Extreme Energy and Climate

A critical review of the UK Government's policy on unconventional fossil fuels and climate change

Paul Mobbs, Mobbs' Environmental Investigations,
3 Grosvenor Road, Banbury OX16 5HN.

May 2014

Correspondence related to this report should be addressed to:
Paul Mobbs,
Mobbs' Environmental Investigations and Research,
3 Grosvenor Road,
Banbury OX16 5HN.
Email – mei@fraw.org.uk

For further information on Paul Mobbs/ Mobbs' Environmental Investigations and Research go to – http://www.fraw.org.uk/mei/

Extreme Energy and Climate – A critical review of the UK Government's policy on unconventional fossil fuels and climate change

Paul Mobbs, Mobbs' Environmental Investigations,
3 Grosvenor Road, Banbury OX16 5HN.

May 2014

Report Contents

Introduction

This report provides a critical analysis of the evidence supporting Government's recent policy announcements on the issue of 'extreme energy' sources (tight oil and gas, shale gas, coalbed methane and underground coal gasification) in the UK – and the implications that the development of these energy sources may have on climate change. Although it has been written as a general review of the evidence concerning extreme energy sources and their impact upon climate, the content of this report is addressed specifically towards the administrative responsibilities of the Department of Energy and Climate Change (DECC) – and how those responsibilities have been discharged by the ministers of that department.

This report provides a commentary on the following:

- The report for DECC by MacKay and Stone – *Potential Greenhouse Gas Emissions Associated with Shale Gas Extraction and Use*[1];
- The Government's recent response to the MacKay-Stone report[2];
- Those parts of the House of Lords Economic Affairs Committee's recent report, *The Economic Impact on UK Energy Policy of Shale Gas and Oil*[3] related to climate change; and
- As part of all the above, a review of evidence concerning the issue of extreme fossil fuels and climate change, and how this in turn influences the policy and legal framework within which these developments are being promoted.

The purpose of this report is to contrast the evidential position of Government policy with the wider body of evidence available on the relationship between extreme energy sources and climate change. Arguably there is a gap between the Government's position and the latest research available on this issue. Furthermore, it is arguable that this gap between the available evidence and the case stated in support of Government policy, and the manner in which the Government is pursuing its policies on the promotion of extreme fossil fuel energy sources, is breaching certain provisions of administrative and environmental law.

Section 1 provides a summary of the main points/conclusions of this report. Section 6 contains specific conclusions and recommendations. The report is extensively referenced, and most of these references are available on-line (links are provided in the references section). All references listed in section 7 are identified in the footnotes on each page within square brackets. Unpublished background information is provided in the Appendices in section 8.

This report is the second in a series of critical reports examining the evidential basis for Government policy in relation to extreme energy sources in the UK. This report should be read in conjunction with the first report in this series, *A critical review of Public Health England's report – “Review of the Potential Public Health Impacts of Exposures to Chemical and Radioactive Pollutants as a Result of Shale Gas Extraction”*[4] Any queries with regard to the content of these reports should be addressed to the author.

1 *Potential Greenhouse Gas Emissions Associated with Shale Gas Extraction and Use* [MacKay 2013]

2 *The Government’s response to the MacKay-Stone report: Potential greenhouse gas emissions associated with shale gas extraction and use* [DECC 2014]

3 *The Economic Impact on UK Energy Policy of Shale Gas and Oil* [EAC 2014]

4 *A critical review of Public Health England's report* [Mobbs 2014]

About Paul Mobbs

Paul Mobbs has worked as an independent environmental consultant, author and lecturer for over 20 years. His first career was in the engineering industry. Since 1992 he has worked in many fields within environmental policy and law – from planning/development and waste management to environmental pollution and land contamination. He occasionally works as an information and communications technology consultant, primarily for non-governmental/community groups.

Since 2002 he has spent a large amount of time carrying out research, writing and lecturing on the issue of energy and the environment – and, in particular, on the issue of the ecological limits to human development and economic growth. Over this period he has lectured at universities and at Parliament, and has written a number of journal/current affairs articles on various aspects of this subject. His book on 'peak energy' in Britain, *Energy Beyond Oil*, was published in 2005. His most recent book was a study of the energy and environmental implications of the use of digital information and communications technologies, *A Practical Guide to Sustainable ICT*[5]

In 2009 he began research work on the proposals for unconventional gas development – initially focusing on shale gas and underground coal gasification. In 2010 this expanded to include coalbed methane proposals as a result of the Government's 14th Onshore Oil and Gas Licensing Round. This makes him one of the earliest 'community-based' researchers on this topic in Britain.

From 2010 he has organised education/lecture tours of different regions where unconventional gas development is likely to take place (2010/11 in Lancashire, 2012 in South Wales/the Midlands, 2013 in The Marches, South Wales and the Midlands) to disseminate information about unconventional gas development. As part of his research to support this work he reviews and collates large quantities of information from public bodies and research institutes. As a result, in a voluntary capacity, he maintains the Free Range Activism Website's (FRAW) On-line Library[6] – which currently houses the largest free collection of scientific papers and technical reports relevant to the examination of extreme energy developments in Britain.

In 2013 he was appointed as an adviser to the University of London School of Advanced Study's Extreme Energy Initiative[7]. He is currently working on a book on extreme energy in the UK, as well as continuing his work assisting communities around Britain which are likely to be affected by unconventional gas development.

5 *A Practical Guide to Sustainable ICT*, Paul Mobbs/Association for Progressive Communications, August 2012 – http://www.apc.org/en/pubs/practical-guide-sustainable-it

6 Free Range On-line Library: 'Extreme Energy' – http://www.fraw.org.uk/library/extreme.html

7 Extreme Energy Initiative – http://extremeenergy.org/

1. Summary and general observations

This report provides a critical analysis of the evidence supporting the Government's recent policy announcements on the issue of 'extreme energy' sources (tight oil and gas, shale gas, coalbed methane and underground coal gasification) in the UK – and the implications that the development of these energy sources has on climate change.

The purpose of this report is to contrast the evidential position of Government policy with the wider body of evidence available on the relationship between extreme energy sources and climate change. Arguably there is a gap between the Government's position and the latest research available on this issue. Furthermore, it is arguable that this gap between the available evidence and Government policy, and the manner in which the Government is pursuing its policies on the promotion of extreme fossil fuel energy sources, is breaching certain provisions of administrative and environmental law.

Section 2. The MacKay-Stone report on shale gas and climate change

The MacKay-Stone report, *Potential Greenhouse Gas Emissions Associated with Shale Gas Extraction and Use*, was launched in early September 2013. Since its launch the report has been used, both by the political and the industrial lobby in favour of extreme fossil fuel development, to argue that new sources of "unconventional" gas in the UK would not create excessive pollution.

Arguably their position regarding the low climate impacts of shale gas cannot be supported from a detailed reading of the text of the report. It states the opposite in fact – that there is no clear evidence to support many of the current assertions about unconventional gas extraction in the UK. As stated in in Appendix B of the report on the comparison of shale and conventional natural gas sources *(my emphasis in bold)* –

> *In the absence of information about the quality of the UK's shale gas* ***we have assumed*** *that shale gas would produce similar emissions to those in the production and processing of conventional gas.*

It would appear, irrespective of any evidence to the contrary, that the Government believes shale gas development in Britain to be acceptable in terms of its impact upon the climate; and that this position is based upon an assumption, not upon fact. This presents significant legal obstacles in relation to the Government's policy, which will be discussed further in section 5.

2A. Shale gas process, impacts and regulation

The MacKay-Stone report was commissioned as an extension to the review previously carried out jointly by the Royal Society and Royal Academy of Engineering (RS/RAE). That review was carried out in early 2012, when there was little peer-reviewed evidence on the impacts of shale gas development. Arguably the preparation of that report was premature, and its conclusions, in the light of more recent evidence, must be considered dated. In turn, the reliance of the MacKay-Stone review on the substance of the RS/RAE report invalidates some of the conclusions MacKay and Stone have drawn.

For example, the description of the impacts of pollution from hydraulic fracturing shows a misunderstanding of the mechanisms involved in hydrogeological pollution migration. Likewise the discussion of pollution from drilling, and from well failure mechanisms, demonstrates a disregard for the large amount of information available on this subject. The idea that hydraulic fracturing only takes place at depth can also be invalidated if we examine the geology of the areas which are to be released under the Government's *14th On-shore Oil and Gas Licensing Round* (see section 8A).

When carrying on any activity which results in a higher risk to society, the primary justification must be that it creates a positive benefit of a scale which outweighs those risks. Arguably one of the root assumptions of the MacKay-Stone report, and in fact of the Government's general policy objective, is that shale gas development in the USA has significantly improved the energy economy. There is today a large body of evidence which questions the financial benefit and environmental safety of shale gas development in the USA. That assertion is, currently, an issue of much debate in the USA – and this debate must be considered if the Government wishes to replicate those same activities here.

The report assumes that the Environment Agency will be able to effectively regulate the impacts of unconventional gas as a result of studying environmental impact assessments (EIAs), produced as part of planning applications. However, EIAs are not mandatory – and recent European proposals to required mandatory assessment were blocked by the UK Government. Likewise, the Treasury's recent initiative, requiring the Environment Agency to issue permits for these developments within two weeks, creates additional challenges to the effectiveness of regulation – and doubts have been expressed regarding the capability of the Agency to undertake this task effectively.

It is not unreasonable to expect that regulation might solve the problematic aspects of unconventional gas developments. The difficulty is that when the Government is pursuing a deliberately deregulatory approach, and cutting the funding for regulatory agencies, it is arguably unrealistic to assume, without any caution, that those regulatory systems will be able to eliminate risk in the manner outlined in the MacKay-Stone report. We have to question the effectiveness of regulation if the Government itself is doing its best to dismantle it – emulating the pattern taken in the USA during the early 2000s.

Building upon the Royal Society/Royal Academy of Engineering review, the MacKay-Stone report makes various assertions about risk, the regulation of environmental pollution, and the safety of the shale gas process. If we look at the evidence available – and in particular at more wide-ranging studies of the environmental risks of oil and gas development – this faith in the low risk of operation, and the way in which regulation can guarantee this, cannot be substantiated. More recent studies have identified significant environmental hazards from these operations. At the same time studies of the financial or energy effects of these processes do not show them to be as positive as anticipated. Therefore, these reports do not demonstrate that the risks of shale gas operations are quantifiable, nor that they are controllable, nor that they are justified by the benefits created.

2B. Shale gas and climate change

The assumption within the Government's energy policy is that natural gas is a cleaner fuel than coal or oil. That, as I will outline below, may be a highly questionable assumption. During 2011/2012 various studies questioned the role of natural gas as a “bridge fuel” to a low carbon energy system. The production of the MacKay-Stone report is, arguably, the Government's attempt to counter these studies, and to bolster the reputation of natural gas.

