shale gas wells brought online that year are used to show that about 900 Gg CH_4 of potential fugitive emissions were generated by these operations, or 228 Mg CH_4 per well – a figure inappropriately used in analyses of the GHG impact of shale gas. Although fugitive emissions from the overall natural gas sector are a proper concern, it is incorrect to suggest that shale gas-related hydraulic fracturing has substantially altered the overall GHG intensity of natural gas production.*
Methane leaks erode green credentials of natural gas, Jeff Tollefson, Nature, vol.493 p.12, 3rd January 2013	*Losses of up to 9% show need for broader data on US gas industry's environmental impact.*
Enrichment of Radon and Carbon Dioxide in the Open Atmosphere of an Australian Coal Seam Gas Field, Tait et al., Environmental Science and Technology, vol.47 pp.3099-3104, 27th February 2013	*Atmospheric radon and carbon dioxide concentrations were used to gain insight into fugitive emissions in an Australian coal seam gas (CSG) field (Surat Basin, Tara region, Queensland).Average CO_2 concentrations over the 24-h period ranged from ~390 ppm at the control site to ~467 ppm near the center of the gas field. A ~3 fold increase in maximum Rn concentration was observed inside the gas field compared to outside of it. There was a significant relationship between maximum and average Rn concentrations and the number of gas wells within a 3 km radius of the sampling sites (n = 5 stations; $p < 0.05$). A positive trend was observed between CO_2 concentrations and the number of CSG wells, but the relationship was not statistically significant. Radon may be useful in monitoring enhanced soil gas fluxes to the atmosphere due to changes in the geological structure associated with wells and hydraulic fracturing in CSG fields.*

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Quantifying sources of methane using light alkanes in the Los Angeles basin, California, Peischl et al., Journal of Geophysical Research: Atmospheres, vol.118 no.10 pp.4974-4990, 27th May 2013	*Methane (CH4), carbon dioxide (CO2), carbon monoxide (CO), and C2-C5 alkanes were measured throughout the Los Angeles (L.A.) basin in May and June 2010. We use these data to show that the emission ratios of CH4/CO and CH4/CO2 in the L.A. basin are larger than expected from population-apportioned bottom-up state inventories, consistent with previously published work. We use experimentally determined CH4/CO and CH4/CO2 emission ratios in combination with annual State of California CO and CO2 inventories to derive a yearly emission rate of CH4 to the L.A. basin. We further use the airborne measurements to directly derive CH4 emission rates from dairy operations in Chino, and from the two largest landfills in the L.A. basin, and show these sources are accurately represented in the California Air Resources Board greenhouse gas inventory for CH4. The addition of CH4 emissions from natural gas pipelines and urban distribution systems and/or geologic seeps and from the local oil and gas industry is sufficient to account for the differences between the top-down and bottom-up CH4 inventories identified in previously published work.*
Methane emissions estimate from airborne measurements over a western United States natural gas field, Karion et al., Geophysical Research Letters, vol.40 no.16, 27th August 2013	*Methane (CH_4) emissions from natural gas production are not well quantified and have the potential to offset the climate benefits of natural gas over other fossil fuels. We use atmospheric measurements in a mass balance approach to estimate CH_4 emissions of 55 ± 15 × 10 kg h-1 from a natural gas and oil production field in Uintah County, Utah, on 1 day: 3 February 2012. This emission rate corresponds to 6.2%-11.7% (1σ) of average hourly natural gas production in Uintah County in the month of February. This study demonstrates the mass balance technique as a valuable tool for estimating emissions from oil and gas production regions and illustrates the need for further atmospheric measurements to determine the representativeness of our single-day estimate and to better assess inventories of CH_4 emissions.*
Anthropogenic emissions of methane in the United States, Miller et al., PNAS, vol. 110 no. 50 pp.20018–20022, 10th December 2013	*This study quantitatively estimates the spatial distribution of anthropogenic methane sources in the United States by combining comprehensive atmospheric methane observations, extensive spatial datasets, and a high-resolution atmospheric transport model. Results show that current inventories from the US Environmental Protection Agency (EPA) and the Emissions Database for Global Atmospheric Research underestimate methane emissions nationally by a factor of ~1.5 and ~1.7, respectively. Our study indicates that emissions due to ruminants and manure are up to twice the magnitude of existing inventories. In addition, the discrepancy in methane source estimates is particularly pronounced in the south-central United States, where we find total emissions are ~2.7 times greater than in most inventories and account for 24 ± 3% of national emissions. The spatial patterns of our emission fluxes and observed methane – propane correlations indicate that fossil fuel extraction and refining are major contributors (45 ± 13%) in the south-central United States. This result suggests that regional methane emissions due to fossil fuel extraction and processing could be 4.9 ± 2.6 times larger than in EDGAR, the most comprehensive global methane inventory. These results cast doubt on the US EPA's recent decision to downscale its estimate of national natural gas emissions by 25 – 30%. Overall, we conclude that methane emissions associated with both the animal husbandry and fossil fuel industries have larger greenhouse gas impacts than indicated by existing inventories.*