Chronologically, MacKay and Stone begin their review with Brown's study of the policy implications of growing shale gas resources. Digging through the literature we can find earlier studies which examine the apparently high rates of fugitive emissions which are common with unconventional fossil fuels, such as the Southern Methodist University study of fugitive emissions in the Barnett Shale.

In January 2011, the Tyndall Centre Manchester published its first review of the potential climate impacts of unconventional gas resources. This concentrated on the whole range of impacts from shale gas, and utilised some industry sources. Citing American Petroleum Institute data, this considered the fugitive greenhouse gas (GHG) emissions from the process to be “insignificant”. That illustrates the low priority given to the climate impacts of oil and gas production at this time.

In June 2011 Howarth et. al. published their assessment of the methane and greenhouse gas footprint of natural gas from shale formations – the first peer-reviewed life-cycle assessment of the climate impacts of shale gas. Integrating the high levels of network loss in the USA, even conventional gas had a significantly higher effect upon warming potentials than previously considered. The emissions from unconventional fossil fuels were higher still.

In August 2011, Jiang et. al. published their study of life-cycle greenhouse gas emissions of Marcellus Shale gas. The study concluded that the impact of Marcellus shale gas is, using a 100-year *global warming potential* (GWP), slightly higher than conventional gas, or equivalent to imported liquefied gas. October saw a new life-cycle assessment by Hultman et al. which assessed the greenhouse impact of unconventional gas for electricity generation. This concluded, using a 100-year GWP, that the greenhouse gas footprint of unconventional gas was around 11% higher than conventional gas and just over half that of coal. Also in October, Timothy Skone of the US Department of Energy gave a presentation which stated, using a 100-year GWP, that on-shore conventional gas production had a similar carbon footprint to unconventional gas, and was lower than imported liquefied gas.

In November 2011, the Tyndall Centre Manchester updated their previous assessment of the climate impacts of shale gas. The overview of that report provided by the MacKay-Stone report is wholly inaccurate, and dismisses the precautionary underpinning which frames their analysis. The updated Tyndall Centre report stated that the scenario for the UK gave additional cumulative emissions associated with the shale gas combustion comprised a substantial proportion, up to 29%, of an emissions budget associated with a better than 50:50 chance of avoiding 2°C warming. The report concluded that the lack of certainty in the data, along with the growing body of evidence for ground and surface water contamination from the US, required the application of the precautionary principle, and shale gas extraction must be delayed until clear evidence of its safety can be presented.

Other papers published around this time also challenged the assumption that shifting from coal to gas would reduce carbon emissions. For example, Wigley found that, unless leakage rates for new methane can be kept below 2%, substituting gas for coal is not an effective means for reducing the magnitude of future climate change; contrary to claims that it will “accelerate the decarbonisation of the world economy”.

January 2012 saw the publication of the first direct rebuttal of Howarth by Cathales et al.. They claimed the data used by Howarth was unrepresentative of the industry's own data, and that parts of the case presented by Howarth exaggerate the level of fugitive emissions by up to a factor of ten. In their assessment, on a 100-year GWP, they stated that the footprint of natural gas is a half to a third that of coal for power generation.

February 2012 saw the publication of the first direct measurements of the leakage from operational oil and gas fields. Pétron's study was the first to report atmospheric methane measurements for estimating oil and gas methane emissions. The measurements suggest that emissions are at least two times higher than estimated through the inventory process. February also saw the publication of a study by Myhrvold and Caldeira – omitted from the MacKay-Stone review – which found very little difference in impact between natural gas and coal in terms of their effect on atmospheric emissions. It concluded that natural gas and carbon capture storage cannot yield substantial temperature reductions – and that achieving substantial reductions in temperatures depended on the rapid deployment of a mix of renewable energy sources, and possibly carbon capture and storage.

In April 2012, Weber and Clavin published their probabilistic life-cycle analysis on emissions from fossil fuels. This highlighted the uncertainties in the data available on impacts, echoing Howarth, Hultman and the Tyndall Centre Manchester in their concern for the accuracy of the data on which almost all these analyses are based.

In June 2012, the Royal Society/Royal Academy of Engineering (RS/RAE) report, which the MacKay-Stone review relies upon to substantiate its support for regulation, was published. This has very little to say about fugitive emissions, or the climate impacts of natural gas relative to other fossil fuels. As with the general basis of Government policy, the RS/RAE report makes an a priori assumption that natural gas is cleaner than other types of fossil fuel, but never seeks to test that assumption by reference to actual data on life-cycle emissions on production and use.

In July 2012, Howarth et al. published their response to Cathales et al., outlining both the flaws in their commentary, and how more recent research backed-up their case for higher emissions from the oil and gas industry. It also examined more recent studies of oil and gas sites in Pennsylvania, and the regulatory system which applied to them – showing that not only were large emissions of un-flared gas permitted by the state authorities, but those releases had been instrumentally demonstrated.

In November 2012, O'Sullivan and Paltsev published their study of potential versus actual greenhouse gas emissions from shale gas. This concluded that in 2010 the total fugitive greenhouse gas emissions from US shale gas-related hydraulic fracturing amounted to 216 Gg CH_4. This represents 3.6% of the estimated 6,002 Gg CH_4 of fugitive emissions from all natural gas production-related sources.

In December 2012 an article in *Nature* reviewed early information from the study carried out in the wake of Pétron's research, being conducted as part of a long-term project by the National Oceanographic and Atmospheric Administration (NOAA). The next study to be published from this research was produced by Peischl et al. in May 2013, examining pollutants released into the air over Los Angeles. This concluded the most probable source for the excess atmospheric methane was a combination of leaks from natural gas pipelines and from oil and gas production centred in the western L.A. basin. The next study in the NOAA's project was published in August 2013, by Karion et al.. This identified discrepancies between the industry's sampling, carried out as part of regulatory emissions inventories, and the actual emissions which were sampled in the field – estimating that 8.8% ± 2.6% of gas production was leaking.

The fact that the Karion study highlighted discrepancies in the emission inventories compiled as part of the regulatory process was not discussed in the MacKay-Stone review. Nor was the fact that this data correlates to previous studies which highlighted such discrepancies between inventories and the level of fugitive emissions, going right back to the Armendariz study in 2009.

At the beginning of September 2013, the MacKay-Stone review was published. In the weeks following a number of studies would be published which added yet more doubt to the position taken in the MacKay-Stone report on the scale of fugitive emissions; and more importantly, how the underlying method by which emissions are calculated make the results very sensitive to the assumptions about the differences between conventional and shale gas sources.

The purpose of using a chronological review of the evidence on unconventional gas and climate change is that it illustrates the lack of hard information which underpins the current knowledge about the emissions from oil and gas production – and therefore the lack of certainty regarding their impacts upon the climate. As noted above, before Howarth's June 2011 paper, the climate impacts of natural gas due to fugitive emissions were considered "insignificant". In less than four years, a whole new field of scientific exploration has developed around the issue of climate and fugitive emissions – and reading across the evidence, we find that there is no certainty about climate impacts; but there is much concern about the potential damage which might be cause by the exploitation of unconventional gas. The fact that this was not discussed or explained within the MacKay-Stone report must be considered a serious flaw in that review.

2C. The influence of methodology on calculated emission rates

The MacKay-Stone report presents the disagreement between different studies in terms of poor data. In my view this contention over 'end results' masks the fundamental mismatch in the methodologies and assumptions which exists in these studies. In this process it is not the partisan argument over method which I find problematic. It's how this misunderstanding influences outcomes, and that these facts are not being communicated to the public and decision-makers.

This tendency to use varying assumptions within the method of assessment, and how it is used by certain studies, was not explained in the MacKay-Stone report. For example, their report relies heavily on the O'Sullivan and Paltsev paper – which uses a well lifetime of either 30 or 15 years, and the supplementary data for their paper gives a production figure for Marcellus shale wells of 3.7bcf to 2.7bcf. In contrast Burnham's study for the US Argonne National Laboratory states a recovery rates of 1.4bcf; and Hughes' analysis in *Nature* notes that a well has a life of only a few years. Arguably then, industry-quoted figures are much higher than other research sources, and that in turn lowers the calculated impacts upon the climate within industry-backed studies (a good example of this tendency would be Cathales' papers).

Another issue is that the performance of unconventional gas wells is highly variable. A recent US Geological Survey report noted the recovery rate for the most productive wells is more than 100 times larger than that from the poorest. As the MacKay-Stone report states, the significance of the variability of the estimated ultimate recovery (EUR) for each well is that it influences the carbon footprint of the gas produced. In which case the problem for the Government is that the MacKay-Stone review, as in the case of O'Sullivan and Paltsev, uses unrealistically high recovery rates – the central EUR figure is twice that of Burnham's statistics for the US Argonne National Laboratory study.

This understatement of impacts also be considered in relation to the life-time of the well. As seen in the USA, very high drilling and development rates must be maintained in order to maintain gas flows. This means that a large part of the resource is developed very quickly, and as development progresses the falling rate of recovery raises the impacts upon the climate – further accentuating the short-term effect upon carbon and methane emissions.

The problem is that, given the assumptions used in studies which support the development of unconventional gas, this is not apparent due to the assumptions in MacKay and Stone's method – and how this influences the assumptions in their own review. In contrast, a number of the papers cited in this report argue, due to the currently critical need to reduce carbon emissions, and the likelihood of breaching tipping points in the climate system over the next few decades, that we should be taking highly conservative assumptions about climate impacts – assessing the carbon footprint over the 20-year period as well as the longer-term 100-year.

If we examine the methodology behind various studies, we see a divergence depending on whether the case is being made in support of shale gas development or not. Those supporting shale gas use high well recovery rates, long well production lifetimes, and a 100-year baseline for assessing climate impacts. This arguably distorts the true environmental impacts due to the demonstrable fact that: average well production is much lower; well productive lifetimes are far shorter; and, when we consider the short-term nature of how this resource will be developed, the "hump" in emissions will have a clear short-term impact, just at the time we are trying to prevent a peak in emissions that will breach tipping points in the climate system. This divergence in method, and its implications for the results of these studies, has not been clearly explained to the public and decision-makers.

2D. Conclusions of the MacKay-Stone study

The MacKay-Stone review states that, with the right safeguards in place, the net effect on UK GHG emissions from shale gas production in the UK will be "relatively small". The report presents calculations claiming to show that the emissions from shale gas development are likely to be low. These data tables, part of a spreadsheet, are presented in the appendices of their report.