Quantifying Fugitive Emission Factors from Unconventional Natural Gas Production Using IPCC Methodologies, R.P. Glancy, Institute for Global Environmental Strategies, December 2013	*This study reviews available literature and data sources related to the fugitive emissions from the production of unconventional gas sources; Shale gas, Tight sands gas and Coalbed methane... The results show that fugitive emissions arising from hydraulic fracturing activities are substantial when compared with typical conventional gas fugitive emissions. Mean life-cycle values for fugitive emissions from Shale gas, Tight sands gas and Coalbed methane are 133%, 100% and 36% higher respectively than those of conventional gas in the developed countries... Developing countries show a similar scale of difference.*
Methane Leaks from North American Natural Gas Systems, Brandt et al., Science, vol.343 pp.733-735, 14th February 2014	*Why might emissions inventories be under-predicting what is observed in the atmosphere? Current inventory methods rely on key assumptions that are not generally satisfied. First, devices sampled are not likely to be representative of current technologies and practices... Second, measurements for generating EFs are expensive, which limits sample sizes and representativeness... Third, if emissions distributions have "heavy tails" (e.g., more high-emissions sources than would be expected in a normal distribution), small sample sizes are likely to under-represent high-consequence emissions sources.*

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Shale Oil and Natural Gas Nexus (SONGNEX): Studying the Atmospheric Effects of Changing Energy Use in the U.S. at the Nexus of Air Quality and Climate Change, Earth System Research Laboratory, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, April 2014	*Energy production and use in the U.S. have seen rapid changes over the past decade. The domestic production of oil and natural gas has grown strongly, natural gas is increasingly replacing coal for the generation of electrical power, and the contribution from renewables has rapidly grown. Many of these shifts have caused significant changes in the atmospheric emissions of trace gases and fine particles that are at the root of the Nation's air quality and climate change issues. However, since the changes in emissions are poorly known, the net effects for air quality and climate change are still very uncertain. Over the past decades, the U.S. has effectively addressed air quality issues and it is important to assure that the changes in our energy infrastructure do not negate some of these positive changes. Likewise, as the Nation is increasingly focused on mitigating the effects of climate change, it is important to know the net changes in emissions of greenhouse gases and other trace gases and fine particles that force the climate to change.*
Toward a better understanding and quantification of methane emissions from shale gas development, Caulton et al., PNAS, vol.111 no.17 pp.6237-6242, 29th April 2014	*The range of regional leak rates found here for the OSA (3-17%) is similar to leak rates found by recent studies across the United States... Although a recent study found production sites, to which they were given access, to be emitting less CH4 than EPA inventories suggest, these regional scale findings and a recent national study indicate that overall sites leak rates can be higher than current inventory estimates. Additionally, a recent comprehensive study of measured natural gas emission rates versus "official" inventory estimates found that the inventories consistently underestimated measured emissions and hypothesized that one explanation for this discrepancy could be a small number of high-emitting wells or components.*
A bridge to nowhere: methane emissions and the greenhouse gas footprint of natural gas, Robert W. Howarth, Energy Science and Engineering, vol.2 no.2 pp.47-60, June 2014	*In April 2011, we published the first peer-reviewed analysis of the greenhouse gas footprint (GHG) of shale gas, concluding that the climate impact of shale gas may be worse than that of other fossil fuels such as coal and oil because of methane emissions. We noted the poor quality of publicly available data to support our analysis and called for further research. The best data available now indicate that our estimates of methane emission from both shale gas and conventional natural gas were relatively robust. Using these new, best available data and a 20-year time period for comparing the warming potential of methane to carbon dioxide, the conclusion stands that both shale gas and conventional natural gas have a larger GHG than do coal or oil, for any possible use of natural gas and particularly for the primary uses of residential and commercial heating. The 20-year time period is appropriate because of the urgent need to reduce methane emissions over the coming 15-35 years.*
A new look at methane and nonmethane hydrocarbon emissions from oil and natural gas operations in the Colorado Denver-Julesburg Basin, Pétron et al. , J. Geophysical Research: Atmospheres, vol.119 pp.6836-6852, 16th June 2014	*Overall, our top-down emission estimates for CH4 and NMHCs from oil and natural gas sources are at least twice as large as available bottom-up emission estimates. Accurate estimates of emissions from oil and natural gas operations at the regional and national levels are still needed to quantify (and minimize) their impacts on climate forcing and air quality... Future research should also include the investigation of the apparent gap between bottom-up and top-down hydrocarbon emission estimates at the regional and national scales to track down which sources are either missing or underestimated and to quantify the contribution of anomalously large emitters, as suggested by Brandt et al. [2014].*
Methane emissions from natural gas production and use: reconciling bottom-up and top-down measurements, David T Allen, Current Opinion in Chemical Engineering, vol.5 pp.78-83, August 2014	*Methane emissions from the natural gas supply chain are a key factor in determining the greenhouse gas footprint of natural gas production and use. Recent estimates of these emissions have varied widely, because of the large population of sources, because of different measurement and estimation approaches, and because of extreme values of emission rates from individual sources that are much larger than population average values of emission rates from sources in the same category (a 'fat-tail' distribution). Reconciling differences between ambient methane concentration measurements (top-down methods) and direct measurement of emissions from individual sources (bottom-up methods) is critical to understanding methane emissions from the natural gas supply chain. A combination of top-down and bottom-up approaches is recommended.*
Noble gases identify the mechanisms of fugitive gas contamination in drinking-water wells overlying the Marcellus and Barnett Shales, Darrah et al., PNAS, 30th September 2014	*Using noble gas and hydrocarbon tracers, we distinguish natural sources of methane from anthropogenic contamination and evaluate the mechanisms that cause elevated hydrocarbon concentrations in drinking water near natural-gas wells. We document fugitive gases in eight clusters of domestic water wells overlying the Marcellus and Barnett Shales, including declining water quality through time over the Barnett. Gas geochemistry data implicate leaks through annulus cement (four cases), production casings (three cases), and underground well failure (one case) rather than gas migration induced by hydraulic fracturing deep underground.*

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Oil and gas wells and their integrity: Implications for shale and unconventional resource exploitation, Davies et al., Marine and Petroleum Geology, September 2014	*The datasets vary considerably in terms of the number of wells examined, their age and their designs. Therefore the percentage of wells that have had some form of well barrier or integrity failure is highly variable (1.9%-75%). Of the 8030 wells targeting the Marcellus shale inspected in Pennsylvania between 2005 and 2013, 6.3% of these have been reported to the authorities for infringements related to well barrier or integrity failure. In a separate study of 3533 Pennsylvanian wells monitored between 2008 and 2011, there were 85 examples of cement or casing failures, 4 blowouts and 2 examples of gas venting.*
Remote sensing of fugitive methane emissions from oil and gas production in North American tight geologic formations, Schneising et al., Earth's Future, vol.2 no.10 pp.548-558, October 2014	*In the past decade, there has been a massive growth in the horizontal drilling and hydraulic fracturing of shale gas and tight oil reservoirs to exploit formerly inaccessible or unprofitable energy resources in rock formations with low permeability. Here we demonstrate that positive methane anomalies associated with the oil and gas industries can be detected from space and that corresponding regional emissions can be constrained using satellite observations. On the basis of a mass-balance approach, we estimate that methane emissions for two of the fastest growing production regions in the United States, the Bakken and Eagle Ford formations, have increased by 990 ± 650 ktCH4 yr-1 and 530 ± 330 ktCH4 yr-1 between the periods 2006-2008 and 2009-2011. Relative to the respective increases in oil and gas production, these emission estimates correspond to leakages of 10.1% ± 7.3% and 9.1% ± 6.2% in terms of energy content, calling immediate climate benefit into question and indicating that current inventories likely underestimate the fugitive emissions from Bakken and Eagle Ford.*
Limited impact on decadal-scale climate change from increased use of natural gas, McJeon et al., Nature, vol.514 pp.482-485, 15th October 2014	*The most important energy development of the past decade has been the wide deployment of hydraulic fracturing technologies that enable the production of previously uneconomic shale gas resources in North America. The climate implications of such abundant natural gas have been hotly debated. Here we show that market-driven increases in global supplies of unconventional natural gas do not discernibly reduce the trajectory of greenhouse gas emissions or climate forcing. Our results, based on simulations from five state-of-the-art integrated assessment models of energy–economy–climate systems independently forced by an abundant gas scenario, project large additional natural gas consumption of up to +170 per cent by 2050. The impact on CO2 emissions, however, is found to be much smaller (from −2 per cent to +11 per cent), and a majority of the models reported a small increase in climate forcing (from −0.3 per cent to +7 per cent) associated with the increased use of abundant gas. Our results show that although market penetration of globally abundant gas may substantially change the future energy system, it is not necessarily an effective substitute for climate change mitigation policy.*
Mapping Methane and Carbon Dioxide Concentrations and δ13C Values in the Atmosphere of Two Australian Coal Seam Gas Fields, Maher et al., J. Water, Air and Soil Pollution, vol.225, 18th November 2014	*Data from this study indicates that unconventional gas may drive large-scale increases in atmospheric CH4 and CO2 concentrations, which need to be accounted for when determining the net GHG impact of using unconventional gas sources... Considering the lack of previous similar studies in Australia, the identified hotspots of GHGs and the distinct isotopic signature within the Tara gas field demonstrate the need to fully quantify GHG emissions before, during and after CSG exploration commences in individual gas fields.*
Methane Emissions from Process Equipment at Natural Gas Production Sites in the United States: Pneumatic Controllers, Allen et al., Environmental Science and Technology, vol.49 no.1 pp.633-640, 9th December 2014	*Emissions from 377 gas actuated (pneumatic) controllers were measured at natural gas production sites and a small number of oil production sites, throughout the United States. A small subset of the devices (19%), with whole gas emission rates in excess of 6 standard cubic feet per hour (scf/h), accounted for 95% of emissions. More than half of the controllers recorded emissions of 0.001 scf/h or less during 15 min of measurement. Pneumatic controllers in level control applications on separators and in compressor applications had higher emission rates than controllers in other types of applications. Regional differences in emissions were observed, with the lowest emissions measured in the Rocky Mountains and the highest emissions in the Gulf Coast. Average methane emissions per controller reported in this work are 17% higher than the average emissions per controller in the 2012 EPA greenhouse gas national emission inventory (2012 GHG NEI, released in 2014); the average of 2.7 controllers per well observed in this work is higher than the 1.0 controllers per well reported in the 2012 GHG NEI.*