To allow further study, a spreadsheet was used to replicate the results of the MacKay-Stone report – allowing different values to be used to assess the sensitivity of their model. This shows that the selection of the 'estimated ultimate recovery' (EUR) value has a significant effect on the output. For example, halving the EUR to a more reasonable 0.9 to 1.9bcf, nearer to values indicated by recent USGS research, increases the emissions per unit of gas by between 200% and 350%.

What these results suggest is that the assumptions of the model are sensitive both to the accuracy of information on the level of fugitive emissions, and also to the selection of the EUR. Given that both of these factors are uncertain, this suggests that the confidence we can have in accurately modelling the impacts of shale gas emissions is low.

The conclusions of the report state that the potential increase in cumulative emissions could be counteracted if equivalent and additional emissions-reduction measures are made somewhere in the world. What this statement ignores is the growing body of evidence that natural gas is not only unsuitable as a "bridge fuel" in the transition to low carbon energy sources; it also fails to consider the evidence that other technological options will also fail to reduce carbon emissions quickly enough in order to avoid problematic disruption to the climate.

Taken as read, we have to look upon the conclusions of the MacKay-Stone review as misleading because they fail to encapsulate both the high level of uncertainty about these impacts, and the problems which exist within the data upon which these assessments are made. Therefore, we cannot attach any validity to the outcomes of this report, or the policy decisions which are based, unquestioningly, upon the results of this review.

2E. The University of Texas/EDF study

The MacKay-Stone report stated that the University of Texas were undertaking a more detailed study on emissions from the natural gas industry. This paper, by Allen et al., was duly published within a week of the MacKay-Stone report. Subsequent Government/industry promotion of the MacKay-Stone report also championed this paper as a justification of its central claim of “relatively small” climate impacts.

The Allen paper does not give up its details with a simple reading of the abstract, or of its conclusions. In order to understand the value of the paper it is necessary – as with the MacKay-Stone review – to probe the method and statistics of the research.

There are problems with the data presented in the study. It is not a full life-cycle review, therefore its conclusions are not directly comparable to, and the statistics for climate impacts will appear smaller than, the papers by Howarth and others. There is also uncertainty about the quality of the statistics – for example, it is not made clear whether these operations were carried out at shale gas, coalbed methane, tight gas or gas production associated with unconventional oil production sites, or a combination of all of these.

Another issue is that the sites sampled in the study were not a randomised sample. The sites were selected by their industry partners – who are not identified in the study. The sites sampled represent only 0.1% of the on-shore conventional and unconventional wells in the USA. Therefore we must question whether such a small and non-randomised sample of the total population of on-shore wells can be considered as statistically significant – and whether these results are even applicable to the national US emissions profile, or that of other states such as the UK.

It is entirely possible that all the sites selected for this study by the industry represented those 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 these tests. And at no point does the Allen paper tackle the disparity between the estimates of fugitive emissions based upon emissions inventories (such as the Allen study), and those which utilise in-field sampling from fixed sites or atmospheric sampling from aircraft – which have found an excess of atmospheric pollutants which indicate far higher emission rates.

The Allen report received extensive media coverage on its launch, and the MacKay-Stone report drew upon its unpublished findings to justify their own claims of “relatively small” impacts from shale gas development. However, when we look deeper into the method and statistical analysis we find that no such claim can be objectively supported by the Allen paper. It is a small, non-randomised sample of sites self-selected by the industry. We must also be sceptical of the impartial nature of this study because, on publication, the authors failed to properly identify their affiliations to the oil and gas industry. It is also wholly silent on the issue as to why large inconsistencies exist between instrumental records of fugitive emissions from these sites, and inventory-based assessments. Therefore we cannot give great weight to the evidence provided by this paper, particularly when its method specifically fails to address the contrary findings in many other peer-reviewed studies.

2F. Recent studies of the climate impacts of extreme fossil fuels

Our understanding of the impacts of unconventional gas development did not stop with the publication of the MacKay-Stone report – although we might infer from the recent publication of the

Government's response to their report that this might be the case.

The general issue of the significance of methane to climate change was highlighted in a paper by Miller et al., published shortly after the MacKay-Stone report. This paper looks at methane emissions from all human sources, and in particular notes the evolving nature of the debate on emissions from the oil and gas sector, and the uncertainty regarding the scale of these emissions. Their study concludes that there is a large inconsistency between the emission inventories for the US oil and gas sector and the levels of emission which can be demonstrated from instrument-based studies. The results indicate that emissions are as much as 4.9 ± 2.6 times larger than the EPA's emission inventories suggest.

Although it is possible to control methane emissions in many ways, what the debate about methane emissions is masking is the greater problem of the disparity between inventory assessments and what the latest instrument-based surveys reveal. It cannot be denied that "reduced emissions completion" (REC) is having an impact in US oil and gas fields. However, that impact is not as significant as its supporters promote. Although the greater problem of methane emissions is being addressed by RECs, this ignores the large rise in carbon dioxide emissions which are the product of gas flaring.

The issue of the inconsistencies between instrument-base and inventory assessments, like the US EPA's national inventory, was developed in Brandt et al.'s paper in February 2014. The criticisms of the US EPA's inventory assessment methods continued with the publication of the review by Moore et al.. This looked at the issue of methane sources across a number of different studies, and noted the problems with inventory assessments, and the way in which this created uncertainties in assessing the true scale of climate impacts.

April 2014 saw the publication of the US National Oceanic and Atmospheric Administration's plan for the study of the emissions from oil and gas fields. It was this work, beginning with Pétron's 2012 study, improved upon by Karion's 2013 study, which highlighted both the scale of emissions from unconventional fossil fuels, and the extent to which this differed from inventory assessments. This research project is due to take place in early 2015, with the first results reported towards the end of that year. Full publication of peer reviewed papers is not likely until 2016.

The next study from the NOAA's project was also published in April 2014. Caulton et al. looked at sites across the Marcellus shale in Pennsylvania. This again was an aircraft-based study, and it discovered a large regional methane flux associated with the shale gas industry. Perhaps the most significant discovery of this study was that there is a large methane release associated with well drilling – from wells which were still being drilled, had not yet been hydraulically fractured, and were not yet in production. This source of emissions is not considered the US EPA's inventory. Considering the implications of this discovery, and reviewing other research sources, the paper notes that natural gas systems are currently estimated to be the top source of anthropogenic CH_4 emission in the United States, and that the inadequate accounting of greenhouse gas emissions hampers efforts to identify and pursue effective greenhouse gas reduction policies.

The end of April 2014 saw the publications of Newell and Raimi's analysis of the net climate impacts of natural gas production. This modelled the effects of the changing patterns of energy use initiated by greater natural gas production. The results of this research do not confirm the common assumption, also made in MacKay and Stone's report as well as in that of the Royal Society/Royal Academy of Engineering, regarding the contribution of natural gas to lowering carbon emissions. Instead they find that shale gas will likely not substantially change global greenhouse gas (GHG) concentrations on its own. Shale gas has led to modest GHG emissions reductions, but these are not sufficient to substantially alter the future path of global GHG concentrations. For this to happen, policies would need to provide stronger incentives to switch to new technologies fuelled by natural gas, renewables, nuclear, and fossil fuels coupled with carbon capture and sequestration. These technologies would in turn need to become more cost-competitive and more broadly deployed on an international scale.

Finally, in May 2014 Howarth produced an updated paper which reviewed the range of research since the 2011 and 2012 papers – and how this new evidence changed the analysis of those earlier papers. More significantly, in this paper Howarth directly addresses the issue of the 'global warming potential' (GWP) of methane; not only noting that the 100-year GWP figure had recently increased, but also that the IPCC stressed the importance of using not just 20-year but also 10-year GWPs. In conclusion, Howarth notes that the uncertainties over the use of natural gas, and the high significance of methane to the overall impacts of global warming, cast doubt upon its role as a “bridge” towards a low carbon economy. As Howarth states, given the sensitivity of the global climate system to methane, why take any risk with continuing to use natural gas at all?

Clearly, this goes to the heart of the assumptions of the MacKay-Stone review – and its assumption of the superiority of using natural gas rather than, for example, an accelerated transition to non-fossil fuel energy sources. The IPCC's 2013 review of the science does indeed note that the selection of a particular GWP is a “value judgement”, and that there is no scientific argument behind using a 100-year value rather than the 10- or 20-year. Given the short-term nature of unconventional gas development it is arguable from the latest IPCC research that MacKay and Stone's review should have used the 20-year GWP. The significance of methane to the overall climate equation is such that not considering the short-term implications of unconventional gas production must be considered irresponsible – and that the Government's policy is evidentially flawed.

Reviewing the information across this section of this report, and considering the implications of the Government's policies on unconventional oil and gas, the MacKay-Stone report represents a two-fold failure. Firstly it is a failure of assessment – as it did not outline the significant uncertainties demonstrated across a wide range of recent research on the impacts of unconventional oil and gas development. In failing to convey these uncertainties when most recent research describes them at great length, and instead concluding that development would have a “relatively small” impact on UK greenhouse gas emissions, we must consider that the report is – whether by design or unintentionally – misleading. Secondly, it represents a failure to protect the public's interests. As is made clear in the *Civil Service Code*, the job of Government advisers is to “provide information and advice, including advice to Ministers, on the basis of the evidence, and accurately present the options and facts”; and not to “ignore inconvenient facts or relevant considerations when providing advice or making decisions”. It is arguable, given the evidence available, that the MacKay-Stone report fails to objectively weigh the evidence on the climate change implications of the Government's policies on unconventional gas. All Government policies or decisions which rely on this report must be considered flawed in their assumptions, and therefore open to challenge by the public.

3. The Government's response to the MacKay-Stone report

In April 2014, the Government published its response to the MacKay-Stone review. It should be noted that the contents of the MacKay-Stone report, and the Government's response to it, were not subject to public consultation. Therefore the questions raised within this study of the Government's policy on unconventional oil and gas could not be formally put to ministers – who proceeded to accept the MacKay-Stone report without any wide critical review of its content.

Although the response accepted a number of recommendations from the report, the statements made in their response raise doubts as to the effectiveness of these measures; and to the technical viability of this entire policy. In fact, what was significant was how little the response engaged with the issues raised in the MacKay-Stone report, and instead used this statement as an opportunity to promote the wider policy of unconventional gas development.

In my view the Government's response to the MacKay-Stone report not only fails to test the assumptions in that report; it also demonstrates a lack of understanding of the geophysics of unconventional fossil fuels. The assertions made in the Government's response, coupled with the failures of the MacKay-Stone report, and the Allen study which was also referenced, demonstrate a clear failure of judgement by the Department of Energy and Climate Change – and by extension, by the Government as a whole. Their policy of promoting unconventional fossil fuels appears to be an ideological position, not supported by objective evidence.