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Direct measurements of methane emissions from abandoned oil and gas wells in Pennsylvania, Kang et al., PNAS, vol.111 no.51 pp.18173-18177, 23rd December 2014	*Methane emissions from abandoned oil and gas wells appear to be a significant source of methane emissions to the atmosphere... The measured wells presented in this paper are likely to be half a century old or older, and the positive flow rates measured at these wells indicate that the methane emissions from these wells may have been occurring for many decades and possibly more than a century. Therefore, the cumulative emissions from abandoned wells may be significantly larger than the cumulative leakage associated with oil and gas production, which has a shorter lifetime of operation.*
Allocating Methane Emissions to Natural Gas and Oil Production from Shale Formations, Zavala-Araiza et al., Sustainable Chemical Engineering, vol.3 no.3 pp.492-498, 28th January 2015	*The natural gas supply chain includes production, processing, and transmission of natural gas, which originates from conventional, shale, coal bed, and other reservoirs. Because the hydrocarbon products and the emissions associated with extraction from different reservoir types can differ, when expressing methane emissions from the natural gas supply chain, it is important to allocate emissions to particular hydrocarbon products and reservoir types. In this work, life cycle allocation methods have been used to assign methane emissions from production wells operating in shale formations to oil, condensate, and gas products from the wells. The emission allocations are based on a data set of 489 gas wells in routine operation and 19 well completion events. The methane emissions allocated to natural gas production are approximately 85% of total emissions (mass based allocation), but there is regional variability in the data and therefore this work demonstrates the need to track natural gas sources by both formation type and production region.*
Measurements of Methane Emissions from Natural Gas Gathering Facilities and Processing Plants: Measurement Results, Mitchell et al., Environmental Science and Technology, vol.49 no.5 pp.3219-3227, 10th February 2015	*Facility-level methane emissions were measured at 114 gathering facilities and 16 processing plants in the United States natural gas system. At gathering facilities, the measured methane emission rates ranged from 0.7 to 700 kg per hour (kg/h) (0.6 to 600 standard cubic feet per minute (scfm)). Normalized emissions (as a % of total methane throughput) were less than 1% for 85 gathering facilities and 19 had normalized emissions less than 0.1%. The range of methane emissions rates for processing plants was 3 to 600 kg/h (3 to 524 scfm), corresponding to normalized methane emissions rates <1% in all cases. The distributions of methane emissions, particularly for gathering facilities, are skewed. For example, 30% of gathering facilities contribute 80% of the total emissions. Emissions rates at these facilities were, on average, around four times the rates observed at similar facilities without substantial venting.*
Sensor transition failure in the high flow sampler: Implications for methane emission inventories of natural gas infrastructure, Howard et al., Journal of the Air and Waste Management Association, vol.65 no.7 id.150324005609009, March 2015	*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 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. 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.*
Mobile Laboratory Observations of Methane Emissions in the Barnett Shale Region, Yacovitch et al., Environmental Science Technology, vol.49 no.13 pp.7889-7895, 9th March 2015	*Results of mobile ground-based atmospheric measurements conducted during the Barnett Shale Coordinated Campaign in spring and fall of 2013 are presented. Methane and ethane are continuously measured downwind of facilities such as natural gas processing plants, compressor stations, and production well pads. Gaussian dispersion simulations of these methane plumes, using an iterative forward plume dispersion algorithm, are used to estimate both the source location and the emission magnitude. The regional distributions of source emissions and ethane/methane enhancement ratios are examined: the largest methane emissions appear between Fort Worth and Dallas, while the highest ethane/methane enhancement ratios occur for plumes observed in the northwestern potion of the region.*

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Quantifying atmospheric methane emissions from the Haynesville, Fayetteville, and northeastern Marcellus shale gas production regions, Peischl et al., Journal of Geophysical Research: Atmospheres, vol.120 pp.2119-2139, 13th March 2015	*Howarth et al. [2011] estimate that routine venting and equipment leaks lead to a loss of 0.3-1.9% of the CH4 produced over the life cycles of both conventional and shale wells. The 1.0-2.1% and the 1.0-2.8% we report as loss rates from the Haynesville and Fayetteville study regions, respectively, are at the upper end of this range. The loss rate from the Marcellus study region, 0.18-0.41%, is at the lower end of this range. Howarth et al. estimated additional CH4 emissions from well completions, liquid unloading, gas processing, and transport, storage, and distribution; however, we do not attempt to compare emissions from these activities at this time.*