4. The House of Lords Economic Affairs Committee inquiry

The report from the House of Lords Economic Affairs Committee (EAC), *The Economic Impact on UK Energy Policy of Shale Gas and Oil*, was published on the 8th May 2014. The report contains many assertions about unconventional oil and gas which have very little evidence to back them up. It cites the conclusion by MacKay and Stone that the carbon footprint of shale gas extraction and use is comparable to gas extracted from conventional sources and lower than the carbon footprint of liquefied natural gas (LNG). As outlined in earlier in relation to the MacKay-Stone report, there is no unequivocal evidence to demonstrate this claim.

In criticising evidence from WWF, Greenpeace and Friends of the Earth, who state that leaking more than 3.2% of methane production has a climate impact worse than coal, their Lordships choose to cite a blog post from the New York Times. Arguably what this blog post represents is “pseudo-science”. In essence, the article claims that the Intergovernmental Panel on Climate Change's research on the global warming potential (GWP) of methane and other gases is irrelevant – and that the scientific consensus around the current use of GWPs is flawed.

The content of the EAC's report demonstrates a predetermination of the issues within their inquiry. They seem to have chosen the evidence they wished to hear because it confirmed their views – rather than weighing a wide range of evidence, and seeking to understand the substantive differences between the cases made, in order to arrive at a conclusion which has objective validity.

It would be possible to write many pages on the flaws in the EAC's report – but in this context it would add little to the consideration of the Government's policy on unconventional gas and climate change. That's because the EAC's report is poorly compiled, and is so biased in favour of the case for the oil and gas industry, that it has no objective value. In my view this report is so full of errors that it must be disregarded as part of this debate.

5. Extreme energy policy and administrative/environmental law

The Government's policies on unconventional fossil fuels do not exist in a vacuum. They must comply with the framework of laws and standards which direct government administration. In this case it is arguable that the errors of fact, and excess of exaggeration over the benefits of unconventional fossil fuels, breach this framework – thereby acting against the public interest.

5A. Misrepresentation of policy and the facts about unconventional fossil fuels

If we read across the whole range of information and policy produced by the Government on unconventional fossil fuels, what we find is a partial and often conflicting view of the research about these technologies, and the policy framework governing their operation. That in turn creates uncertainty about regulation, which leaves gaps in the protection of the environment and human health. As a result the Government's optimism bias creates opportunities where these processes might create severe harm to the environment and human health.

As well as problems with the factual basis of policy, the Government have also been carrying out arguably incompatible actions as part of creating a new policy framework to support unconventional fossil fuels – including reducing the ability of the public to object to these developments through various policy initiatives from a number of Government departments.

The MacKay-Stone report on climate change shares many general similarities with Public Health England's (PHE) recent study of the health impacts of shale gas. Both reports had methodological flaws; both poorly reviewed the available evidence on the issue under consideration; and as a result, both reached highly tenuous conclusions about the effects of these processes upon the environment.

Neither of these reports answer the public's criticisms of the process to date, because neither report is able to address the weight of evidence which puts the contrary position to their conclusions. Therefore the content of these reports will not assuage public criticism. Arguably, as with the general information produced by the Government on this subject, the difficulties with the content of these reports exist because of political pressures placed upon those carrying out these reviews.

The way in which the policy agenda surrounding unconventional fossil fuels has been organised, and the way in which scientific evidence has been commissioned and presented, has arguably infringed the various codes of conduct covering ministers, civil servants and scientific advisers. As is made clear in the *Civil Service Code*, the job of Government advisers is to “provide information and advice, including advice to Ministers, on the basis of the evidence, and accurately present the options and facts”; and not to “ignore inconvenient facts or relevant considerations when providing advice or making decisions”. What is at odds here is that both the MacKay-Stone and PHE reviews, by failing to assess the widest range of evidence and to fairly represent the nature of that evidence to ministers and the public, raise questions about the impartiality of these reports.

If we look at the manner in which the Government has implemented its policies in relation to unconventional fossil fuels, and the scientific advice sought to justify those claims, there are clear gaps between the available body of evidence about these processes, and the statements of ministers and their advisers in promoting policies in support of their use. In my view – and given the serious consequences of this policy for human health, the climate and the environment – these actions mislead the public, and act against the public's interests. As a result of the serious impacts which might ensue, these actions arguably breach the *Civil Service Code*, the *Ministerial Code*, and the *Principles Of Scientific Advice To Government*.

5B. The precautionary principle

For some time it has been arguable as to the exercisability of the precautionary principle directly within UK law. As part of the harmonisation of European environmental and planning policy, Article 191 of the Treaty of Lisbon/the Treaty on the Functioning of the European Union modifies the general objectives at the root of European environmental law –

> *Union policy on the environment shall aim at a high level of protection taking into account the diversity of situations in the various regions of the Union. It shall be based on the precautionary principle and on the principles that preventive action should be taken, that environmental damage should as a priority be rectified at source and that the polluter should pay.*

The first stage in the application of the precautionary principle is the acceptance that uncertainty exists; the characterisation of uncertainty – which is a practical aspect of all "science" rather than the statement of what is "certain" – then follows on from this acceptance. In my view the MacKay-Stone report, and the response of the Government to that report published in April 2014, seek to deny that any uncertainty exists; and therefore blindly adopt measures which fit the Government's views, rather than opening up the analysis of policy to identify the scope of these uncertainties.

The use of the MacKay-Stone report to make certain arguments in relation to climate change and shale gas is another example of failure to consider uncertainty – since the arguments used in that report are based upon assumptions which fit the requirements of policy, not objectively quantified risks. Furthermore, the reliance of that report upon unrepresentative studies, to argue the case for the equivalence of conventional and unconventional gas production, represents a spurious argument – since it seeks to advance certainty where no such certainty can be demonstrated.

The MacKay-Stone report concludes that –

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

In fact there is currently a very high degree of uncertainty as to the nature and extent of the climate impacts from unconventional oil and gas production – as there are uncertainties in the way the MacKay-Stone report evaluates those risks, both in the assumptions of its modelling, and in the dismissal of research which questions those assumptions. As the MacKay-Stone report makes no attempt to consider the precautionary approach, it stands in defiance to the objectives at the root of Community environmental law. As a result of the Government's failure to make appropriate corrections in their response to that report, those flaws have now been transposed into Government policy. Therefore any decisions made with reference to the MacKay-Stone report must be considered flawed, and open to challenge by the public.

5C. Decision-making bias and likely misconduct in public office

There comes a point when, as citizens, we have to ask whether our political system has the capacity to adapt and change, and to address itself to foreseeable challenges; or whether that process has become so compromised by vested interests that it blindly enacts policies which exacerbate our objective ecological situation.

This argument comes to a head with the issue of unconventional oil and gas development – because so many elements of our political processes are directly influenced by the fossil fuel lobby. For example, Lord Browne, non-executive minister at the Cabinet Office is a managing director of

Riverstone, who have a major stake in Cuadrilla (Britain's leading shale gas company) as well as other global energy interests, and is also the Chairman of Cuadrilla.

If should be noted that the Ministerial Code states that, "Ministers must ensure that no conflict arises, or appears to arise, between their public duties and their private interests". Note the specific points that it is not required to prove a conflict of interest – the "appearance" of such conflicts is a breach of the code.

Ministers, as quasi-judicial decision-makers, must act in a fair and unbiased way – a principle enshrined in both the *Ministerial Code* and the *Civil Service Code*. They are required not only to act impartially, but to be seen to act impartially in the interests of justice. In a 2001 ruling the House of Lords updated the definition of bias in public office with the "Porter test" –

> *The question is whether the fair-minded and informed observer, having considered the facts, would conclude that there was a real possibility that the tribunal was biased.*

Bias on the part of a public body is a serious matter. It infringes the various codes of practice, discussed earlier in this report; and in the worse case it might lead to personal action against those involved for the criminal offence of "misconduct in a public office". For that reason it is important to be precise both about the claim of bias, and the evidence for that claim.

In my view:

- **In evaluating the evidence reviewed by MacKay and Stone in the formulation of their report, it is not possible to correlate their conclusions to the weight of evidence which exists on this issue – both today, and even at the time the report was published. The certainty of "relatively small" risks to the climate from developing unconventional fossil fuels in the UK cannot be proven if we look at the evidence available at this time.**
- **Given the Government's current ideological drive in support of fossil fuels, and against renewable energy sources, there is a suspicion that MacKay and Stone – due to pressure from DECC – did not carry out the study in an impartial manner, and have reached a biased conclusion.**
- **In turn, the support given to the conclusions of the MacKay-Stone report by leading ministers and the Government, combined with the fact that financial interests close to the oil and gas lobby have influence within the Cabinet, leads to the conclusion that Government policy on this matter is biased in favour of those vested interests – in prejudice to the interests of the public.**

As a result – and given the potentially serious implications for the climate, the environment and human health if this policy is forced through – those involved in the promotion of this policy are arguably acting outside the law, and the various codes of conduct which apply to conduct of Government business. Therefore evidence exists to suggest that those involved in the promotion of this policy should be investigated for the offence of 'misconduct in a public office'.

In conclusion, the issue of energy and the environment is complex, and is innately linked to the deeper economic values at the heart of society. Arguably the attraction of unconventional fossil fuels is that they offer a means of perpetuating the "normal" business of society, and therefore avoid the need to undertake painful structural changes to the operation of all aspects of society in order to deal with climate change, resource depletion, and environmental damage – and ultimately transition society in to a far more stable and sustainable mode of operation.

It may be that those involved believe that they are acting in the public interest. However, given the uncertain evidence upon which they rely to justify this, and their infringement of various rules to perpetuate these policies in the absence of clear evidence, such beliefs cannot be objectively justified. Therefore, in the absence of clear evidence to support their actions, the Government's policies in support of unconventional fossil fuels must be suspended, and alternative options sought. Should that not be the case, then it requires public action to force a review, and ultimately halt, this misguided project.

2. The MacKay-Stone report on shale gas and climate change

The MacKay-Stone report, *Potential Greenhouse Gas Emissions Associated with Shale Gas Extraction and Use*[8], was launched in early September 2013. The content of the report was not subject to an open public consultation over its factual content or policy recommendations.

Since its launch the report has been used, both by the political and industrial lobbies in favour of extreme fossil fuel development, to argue that new sources of "unconventional" gas in the UK would not create excessive greenhouse gas emissions. Alongside the recent Public Health England review[9], and the British Geological Survey's resource studies[10], this report forms part of a public relations initiative by the Government to justify their support for unconventional fossil fuel sources in Britain.

Arguably MacKay and Stone's position regarding the low climate impacts of shale gas cannot be supported from a detailed reading of the text of their report. It states the opposite in fact – that there is no clear evidence to support many of the conclusions about unconventional gas extraction in the UK.

The purposes of the MacKay Stone report are stated in the text[11] –

> *This report considers the available evidence on the life-cycle GHG emissions from shale gas extraction and use and the need for further research. Specifically, this report now examines two sets of GHG emissions: (1) those associated with the drilling for, removal and transportation of shale gas ('extraction') and (2) those associated with the use of shale gas. These shale emissions are compared with the GHG emissions from extraction and use of other fuels, including conventional gas drilling, Liquefied Natural Gas (LNG) and coal.*

In this review I will not examine the comparisons with conventional, piped or liquefied gas (LNG). Instead I focus solely on how the figures for the impacts of shale gas were arrived at in the report, and what contemporary and more recent studies can tell us about the validity of the report's conclusions.

When the report was first published I queried its content with the Department of Energy and Climate Change (DECC). In my view the evidence outlined in the report did not appear to be complete – in particular, the references to various appendices. However, it appears that the report was complete, and that the statements made must be considered "as is". In particular, the evidence presented in Appendix B of the report on the comparison of shale and conventional natural gas sources[12] (my emphasis in bold) –

> *In the absence of information about the quality of the UK's shale gas* ***we have assumed*** *that shale gas would produce similar emissions to those in the production and processing of conventional gas.*

It would appear, irrespective of any evidence to the contrary, that the Government believes shale gas development in Britain to be acceptable in terms of its impact upon the climate; and

8 *Potential Greenhouse Gas Emissions Associated with Shale Gas Extraction and Use* [MacKay 2013]

9 *Review of the Potential Public Health Impacts of Exposures to Chemical and Radioactive Pollutants as a Result of Shale Gas Extraction* [PHE 2013]

10 *Bowland Shale Gas Study* [BGS 2013]
Weald Basin Jurassic Shale Study [BGS 2014]

11 paragraph 9, page 11, *Potential Greenhouse Gas Emissions Associated with Shale Gas...* [MacKay 2013]

12 paragraph 118, Appendix B, page 43, ibid.

that this position is based upon an assumption, not upon established or verifiable fact. This presents a significant legal obstacle in relation to the Government's energy policy, which will be discussed further in section 5.

The report does make various observations upon the evidence available on shale gas emissions and climate change – which I will explore below. In the following sections I will explore the MacKay-Stone report's examination of the evidence, and show how their analysis differs from the wide range of research now available.

A. Shale gas process, impacts and regulation

The MacKay-Stone review was commissioned, as outlined in the text[13], as an extension to the review previously carried out jointly by the Royal Society and Royal Academy of Engineering (RS/RAE). That review was carried out in 2012 when – as outlined in my previous report[14] on the Public Health England's (PHE) shale gas review[15] – there was very little peer-reviewed evidence on the impacts of shale gas development. Arguably the preparation of both the RS/RAE and PHE reports was premature, and as with the MacKay-Stone review their conclusions, in the light of more recent evidence, must be considered dated.

Arguably the RS/RAE report contains serious factual flaws, and does not reflect the full range of evidence available at the time of its production – evidence which presents a far less certain view of the impacts which these operations generate. In turn, the reliance of the MacKay-Stone review on the substance of the RS/RAE report invalidates some of the conclusions they have drawn.

For example, MacKay-Stone report states[16] –

> *Fracture propagation is unlikely to cause any contamination of aquifers. The risk of fractures propagating to reach overlying aquifers is very low provided that shale gas extraction takes place at depths of many hundreds of metres or several kilometres. Even if fractures reached overlying aquifers, the necessary pressure conditions for contaminants to flow are very unlikely to be met given the UK's shale gas hydrogeological environments.*

This topic is also considered later in the report[17] –

> *The fracture growth height is dependent on the geology and design (number and spacing of stages, fluid chemistry, and injection rates and volumes) with Davies et al. (2012) reporting a maximum recorded fracture height of 588 m in a study of US data, some with much larger hydraulic fracturing volumes than would ever be considered in the UK.*

This shows a fundamental misunderstanding of the mechanisms involved in hydrogeological pollution migration. The pressure wave resulting from hydraulic fracturing, as outlined in recent

13 paragraph 8, ibid.

14 section 8d, *A critical review of Public Health England's report...* [Mobbs 2014]

15 *Review of the Potential Public Health Impacts of Exposures to Chemical and Radioactive Pollutants as a Result of Shale Gas Extraction* [PHE 2013]

16 paragraph 7, point 'b', page 10, *Potential Greenhouse Gas Emissions Associated with Shale Gas...* [MacKay 2013]

17 paragraph 30, page 16, ibid.

papers, is unlikely to push pollutants long distances underground[18]. However, it has been shown that the pressure wave can be detected up to a kilometre away[19]. And while the pressure wave does not transport pollution, it does indicate a physical connection which, via natural geological fluid flow patterns operating over decades, can move pollutants towards surface waters and aquifers[20].

For another example, let's consider[21] –

> *Well integrity is the highest priority. More likely causes of possible contamination include faulty wells. The UK's unique well examination scheme was set up so that independent, specialist experts could review the design of every well. This scheme must be made fit for purpose for onshore activities.*

This point is amplified later in the MacKay-Stone report[22] –

> *...Jackson et al. found evidence of gas escaping from wells into aquifers, concluding that the likely cause is poor well construction. We believe that sufficient regulations are in place that leakage of gas into aquifers is unlikely to occur – UKOOG guidelines clearly set out good practice in well design and these guidelines should be made mandatory. Future advances in self-healing cement are likely to mitigate this risk further.*

There are many studies demonstrating the opposite case to the above assertion[23]. Also, irrespective of industry guidelines cited, which of themselves carry no legal force, it would be unreasonable to assume that the failures seen in recent on-shore operations in the USA[24] or Australia[25] would not be repeated here in the future. For example, recent studies examining the record in US shale gas regions, which use much the same drilling technologies as will be used in the UK, show a catalogue of well failures[26]. And as stated in a 2011 United Nations Environment Programme (UNEP) study[27] –

> *Hydrologic fracking may result in unavoidable environmental impacts even if unconventional gas is extracted properly, and more so if done inadequately. Even if risk can be reduced theoretically, in practise many accidents from leaky or malfunctioning equipment as well as from bad practises are regularly occurring. This may be due to high pressure to lower the costs or to improper staff training, or to undetected leaks leading to contamination of the ground water.*

Not every oil and gas well that is drilled fails, and often they would not fail immediately – but we can say that inevitably a proportion of wells will fail. From a statistical point of view while it is not possible

18 *Oil and gas wells and their integrity: Implications for shale and unconventional resource exploitation* [Davies 2014]

19 *Comment on Davies et al 2012 – Hydraulic Fractures: How far can they go?* [Lacazette 2013]

20 *Potential Contaminant Pathways from Hydraulically Fractured Shale to Aquifers* [Myers 2012]

21 paragraph 7, point 'c', page 10, *Potential Greenhouse Gas Emissions Associated with Shale Gas...* [MacKay 2013]

22 paragraph 62, page 23, ibid.

23 For example:
Why Oilwells Leak: Cement Behavior and Long-Term Consequences [Dusseault 2000]
Evaluation of the CO2 Leakage Risk Along the Abandoned Wells in the French Context [Sy 2012]

24 *A Critical Review of the Risks to Water Resources from Unconventional Shale Gas Development and Hydraulic Fracturing in the United States* [Vengosh 2014]

25 Leakage testing of coal seam gas wells in the Tara 'rural residential estates' vicinity [Queensland 2010]

26 *Fluid Migration Mechanisms Due To Faulty Well Design And/Or Construction* [Ingraffea 2013]

27 Conclusions, page 11, *Gas fracking: Can we safely squeeze the rocks?* [UNEP 2012]

to say that a particular well might leak at the point it is drilled, when we average across the hundreds of wells drilled for unconventional oil and gas fields it is possible to state that a certain proportion will fail. The failure of wells is a long-studied phenomena in the oil and gas industry, and, as outlined in studies in the industry's own journals, is understood[28] –

> *Despite these advances, many of today's wells are at risk. Failure to isolate sources of hydrocarbon either early in the well construction process or long after production begins has resulted in abnormally pressured casing strings and leaks of gas into zones that would otherwise not be gas-bearing. Abnormal pressure at the surface may often be easy to detect, although the source or root cause may be difficult to determine. Tubing and casing leaks, poor drilling and displacement practices, improper cement selection and design, and production cycling may all be factors in the development of gas leaks.*
>
> *Since the earliest gas wells, uncontrolled migration of hydrocarbons to the surface has challenged the oil and gas industry. Gas migration, also called annular flow, can lead to sustained casing pressure (SCP), sometimes called sustained annular pressure (SAP). Sustained casing pressure can be characterized as the development of annular pressure at the surface that can be bled to zero, but then builds again. The presence of SCP indicates that there is communication to the annulus from a sustainable pressure source because of inadequate zonal isolation. Annular flow and SCP are significant problems affecting wells in many hydrocarbon-producing regions of the world.*

One of the most recent reviews of well failure[29], carried out as part of the Government-supported 'ReEFINE' (Researching Fracking In Europe) Project at the University of Durham[30], stated –

> *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. In the UK, 2152 hydrocarbon wells were drilled onshore between 1902 and 2013 mainly targeting conventional reservoirs. UK regulations, like those of other jurisdictions, include reclamation of the well site after well abandonment. As such, there is no visible evidence of 65.2% of these well sites on the land surface today and monitoring is not carried out. The ownership of up to 53% of wells in the UK is unclear; we estimate that between 50 and 100 are orphaned. Of 143 active UK wells that were producing at the end of 2000, one has evidence of a well integrity failure.*

Although the RS/RAE review maintains that “The UK’s unique well examination scheme was set up so that independent, specialist experts could review the design of every well”, the recent Davies study casts doubt upon this by highlighting the failure to manage our historic complement of on-shore wells; and that almost two-thirds of the wells drilled to date are not monitored, and at least one of those which is monitored has demonstrable well failures. Therefore the general assertion that regulation can manage the environmental implications of well drilling – including the likely long-term leakage of greenhouse gases following the abandonment of these wells (as outlined in a recent French study of

28 *From Mud to Cement – Building Gas Wells* [Brufatto 2003]

29 *Oil and gas wells and their integrity: Implications for shale and unconventional resource exploitation* [Davies 2014]

30 *Researching Fracking in Europe* – https://www.dur.ac.uk/refine/

well failures by Sy[31]) – cannot be demonstrated.