Stream Measurements Locate Thermogenic Methane Fluxes in Groundwater Discharge in an Area of Shale-Gas Development, Heilweil et al., Environmental Science and Technology, vol.49 no.7 pp.4057-4065, 18th March 2015	*The environmental impacts of shale-gas development on water resources, including methane migration to shallow groundwater, have been difficult to assess. Monitoring around gas wells is generally limited to domestic water-supply wells, which often are not situated along predominant groundwater flow paths. A new concept is tested here: combining stream hydrocarbon and noble-gas measurements with reach mass-balance modeling to estimate thermogenic methane concentrations and fluxes in groundwater discharging to streams and to constrain methane sources. Modeling indicates a groundwater thermogenic methane flux of about 0.5 kg d-1 discharging into Sugar Run, possibly from this fugitive gas source. Since flow paths often coalesce into gaining streams, stream methane monitoring provides the first watershed-scale method to assess groundwater contamination from shale-gas development.*
Atmospheric Emission Characterization of Marcellus Shale Natural Gas Development Sites, Goetz et al., Environmental Science &Technology, 21st April 2015	*Emission rates from compressor stations ranged from 0.006 to 0.162 tons per day (tpd) for NOx, 0.029 to 0.426 tpd for CO, and 67.9 to 371 tpd for CO2. CH4 and C2H6 emission rates from compressor stations ranged from 0.411 to 4.936 tpd and 0.023 to 0.062 tpd, respectively. Although limited in sample size, this study provides emission rate estimates for some processes in a newly developed natural gas resource and contributes valuable comparisons to other shale gas studies.*
Measurements of methane emissions from natural gas gathering facilities and processing plants: measurement methods, Roscioli et al., Atmospheric Measurement Technology, vol.8 pp.2017-2035, 7th May 2015	*Increased natural gas production in recent years has spurred intense interest in methane (CH4) emissions associated with its production, gathering, processing, transmission, and distribution. Gathering and processing facilities are unique in that the wide range of gas sources (shale, coal-bed, tight gas, conventional, etc.) results in a wide range of gas compositions, which in turn requires an array of technologies to prepare the gas for pipeline transmission and distribution. We present an overview and detailed description of the measurement method and analysis approach used during a 20-week field campaign studying CH4 emissions from the natural gas G&P facilities. Combining downwind methane, ethane (C2H6), carbon monoxide (CO), carbon dioxide (CO2), and tracer gas measurements with on-site tracer gas release allows for quantification of facility emissions and in some cases a more detailed picture of source locations.*
Fracking Cannot Be Reconciled with Climate Change Mitigation Policies, Staddon & Depledge, Environmental Science Technology, vol.49 no.14 pp.8269-8270, July 2015	*Addressing climate change and meeting our energy needs are two of the greatest challenges that societies face. Many obstacles hinder progress. The search for inexpensive and plentiful energy supplies appears to be at odds with climate change mitigation commitments. The desire for short-term (next 30 years) energy security has reinvigorated investment in fossil fuel technologies and led to a North American boom in hydraulic fracturing for shale gas (fracking). However, fracking contributes both directly and indirectly to greenhouse gas emissions, further driving anthropogenic climate change. Here we consider the implications and conclude that the expansion of fracking is incompatible with climate change mitigation.*
Aircraft-Based Estimate of Total Methane Emissions from the Barnett Shale Region, Karion et al., Environmental Science & Technology, vol.49 no.13 pp.8124-8131, 7th July 2015	*Our top-down final emissions estimate is lower per unit of natural gas produced (1.3–1.9%) than has been found in several previous airborne studies of other oil and gas basins... current results for the Barnett region indicate that the EPA's GHGRP, which relies on self-reported data only from large producers and facilities, significantly underestimates (by a factor of 3) total natural gas and petroleum associated emissions from the Barnett. We also find that the globally gridded EDGAR inventory underestimates emissions from the oil and gas sector in this geographic region by a factor of almost 5, indicating that it should be used with great caution for the oil and gas sector.*

PAPER	EXTRACT
Characterizing Fugitive Methane Emissions in the Barnett Shale Area Using a Mobile Laboratory, Lan et al., Environmental Science & Technology, vol.49 no.13 pp.8139-8146, 7th July 2015	*Model results show that well pads emissions rates had a fat-tailed distribution, with the emissions linearly correlated with gas production. Using this correlation, we estimated a total well pad emission rate of 150,000 kg/h in the Barnett Shale area. It was found that CH4 emissions from compressor stations and gas processing plants were substantially higher, with some "super emitters" having emission rates up to 3447 kg/h, more then 36,000-fold higher than reported by the Environmental Protection Agency (EPA) Greenhouse Gas Reporting Program (GHGRP).*
Aircraft-Based Measurements of Point Source Methane Emissions in the Barnett Shale Basin, Lavoie et al., Environmental Science & Technology, vol.49 no.13 pp.7904-7913, 7th July 2015	*For the eight sources, CH4 emission measurements from the aircraft-based mass balance approach were a factor of 3.2-5.8 greater than the GHGRP-based estimates. Summed emissions totalled 7022 ± 2000 kg hr-1, roughly 9% of the entire basin-wide CH4 emissions estimated from regional mass balance flights during the campaign. Emission measurements from five natural gas management facilities were 1.2-4.6 times larger than emissions based on the national study.*