Other assumptions within the MacKay-Stone report, following on from the RS/RAE review, can be invalidated by analysing the Governments current development proposals, and highlighting where these proposals would violate the conditions of the various reports. For example, the MacKay-Stone report, quoting that RS/RAE report, states[32] –

> *The risk of fractures propagating to reach overlying aquifers is very low provided that shale gas extraction takes place at depths of many hundreds of metres or several kilometres.*

If we look at the areas offered under DECC's *14th On-shore Oil and Gas Licensing Round*[33], it is arguable that some of the zones identified do not meet these criteria – and at least one is much shallower than the depth stated above. As outlined in my previous report[34] an area offered under the 14th Licensing Round, on the border of North Oxfordshire and Buckinghamshire, has an identified deposit of gas slightly less than 200 metres below the ground surface (as reproduced in Appendix 8A of this report). Therefore, if the MacKay-Stone report is intended to apply to all areas currently under review for licensing, certain areas do not meet the standards of safety recommended in their report. Therefore the Government is in error when it quotes the report as part of its “case for the safe and responsible exploration of shale gas in the UK”[35], because there are exceptions to its policy.

When carrying on any activity which results in a higher risk to society, the primary justification must be that it creates a positive benefit of a scale which outweighs those risks. Arguably one of the root assumptions of the MacKay-Stone report, and in fact of the Government's general policy objective, is stated near the beginning of the report[36] –

> *Shale gas development has been of increasing importance in the USA for some years*

That assertion is, currently, an issue of much debate in the USA – and this debate must be considered given that the Government wishes to replicate those same activities here.

Some have argued that the underlying drive behind the expansion of shale gas in the USA was purely financial – it was a questionable 'investment vehicle' driven by the finance and industrial lobby[37]. In turn, as with the credit bubble which led to the 2007/8 economic crash, that has led to large losses by investors – argued by some to be as high as $35 billion across the USA[38] – as the true performance of these processes has been revealed by experience.

There have also been a number of questions raised about the viability of the technology outside the artificially engineered conditions of the US energy market[39], its arguably higher health impacts[40], and

31 *Evaluation of the CO2 Leakage Risk Along the Abandoned Wells in the French Context* [Sy 2012]

32 paragraph 7, point 'b', page 10, *Potential Greenhouse Gas Emissions Associated with Shale Gas...* [MacKay 2013]

33 *Strategic Environmental Assessment for Further Onshore Oil and Gas Licensing: Environmental Report* [DECC 2013a]

34 page 38 and Appendix C, *A critical review of Public Health England's report...* [Mobbs 2014]

35 *Edward Davey today made the case for the safe and responsible exploration of shale gas in the UK, in line with UK’s climate change targets* [DECC 2013b]

36 paragraph 2, page 9, *Potential Greenhouse Gas Emissions Associated with Shale Gas...* [MacKay 2013]

37 *Shale And Wall Street: Was The Decline In Natural Gas Prices Orchestrated?* [Rogers 2013]

38 *US shale gas and tight oil industry performance: challenges and opportunities* [OIES 2014]

39 *Drill Baby Drill : Can Unconventional Fuels Usher in a New Era of Energy Abundance* [Hughes 2013a]

40 *Potential Public Health Hazards, Exposures and Health Effects from Unconventional Natural Gas* [Adgate 2014]

its uncertain climate impacts[41]. The lower financial and energy return in comparison to traditional "conventional" fossil fuels sources, and the short-term life-cycle of their operation, also raise questions as to their value in delivering either cheaper fuel[42], or avoiding geopolitical bottlenecks in the future supply of energy[43].

For example, as outlined in a February 2013 article in *Nature*[44] –

> *A pattern of events has emerged. When a play is discovered, a leasing frenzy ensues. This is followed by a drilling boom because the lease assignments, often 3–5 years long, can be terminated if the site is not producing gas. Sweet spots – small areas with high productivity – are identified and drilled off first, with marginal areas targeted next. Average well quality (as determined by initial productivity) rises at first and then declines.*
>
> *In four of the top five shale-gas plays, average well productivity has been falling since 2010. In the Haynesville play, an average well delivered almost one-third less gas in 2012 than in 2010. The exception is the Marcellus: supply is rising in this young, large play as sweet spots are still being found and exploited.*
>
> *Wells decline rapidly within a few years. Those in the top five US plays typically produced 80–95% less gas after three years. In my view, the industry practice of fitting hyperbolic curves to data on declining productivity, and inferring lifetimes of 40 years or more, is too optimistic...*
>
> *Governments and industry must recognize that shale gas and oil are not cheap or inexhaustible: 70% of US shale gas comes from fields that are either flat or in decline. And the sustainability of tight-oil production over the longer term is questionable.*
>
> *High-productivity shale plays are not ubiquitous, as some would have us believe. Six out of 30 plays account for 88% of shale-gas production, and two out of 21 plays account for 81% of tight-oil production. Much of the oil and gas produced comes from relatively small sweet spots within the fields. Overall well quality will decline as sweet spots become saturated with wells, requiring an ever-increasing number of wells to sustain production. Production will ultimately be limited by available drilling locations, and when they run out, production will fall at rates of 30–50% per year. This is projected to occur within 5 years for the Bakken and Eagle Ford tight-oil plays.*

If the nature of unconventional/extreme fossil fuel sources are that they are a short-term, but potentially highly damaging source of energy, then we must question the balance of risks and benefits used to justify their exploitation. That, clearly, has not happened within the MacKay-Stone report – nor the RS/RAE review which it builds upon. Consequently, without a clear exposition of the potential risks and likely benefits, it cannot be demonstrated that the development of these energy sources can, on the balance of probabilities, be justified (this will be examined in subsection C below).

Finally, another aspect of the environmental impacts outlined in the MacKay-Stone review relates to the regulation of the wastewater produced by the process, and how this might be managed[45] –

> *In the UK the wastewater would have to be responsibly managed and would require treatment before being discharged. Depending on the level of treatment the discharge could ultimately be to*

41 *Air sampling reveals high emissions from gas field* [Tollefson 2012]

42 *Unconventional wisdom: An economic analysis of US shale gas and implications for the EU* [IDDRI 2014]

43 *Economic vulnerability to Peak Oil* [Kerschner 2013]

44 *A reality check on the shale revolution* [Hughes 2013b]

45 paragraph 54, page 22, *Potential Greenhouse Gas Emissions Associated with Shale Gas...* [MacKay 2013]

a local water course (under permit from the Environment Agency) or to a suitably sized sewage treatment works with a trade effluent agreement from the associated water company.

The issue of regulatory functions is revisited later in the report[46] –

The Environment Agency's latest approach to permitting of shale gas exploration sites will consider releases to air within environmental impact assessments (EIAs)... The Agency will review the EIAs for individual sites in order to determine if there is a need to quantify their releases, and if so it may require that monitoring or other methods are used for that purpose. The Environment Agency's latest approach is to harmonise its regulation of all onshore sites for exploration and production of oil or gas, so that the regimes for "conventional" and "unconventional" sites are similar. The Environment Agency is reviewing the considerations to be addressed when quantifying fugitive methane releases to air from shale gas exploration sites.

Quite apart from the evidence that the wastewater from shale gas extraction cannot be adequately managed via conventional wastewater treatment plants[47], from a purely procedural point of view we have to question the over-reliance on regulation as a means to ensure safety. For example, environmental impact assessments (EIAs) for oil and gas extraction sites are not mandatory (under Schedule 1 of the EIA regulations); and are not required (under Schedule 2) for sites when the development area is less than half of a hectare[48]. In early 2014, the UK Government helped to block European proposals to require mandatory EIAs of all unconventional fossil fuel developments[49].

We also have to question whether, even if an EIA is produced for a development, it will be assessed to the necessary degree in order to tests its assumptions. In July 2013 the Treasury issued a new framework for the permitting of shale gas developments[50]. This set a target for the Environment Agency to introduce new procedures, by February 2014, to process permit applications for shale gas within 2 weeks. In August 2013, as required by the Treasury statement, the Environment Agency issued a new draft technical guidance for consultation on the new permitting process[51].

However, at no point is it outlined exactly how the Environment Agency will be able to carry out all the assessment procedures required to review the detail of EIAs and issue the necessary environmental permits within two weeks – especially as there may be multiple applications lodged with the Agency on a weekly basis once the industry starts its drive for production. As stated in the recent report from the House of Lords Economic Affairs Committee[52] –

Some witnesses questioned whether the individual regulators had sufficient resources to manage when activity increases. Mr Parr said his question was "whether they have the capacity to manage the sort of expansion that is being proposed and to develop whole new areas of

46 paragraph 100, page 36, *Potential Greenhouse Gas Emissions Associated with Shale Gas...* [MacKay 2013]

47 For example see:
Assessment of Effluent Contaminants from Three Facilities Discharging Marcellus Shale Wastewater... [Ferrar 2013]
Impact of Shale Gas Development on Regional Water Quality [Vidic 2013]
Impacts of Shale Gas Wastewater Disposal on Water Quality in Western Pennsylvania [Warner 2013]

48 Table section 2(e), paragraph 2, Schedule 2, *The Town and Country Planning (Environmental Impact Assessment) Regulations 2011* – http://www.legislation.gov.uk/uksi/2011/1824/schedule/2/made

49 *UK defeats European bid for fracking regulations* [Guardian 2014a]

50 paragraph 4.34, *Investing in Britain's future* [HM Treasury 2013a]

51 *Onshore oil and gas exploratory operations: technical guidance – Consultation Draft* [EA 2013a]

52 paragraph 225, *The Economic Impact on UK Energy Policy of Shale Gas and Oil* [EAC 2014]

understanding and expertise". The Environment Agency was of particular concern. Mr Bennett told us that "there are already very significant concerns about a lack of capacity within regulators like the Environment Agency to even deliver on their current expectations". Professor Smythe wrote that "the weakest point of the regulatory process concerns the Environment Agency" and said they appear to have "insufficient in-house expertise". It was reported earlier this year that the total number of staff at the Environment Agency was to be reduced from 11,250 to around 9,700 by October 2014.

It is not unreasonable to expect that regulation might solve the problematic aspects of unconventional gas developments – such as emissions to air, groundwater pollution, or the generation of waste. The difficulty is that when the Government is pursuing a deliberately deregulatory approach, and cutting the funding for regulatory agencies, while at the same time the development of this industry will add substantial regulatory burdens – it is arguably unrealistic to assume, without any caution, that those regulatory systems will be able to eliminate risk in the manner outlined in the MacKay-Stone report.