Constructing a Spatially Resolved Methane Emission Inventory for the Barnett Shale Region, Lyon et al., Environmental Science & Technology, vol.49 no.13 pp.8147-8157, 7th July 2015	*Our detailed, spatially explicit methane emission inventory for the Barnett Shale region illustrates the limitations of relying on commonly used data sources such as Greenhouse Gas Inventory (GHGI) and Greenhouse Gas Reporting Program (GHGRP) to estimate regional emissions. The GHGI Natural Gas Systems section relies primarily on national emission factors developed in the 1990s to estimate natural gas industry emissions and may not reflect regional differences or recent changes in emission profiles. The GHGRP only includes emissions from facilities meeting a reporting threshold and excludes most emissions from the gathering sector and certain emission sources; therefore, it is inherently an underestimate of emissions and should not be viewed as a complete emission inventory.*
Measurements of methane emissions from natural gas gathering facilities and processing plants: measurement methods, Roscioli et al., Atmospheric Measurement Technology, vol.8 pp.2017-2035, 7th May 2015	*Our detailed, spatially explicit methane emission inventory for the Barnett Shale region illustrates the limitations of relying on commonly used data sources such as Greenhouse Gas Inventory (GHGI) and Greenhouse Gas Reporting Program (GHGRP) to estimate regional emissions. The GHGI Natural Gas Systems section relies primarily on national emission factors developed in the 1990s to estimate natural gas industry emissions and may not reflect regional differences or recent changes in emission profiles. The GHGRP only includes emissions from facilities meeting a reporting threshold and excludes most emissions from the gathering sector and certain emission sources; therefore, it is inherently an underestimate of emissions and should not be viewed as a complete emission inventory.*
Using Multi-Scale Measurements to Improve Methane Emission Estimates from Oil and Gas Operations in the Barnett Shale Region, Texas, Harriss et al., Environmental Science and Technology, vol.49 no.13 pp.7524-7526, 7th July 2015	*A growing body of work using varying analytical approaches is yielding estimates of methane emissions from the natural gas supply chain. For shorthand, the resulting emission estimates can be broadly described as top-down or bottom-up. Top-down estimates are determined from measured atmospheric methane enhancements at regional or larger scales. Bottom-up estimates rely on emissions measurements made directly from components or at the site level. (We note that bottom-up emission estimates may rely on data obtained with emission quantification methods sometimes labeled as top-down.) Both approaches have strengths and weaknesses. Top-down estimates cannot easily distinguish emissions from specific source types, limiting the development of informed mitigation strategies. Bottom-up estimates are resource intensive, and may not provide sufficient statistical characterization of each source type to accurately estimate total emissions.*
Methane Emissions from Leak and Loss Audits of Natural Gas Compressor Stations and Storage Facilities, Johnson et al., Environmental Science Technology, vol.49 no.13 pp.8132-8138, 7th July 2015	*As part of the Environmental Defense Fund's Barnett Coordinated Campaign, researchers completed leak and loss audits for methane emissions at three natural gas compressor stations and two natural gas storage facilities. All sites had a combined total methane emissions rate of 94.2 kg/h, yet only 12% of the emissions total resulted from leaks. Methane slip from exhausts represented 44% of the total emissions. Remaining methane emissions were attributed to losses from pneumatic actuators and controls, engine crankcases, compressor packing vents, wet seal vents, and slop tanks. Average measured wet seal emissions were 3.5 times higher than GRI values but 14 times lower than those reported by Allen et al. Reciprocating compressor packing vent emissions were 39 times higher than values reported by GRI, but about half of values reported by Allen et al.*

PAPER	EXTRACT
Airborne Ethane Observations in the Barnett Shale: Quantification of Ethane Flux and Attribution of Methane Emissions, Smith et al., Environmental Science Technology, vol.49 no.13 pp.8158-8166, 7th July 2015	*We present high time resolution airborne ethane (C2H6) and methane (CH4) measurements made in March and October 2013 as part of the Barnett Coordinated Campaign over the Barnett Shale formation in Texas. Ethane fluxes are quantified using a downwind flight strategy, a first demonstration of this approach for C2H6. Additionally, ethane-to-methane emissions ratios (C2H6:CH4) of point sources were observationally determined from simultaneous airborne C2H6 and CH4 measurements during a survey flight over the source region. On the basis of two analyses, we find 71-85% of the observed methane emissions quantified in the Barnett Shale are derived from fossil sources. The average ethane flux observed from the studied region of the Barnett Shale was 6.6 ± 0.2 × 103 kg hr-1 and consistent across six days in spring and fall of 2013.*
Integrating Source Apportionment Tracers into a Bottom-up Inventory of Methane Emissions in the Barnett Shale Hydraulic Fracturing Region, Townsend-Small et al., Environmental Science Technology, vol.49 no.13 pp.8175-8182, 7th July 2015	*A growing dependence on natural gas for energy may exacerbate emissions of the greenhouse gas methane (CH4). Identifying fingerprints of these emissions is critical to our understanding of potential impacts. Here, we compare stable isotopic and alkane ratio tracers of natural gas, agricultural, and urban CH4 sources in the Barnett Shale hydraulic fracturing region near Fort Worth, Texas. Thermogenic and biogenic sources were compositionally distinct, and emissions from oil wells were enriched in alkanes and isotopically depleted relative to natural gas wells. Future top-down studies may benefit from the addition of δD-CH4 to distinguish thermogenic and biogenic sources.*
Constructing a Spatially Resolved Methane Emission Inventory for the Barnett Shale Region, Lyon et al., Environmental Science & Technology, vol.49 no.13 pp.8147-8157, 7th July 2015	*Our detailed, spatially explicit methane emission inventory for the Barnett Shale region illustrates the limitations of relying on commonly used data sources such as Greenhouse Gas Inventory (GHGI) and Greenhouse Gas Reporting Program (GHGRP) to estimate regional emissions. The GHGI Natural Gas Systems section relies primarily on national emission factors developed in the 1990s to estimate natural gas industry emissions and may not reflect regional differences or recent changes in emission profiles. The GHGRP only includes emissions from facilities meeting a reporting threshold and excludes most emissions from the gathering sector and certain emission sources; therefore, it is inherently an underestimate of emissions and should not be viewed as a complete emission inventory.*
Toward a Functional Definition of Methane Super-Emitters: Application to Natural Gas Production Sites, Zavala-Araiza et al., Environmental Science Technology, vol.49 no.13 pp.8167-8174, 7th July 2015	*Emissions from natural gas production sites are characterized by skewed distributions, where a small percentage of sites—commonly labelled super-emitters—account for a majority of emissions. A better characterization of super-emitters is needed to operationalize ways to identify them and reduce emissions. We designed a conceptual framework that functionally defines super-emitting sites as those with the highest proportional loss rates (methane emitted relative to methane produced). Because the population of functionally super-emitting sites is not expected to be static over time, continuous monitoring will likely be necessary to identify them and improve their operation. This work suggests that achieving and maintaining uniformly low emissions across the entire population of production sites will require mitigation steps at a large fraction of sites.*
University of Texas study underestimates national methane emissions at natural gas production sites due to instrument sensor failure, Touché Howard, Energy Science and Engineering, vol.3 no.5 p.443-455, 4th August 2015	*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 under-reporting 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 well-head 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. 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.*

PAPER	EXTRACT
Methane emissions and climatic warming risk from hydraulic fracturing and shale gas development: implications for policy, Robert Howarth, Energy and Emission Control Technologies, vol.3 pp.45-54, 8th October 2015	*Over the past decade, shale gas production has increased from negligible to providing >40% of national gas and 14% of all fossil fuel energy in the USA in 2013. This shale gas is often promoted as a bridge fuel that allows society to continue to use fossil fuels while reducing carbon emissions since less carbon dioxide is emitted from natural gas (including shale gas) than from coal and oil per unit of heat energy. However, significant quantities of methane are emitted into the atmosphere from shale gas development: an estimated 12% of total production considered over the full life cycle from well to delivery to consumers, based on recent satellite data. When methane emissions are included, the greenhouse gas footprint of shale gas is significantly larger than that of conventional natural gas, coal, and oil. Because of the increase in shale gas development over recent years, the total greenhouse gas emissions from fossil fuel use in the USA rose between 2009 and 2013, despite the decrease in carbon dioxide emissions. Given the projections for continued expansion of shale gas production, this trend of increasing greenhouse gas emissions from fossil fuels is predicted to continue through 2040.*
Effect of methane leakage on the greenhouse gas footprint of electricity generation, Sanchez & Mays, Climatic Change, vol.133 no.2, pp 169-17, November 2015	*This paper answers this question using a simple model, which assumes that the comprehensive GHG footprint is the sum of the carbon dioxide-equivalent emissions resulting from (1) electricity generation and (2) natural gas leakage. Results, presented on a straightforward plot of GHG footprint versus time horizon, show that natural gas leakage of 2.0% or 4.8% eliminates half of natural gas's GHG footprint advantage over coal at 20- or 100-year time horizons, respectively. Leakage of 3.9% or 9.1% completely eliminates the GHG footprint advantage at 20- and 100-year time horizons, respectively. A two-parameter power law approximation of the IPCC's equation for GWP is utilized and gives equivalent results. Results indicate that leakage control is essential for natural gas to deliver a smaller GHG footprint than coal.*
Fugitive emissions of methane from abandoned, decommissioned oil and gas wells, Boothroyd et al., Science of The Total Environment, 15th March 2016	*The study has detected elevated concentrations of soil gas methane above decommissioned (abandoned) oil and gas wells. The study showed that for 31 of the 102 wells (30%) the soil gas CH4 was significantly higher than that for their respective control sites with the maximum observed being 147% greater than the control... The relative CH4 concentration above wells did not significantly increase with the age of the well since drilling and 40% of the most recent wells surveyed showed leaks implying that leaks develop early in the post-production life of a decommissioned well.*
Reconciling divergent estimates of oil and gas methane emissions, Zavala-Araiza et al., PNAS, vol.112 no.51 pp.15597-15602, 22nd December 2015	*Published estimates of methane emissions from atmospheric data (top-down approaches) exceed those from source-based inventories (bottom-up approaches), leading to conflicting claims about the climate implications of fuel switching from coal or petroleum to natural gas. Based on data from a coordinated campaign in the Barnett Shale oil and gas-producing region of Texas, we find that top-down and bottom-up estimates of both total and fossil methane emissions agree within statistical confidence intervals. Measured oil and gas methane emissions are 90% larger than estimates based on the US Environmental Protection Agency's Greenhouse Gas Inventory and correspond to 1.5% of natural gas production. This rate of methane loss increases the 20-y climate impacts of natural gas consumed in the region by roughly 50%.*