Building upon the Royal Society/Royal Academy of Engineering review, the MacKay-Stone report makes various assertions about environmental risk, the regulation of environmental pollution, and the safety of the shale gas process. If we look at the evidence available at that time, and in particular at more wide-ranging studies of the environmental risks of oil and gas development, this faith in the low risk of operation, and the way in which regulation can guarantee this, cannot be substantiated. More recent studies have identified significant environmental hazards from these operations. At the same time studies of the financial or energy effects of these processes do not show them to be as positive as anticipated. Therefore, these reports do not demonstrate that the risks of operation are quantifiable, nor that they are controllable, nor that they are justified by the benefits created.

B. Shale gas and climate change

The assumption within the Government's energy policy – which on the basis of a cursory examination may appear to be correct – is that natural gas is a cleaner fuel than coal or oil. That, as I will outline below, may be a highly questionable assumption. When burnt, it produces the least carbon dioxide of the fossil fuels. However, during 2011/2012 that view was challenged with the publication of various studies which questioned the life-cycle impacts of unconventional fossil fuels; and those same studies even cast doubt upon the previously assumed low impacts of conventional natural gas. That in turn raises a question concerning the efficacy of natural gas as a "bridge fuel" to a low carbon economy.

The production of the MacKay-Stone report is, arguably, the Government's attempt to counter these studies, and to bolster the reputation of natural gas. A large section of that report – paragraphs 37 to 89 – is devoted to a review of the studies which challenge or support the "low carbon" thesis for natural gas. In this subsection I will review these various papers, before moving on to look at the mechanics of why these different studies disagree over the level of impacts in the following subsections.

Various papers have outlined the importance of limiting the rate of anthropogenic carbon emissions in order to avoid a dangerous level of heating (generally described as 2ºC above the long-term average). The MacKay-Stone report references two *Nature* papers in support of this[53], as well as documentation – now superseded by the *Fifth Assessment Report*[54] (AR5) – from the Intergovernmental Panel on Climate Change (IPCC). The latest IPCC report on the mitigation of climate change considered unconventional fossil fuels, and states[55] (my emphasis in bold) –

> *A key development since AR4 is the rapid deployment of hydraulic-fracturing and horizontal-drilling technologies... the increasing utilization of gas has raised the issue of fugitive emissions of methane from both conventional and shale gas production... 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.***

Natural gas is mainly methane – which as a greenhouse gas has an impact much higher than carbon dioxide. Even a small amount of leakage can significantly diminish the assumed benefits of natural gas compared to other fossil fuels. The IPCC's AR5 mitigation report reviewed the available evidence, and, as outlined above, determined that there are great uncertainties – in contrast to the more certain view of the MacKay-Stone report, that emissions in the UK would be "relatively small"[56].

In order to make better sense of the evidence, I will take the information reviewed in the MacKay-Stone report and examine it chronologically – to show how the knowledge of impacts has evolved:

Chronologically, MacKay and Stone begin their review with Brown's study[57] of the policy implications of developing shale gas resources. This identified the potentially large resource of unconventional gas.

Brown did not consider environmental impacts, but if you dig through the literature you can find earlier studies which examine the apparently high rates of fugitive emissions which are common with unconventional fossil fuels. For example, in 2009, the Environmental Defense Fund (now involved with the University of Texas/Allen study into fugitive emissions from unconventional fossil fuels) commissioned work from the Southern Methodist University on fugitive emissions in the Barnett Shale[58]. Although this study, like others produced around this time[59], was primarily looking at the source of environmental toxins, it also identified the scope for large releases of methane.

In January 2011, the Tyndall Centre Manchester published its first review of the potential climate impacts of shale gas[60]. This concentrated on the whole range of impacts, and identified the largely unquantified nature of the fugitive gaseous emissions from the process[61]. In terms of climate change

53 *Warming caused by cumulative carbon emissions towards the trillionth tonne* [Allen 2009]
Greenhouse-gas emission targets for limiting global warming to 2ºC [Meinshausen 2009]

54 *Fifth Assessment Report* (AR5), Intergovernmental Panel on Climate Change, 2014 – http://www.ipcc.ch/report/ar5/

55 pages 18/19, chapter 7, *Climate Change 2014: Mitigation of Climate Change*, IPCC WGIII AR5 [IPCC 2014]

56 paragraph 106, page 37, *Potential Greenhouse Gas Emissions Associated with Shale Gas...* [MacKay 2013]

57 *Abundant Shale Gas Resources: Some Implications for Energy Policy* [Brown 2010]

58 *Emissions from Natural Gas Production in the Barnett Shale Area* [Armendariz 2009]

59 *Potential Exposure-Related Human Health Effects of Oil and Gas Development: A White Paper* [Witter 2008]

60 *Shale gas: A provisional assessment of climate change and environmental impacts* [Tyndall 2011a]

61 See Tables 3.2/3.3, pages 43/44, ibid.

impacts, this review concluded that[62] –

> *All four scenarios see the majority of shale gas being exploited before 2050 and the cumulative emissions associated with the use of this shale gas ranged from 284-609 $MTCO_2$. To give this some context this amounts to between 2.0 to 4.3% of the total emissions for the UK under the intended budget proposed by the UK Committee on Climate Change. Assuming that the carbon budget is adhered to then this should not result in additional emissions in the UK.*

The Tyndall Centre Manchester review utilised some industry sources, and the *Draft Supplemental Generic Environmental Impact Statement*[63] which had been produced by New York State's Department of Environmental Conservation in September 2009. However, the New York DEC review, citing American Petroleum Institute data from 2003, considered that the fugitive greenhouse gas (GHG) emissions from the process were *"insignificant"*. That illustrates the low priority given to considering the climate impacts of oil and gas production at that time.

In June 2011 that position changed. Howarth et. al. published their assessment of the *methane and the greenhouse gas footprint of natural gas from shale formations*[64] – the first peer-reviewed *life-cycle assessment* of the climate impacts of shale gas. In parallel, members of that group published a more extensive report on the *indirect emissions from Marcellus shale gas development*[65] (which included additional factors, such as land disturbance). This noted the previously low climate impacts attributed to fugitive emissions, and then sought to provide a more robust estimate using more recent data from the Marcellus shale region and elsewhere.

The significance of the Howarth study is that it is a life-cycle analysis, assessing emissions from the initial drilling of the well, through gas processing and transmission, and on through distribution to the point of gas consumption. Integrating the high levels of network loss in the USA[66], even conventional gas had a significantly higher effect upon warming potentials than previously considered. The highest estimates for conventional production produced an impact similar to coal on a *100-year global warming potential* (GWP), and were higher than coal on a *20 year GWP*. However, the fugitive emissions from unconventional fossil fuels were higher still. As a measure of emissions against the gas produced, this study estimates the range to be from 0.55-1.2gC/MJ.

The importance of the length of the global warming potential is highly significant. The impact on a 20-year baseline is 2½ times greater than the 100-year figure; and the 10-year figure is almost 3¼ times greater. Coal does not have this same level of impact in the short term because its emissions are dominated by carbon dioxide. In contrast natural gas, because of the significance of methane emissions, can have a higher short-term impact than coal burning. Obviously, if we're looking at the long-term impact of emissions, then the impact of coal over 100 years is of great concern. But, if we're trying to avoid triggering damaging climate feedback mechanisms – such as melting polar ice or Arctic tundra – then the short-term effects of gases like methane is also critically important. However, if we do not assess these impacts on a 10- or 20-year baseline, only a 100-year baseline, these short-term effects will be ignored.

62 section 5.2.2, page 73, ibid.

63 *Draft Supplemental Generic Environmental Impact Statement (SGEIS) on the Oil, Gas and Solution Mining Regulatory Program* [New York 2009]

64 *Methane and the greenhouse-gas footprint of natural gas from shale formations* [Howarth 2011]

65 *Indirect Emissions of Carbon Dioxide from Marcellus Shale Gas Development* [Santoro 2011]

66 *Methane Leaks from North American Natural Gas Systems* [Brandt 2014]

In August 2011, Jiang et. al. published their study of *life-cycle greenhouse gas emissions of Marcellus Shale gas*[67]. This study is interesting as it calculates the sensitivity of the method to different levels of gas recovery and well operating lifetimes – finding that shortening the operating life of the well, and/or reducing the volume of gas produced, worsened the climate impact of the well. The study concludes that the impact of Marcellus shale gas is 1.8gCO_2e/MJ (or 0.48gC/MJ) *using a 100-year GWP* – which is stated to be slightly higher than conventional gas, or equivalent to imported liquefied gas. According to Howarth's normalisation of various study results[68], this paper put the emissions at a half to a three-quarters less than the Howarth study – 0.3gC/MJ.

October 2011 saw a new life-cycle assessment by Hultman et al. which assessed *the greenhouse impact of unconventional gas for electricity generation*[69]. This concluded, *using a 100-year GWP*, that the greenhouse gas footprint of unconventional gas was around 11% higher than conventional gas and just over half that of coal. Howarth's normalisation of results put the total life-cycle emissions at 0.57gC/MJ – similar to the lower boundary of Howarth's results.

Hultman was primarily using the US Environmental Protection Agency's emissions data. However, they noted the uncertainties regarding this, and other data which various assessments were based upon at that time –

> *It is possible that the numbers are off by a factor of two, or even ten. Unfortunately, just as the data are uncertain, so too are the uncertainties. As such, we have decided not to make an estimate of how far off these numbers are.*

Also in October, Timothy Skone of the US Department of Energy gave a presentation (not peer-reviewed or published in a journal) which has been since quoted extensively[70]. This stated, *using a 100-year GWP*, that on-shore conventional gas production had a similar carbon footprint to unconventional gas, was twice that of off-shore conventional gas, and was lower than imported liquefied gas (note – *similar conclusions as the MacKay-Stone review*). On a *20-year GWP*, both conventional and unconventional gas had a higher footprint than liquefied gas, and around 2½ times that of off-shore conventional gas. Howarth's normalised life-cycle emission value from this study was 0.37gC/MJ.

In November, the Tyndall Centre Manchester updated their previous assessment of the climate impacts of shale gas[71]. Reading across the content of both reports, the general overview provided by the MacKay-Stone report notes that[72] –

> *Two papers from the Tyndall Centre discuss the climate change impact of shale gas and analyse the recent historical impact of US shale gas on emissions... In a world with no carbon constraint, they argue that shale gas exploitation is likely to lead to increased energy use and increased emissions.*

This, in my view, is a *wholly inaccurate reading* of the updated report – and misses the

67 *Life cycle greenhouse gas emissions of Marcellus shale gas* [Jiang 2011]
68 Table 1, *Venting and Leaking of Methane from Shale Gas Development: Response to Cathles et al.* [Howarth 2012a] *Venting and Leaking of Methane from Shale Gas Development: Response to Cathles et al. – Electronic Supplemental Materials* [Howarth 2012b]
69 *The greenhouse impact of unconventional gas for electricity generation* [Hultman 2011]
70 *Life Cycle Greenhouse Gas Inventory of natural Gas Extraction, Delivery and Electricity Production* [Skone 2011]
71 *Shale gas: An updated assessment of environmental and climate change impacts* [Tyndall 2011b]
72 paragraph 86, page 32, *Potential Greenhouse Gas Emissions Associated with Shale Gas...* [MacKay 2013]

precautionary underpinning of the way in which their analysis is framed.