A large increase in U.S. methane emissions over the past decade inferred from satellite data and surface observations, Turner et al., Geophysical Research Letters, vol.43, 16th March 2016	*National inventory estimates from the U.S. Environmental Protection Agency indicate no significant trend in U.S. anthropogenic methane emissions from 2002 to present. Here we use satellite retrievals and surface observations of atmospheric methane to suggest that U.S. methane emissions have increased by more than 30% over the 2002–2014 period. The trend is largest in the central part of the country, but we cannot readily attribute it to any specific source type. This large increase in U.S. methane emissions could account for 30–60% of the global growth of atmospheric methane seen in the past decade.*
Climate benefits of natural gas as a bridge fuel and potential delay of near-zero energy systems, Zhang et al., Applied Energy, vol.167 pp.317-322, April 2016	*Natural gas has been suggested as a "bridge fuel" in the transition from coal to a near-zero emission energy system. However, the expansion of natural gas risks a delay in the introduction of near-zero emission energy systems, possibly offsetting the potential climate benefits of a gas-for-coal substitution. We use a schematic climate model to estimate CO2 and CH4 emissions from integrated energy systems and the resulting changes in global warming over various time-frames. Then we evaluate conditions under which delayed deployment of near-zero emission systems would result in loss of all net climate benefit (if any) from using natural gas as a bridge. Considering only physical climate system effects, we find that there is potential for delays in deployment of near-zero-emission technologies to offset all climate benefits from replacing coal energy systems with natural gas energy systems, especially if natural gas leakage is high, the natural gas energy system is inefficient, and the climate change metric emphasizes decadal time scale changes.*

PAPER	EXTRACT
Fugitive emissions from the Bakken shale illustrate role of shale production in global ethane shift, Kort et al., Geophysical Research Letters, vol.43 no.9 pp.4617-4623, 16th May 2016	*Ethane is the second most abundant atmospheric hydrocarbon, exerts a strong influence on tropospheric ozone, and reduces the atmosphere's oxidative capacity. Global observations showed declining ethane abundances from 1984 to 2010, while a regional measurement indicated increasing levels since 2009, with the reason for this subject to speculation. The Bakken shale is an oil and gas-producing formation centered in North Dakota that experienced a rapid increase in production beginning in 2010. We use airborne data collected over the North Dakota portion of the Bakken shale in 2014 to calculate ethane emissions of 0.23 ± 0.07 (2σ) Tg/yr, equivalent to 1–3% of total global sources. Emissions of this magnitude impact air quality via concurrent increases in tropospheric ozone. This recently developed large ethane source from one location illustrates the key role of shale oil and gas production in rising global ethane levels.*
Airborne methane remote measurements reveal heavy-tail flux distribution in Four Corners region, Frankenberg et al., PNAS, vol.113 no.35 pp.9734-9739, 30th August 2016	*Space-based observations have identified the Four Corners region in the Southwest United States as an area of large CH4 enhancements. We conducted an airborne campaign in Four Corners during April 2015 with the next-generation Airborne Visible/Infrared Imaging Spectrometer (near-infrared) and Hyperspectral Thermal Emission Spectrometer (thermal infrared) imaging spectrometers to better understand the source of methane by measuring methane plumes at 1- to 3-m spatial resolution. Our analysis detected more than 250 individual methane plumes from fossil fuel harvesting, processing, and distributing infrastructures, spanning an emission range from the detection limit 2 kg/h to 5 kg/h through 5,000 kg/h. Observed sources include gas processing facilities, storage tanks, pipeline leaks, and well pads, as well as a coal mine venting shaft.*
Identification and characterization of high methane-emitting abandoned oil and gas wells, Kang et al., PNAS (preprint), September 2016	*Recent measurements of methane emissions from abandoned oil/gas wells show that these wells can be a substantial source of methane to the atmosphere, particularly from a small proportion of high-emitting wells. However, identifying high emitters remains a challenge. We couple 163 well measurements of methane flow rates; ethane, propane, and n-butane concentrations; isotopes of methane; and noble gas concentrations from 88 wells in Pennsylvania with synthesized data from historical documents, field investigations, and state databases. Repeat measurements over 2 years show that flow rates of high emitters are sustained through time.*
An improved method for estimating GHG emissions from onshore oil and gas exploration and development in China, Chen et al., Science of The Total Environment, vol.574 pp.707-715, 1st January 2017	*Greenhouse gas (GHG) emissions from oil and gas exploration and development are major contributors to emission inventories in oil and natural gas (ONG) systems. For the developing countries, including China, studies of this aspect of the industry, being at an early stage, lack a unified method of calculation, and this leads to varied projections of national emissions. In this paper, progress is reported on direct measurement of CH4 and CO2 emissions along the oil and gas value chain, for four oil and gas fields. An improved calculation method (classification calculation method), which considers the production status of each type of oil and gas field in China, is proposed for the first time in this study.*

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