If the Tyndall Centre felt that they had to conduct an update less than a year after their original paper, we should first question precisely what new evidence it was which warranted such a review. The updated report states[73] –

> *Since our earlier analysis, a range of reports and journal articles on shale gas have been published, giving the impression of a substantial increase in meaningful data alongside a more developed understanding of the issues. However, whilst the knowledge base has certainly improved, closer scrutiny of the 'new' information reveals that much of it builds on similar and very provisional data sources, and accordingly represents only a small improvement in the robustness of earlier analyses.*

In terms of the newly quantified impacts of shale gas in the UK, the report states[74] –

> *Assuming that 50% of this resource is exploited by 2050, these scenarios give additional cumulative emissions associated with the shale gas combustion of 95-286 $GtCO_2$, resulting in an additional atmospheric concentration of CO_2 of 5-16ppmv for the period 2010-2050. These emissions would occupy a substantial proportion, up to 29%, of an emissions budget associated with a better than 50:50 chance of avoiding 2°C warming.*

The report concludes[75] –

> *It is important to stress that one of the main findings of this work is that there is a paucity of information on which to base an analysis of how shale gas could impact GHG emissions and what environmental and health impacts its extraction may have. While every effort has been made to ensure the accuracy of the information in the report, it can only be as accurate as the information on which it draws. In itself, this lack of information can be seen as a finding, as along with the growing body of evidence for ground and surface water contamination from the US and the requirement for the application of the precautionary principle in the EU, shale gas extraction in the UK must surely be delayed until clear evidence of its safety can be presented.*

That is a very different point of view to the MacKay-Stone appraisal. It should also be noted that other papers published around this time – but not considered in the MacKay-Stone review – also challenged the assumption that shifting from coal to gas would reduce carbon emissions. For example, Wigley[76] examined the difference in outcomes in the transition from coal to gas when we look at the total impacts modelled across the climate system. The results were –

> *In summary, our results show that the substitution of gas for coal as an energy source results in increased rather than decreased global warming for many decades – out to the mid 22nd century for the 10% leakage case... Our results are critically sensitive to the assumed leakage rate. In our analysis, the warming results from two effects: the reduction in SO_2 emissions that occurs due to reduced coal combustion; and the potentially greater leakage of methane that accompanies new gas production relative to coal.*

73 Executive summary, page 3, ibid.

74 section 6.2.2, page 10, ibid.

75 section 6.5, page 18, ibid.

76 *Coal to gas: the influence of methane leakage* [Wigley 2011]

And concluded –

The most important result, however, in accord with the above authors, is that, unless leakage rates for new methane can be kept below 2%, substituting gas for coal is not an effective means for reducing the magnitude of future climate change. This is contrary to claims... with regard to the exploitation of shale gas, that it will "accelerate the decarbonisation of the world economy".

January 2012 saw the publication of the first direct rebuttal of Howarth by Cathales et al.[77] – which Cathales would expand in a second paper[78] later in June. What Cathales claimed was that the data used by Howarth was unrepresentative of the industry's own data; and that the rates of leakage, and the practical limitations on the management of gas, would not allow such high rates of emission to take place. Consequently parts of the case presented by Howard exaggerate the level of fugitive emissions by up to a factor of ten. In their assessment, *on a 100-year GWP*, they state that the footprint of natural gas is a half to a third that of coal for power generation.

However, within Cathales' response there is an untested assumption that gas is an inevitably less polluting fuel, and hence that shifting to gas must inevitably be beneficial. That assumption can be tested alongside the results of other studies which model whole climate impacts, such as those of Wigley or the Tyndall Centre Manchester. Also, Cathales makes no attempt to argue over the relative impacts of using different global warming potentials in the calculation of carbon footprints – and instead flatly criticises the use of the 20-year GWP on the basis that the higher generation efficiency of gas plants makes its use unwarranted – a point which fails to take account of the fact that in many developed nations the majority of natural gas is used for space heating, not for power generation.

Note that Howarth's normalised emissions footprint for Cathales assumptions produced a value of 0.14-0.36gC/MJ – the lowest figure of any of the studies they assessed.

Returning to the points regarding the reliability of data, it should be noted that the information used by Howarth is not "their" data. It was purchased from one of the US energy industry's service companies who maintain proprietary databases of information on the industry (in that case, IHS Consulting in Houston, Texas). The difficulty is that, in using this data, proprietary rights prevent its general dissemination and review – which makes the limitations or gaps in its collection opaque. And in criticising Howarth's use of this data, Cathales is also referencing similar sources of proprietary industry information, and so ultimately the specific values used cannot be objectively tested.

The difficulty is that while we rely on third-party data, collected to different standards and perhaps incompatible methods, we can't place any certainty on the conclusions drawn. What is required is direct, instrumental data demonstrating the scale of leakage, collected according to a clear method and to known test standards. That way we can attribute greater certainty to the results.

February 2012 saw the publication of the first direct measurements of the leakage from operational oil and gas fields. Pétron's study provided a *hydrocarbon emissions characterization in the Colorado Front Range*[79]. However, we have to be cautious on the use of these results because, as the first pilot study applying this method, on its own the results may not be representative.

The Pétron's study states –

77 *A commentary on "The greenhouse-gas footprint of natural gas in shale formations"* [Cathales 2012a]

78 *Assessing the greenhouse impact of natural gas* [Cathales 2012b]

79 *Hydrocarbon emissions characterization in the Colorado Front Range: A pilot study* [Petron 2012]

> *A mix of venting emissions (leaks) of raw natural gas and flashing emissions from condensate storage tanks can explain the alkane ratios we observe in air masses impacted by oil and gas operations in northeastern Colorado... We use the observed ambient molar ratios and flashing and venting emissions data to calculate top-down scenarios for the amount of natural gas leaked to the atmosphere and the associated methane and non-methane emissions. 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.*

What this means is that the industry's sampling of operational sites, which is then used to create emissions inventories for regulating the industry as a whole, does not correlate to the measurements taken in the air above these sites; and that in fact, the rates of emission are perhaps, on average, twice as high as those declared by the industry. That in turn would invalidate the case made by Cathales, which was based upon emission inventory data.

The significance of these findings were reported at the time in an article in *Nature*[80] –

> *Led by researchers at the National Oceanic and Atmospheric Administration (NOAA) and the University of Colorado, Boulder, the study estimates that natural-gas producers in an area known as the Denver-Julesburg Basin are losing about 4% of their gas to the atmosphere – not including additional losses in the pipeline and distribution system. This is more than double the official inventory, but roughly in line with estimates made in 2011 that have been challenged by industry. And because methane is some 25 times more efficient than carbon dioxide at trapping heat in the atmosphere, releases of that magnitude could effectively offset the environmental edge that natural gas is said to enjoy over other fossil fuels.*

The MacKay-Stone report considered the study by Pétron, but dismisses it by stating[81] –

> *A study by Petron et al. was the first study to report atmospheric methane measurements for estimating oil and gas methane emissions. The measurements suggest that emissions are at least two times higher than estimated through the inventory process, whilst the authors acknowledge the difficulties of attributing the results to an exact source. New regulations have been put in place since the time of measurement.*

February also saw the publication of a study by Myhrvold and Caldeira[82] – omitted from the MacKay-Stone review – examining the greenhouse gas implications of a transition to a low carbon electricity system. This study, like Wigley, also found very little difference in impact between natural gas and coal in terms of their effect on atmospheric emissions –

> *Technologies that offer only modest reductions in emissions, such as natural gas and carbon capture storage, cannot yield substantial temperature reductions this century. Achieving substantial reductions in temperatures relative to the coal-based system will take the better part of a century, and will depend on rapid and massive deployment of some mix of conservation, wind, solar, and nuclear, and possibly carbon capture and storage.*

80 *Air sampling reveals high emissions from gas field* [Tollefson 2012]

81 paragraph 46, page 19, *Potential Greenhouse Gas Emissions Associated with Shale Gas...* [MacKay 2013]

82 *Greenhouse gases, climate change and the transition from coal to low-carbon electricity* [Myhrvold 2012]

In April 2012, Weber and Clavin published their probabilistic life-cycle analysis[83] of emissions from fossil fuels. Combining data from a number of different studies, Weber and Clavin demonstrated that the variance of the life-cycle data for conventional gas, shale gas, and shale gas using "green completion", all overlapped – although on a mean value green completions were lower than either conventional gas or unabated shale gas. This highlights the uncertainties in the data available on impacts. Echoing Howarth, Hultman and the Tyndall Centre Manchester in their concern for the accuracy of the data on which almost all these analyses are based, they stated –

> *Despite the large recent interest in the issue, data are extremely scarce for several sources of greenhouse gas emissions associated with shale gas production. Nearly all of the studies examined here used two sources for at least some of the emissions data, and the uncertainty in these underlying API and EPA data is unknown. Further, the carbon footprint of shale gas is dependent on not only the amount of one-time emissions but also the ultimate production of each type of well, which varies considerably between individual wells and basins.*

In June 2012, the RS/RAE report, which the MacKay-Stone review relies upon to substantiate its support for regulation, was published. This has very little to say about fugitive emissions, or the climate impacts of natural gas relative to other fossil fuels. As with the general evidential basis of Government policy, the RS/RAE report makes an a priori assumption that natural gas is cleaner than other types of fossil fuel, but never seeks to test that assumption by reference to actual data on emissions.

The RS/RAE report does note the Howarth study, stating[84] –

> *There are few reliable estimates of the carbon footprint of shale gas extraction and use in the peer reviewed literature. One US study from Cornell University concluded that the carbon footprint of shale gas extraction is significantly larger than conventional gas extraction owing to potential leakages of methane. The same study recognised the large uncertainty in quantifying these methane leakages, highlighting that further research is needed.*

Therefore the RS/RAE review – on which the Government policy agenda relies heavily for its justification, and which MacKay-Stone cite in support of their case on the effectiveness of regulation – not only ignored the developing critique of the "low carbon" nature of natural gas, it also failed to consider the effect of new instrument-based studies upon this debate and the efficacy of the data collected as part of emissions inventories.

In July 2012 Howarth et al. published their response to Cathales[85], outlining both the flaws in the commentary, and how more recent research published, by the US Environmental Protection Agency[86] and others, backed-up their case for higher emissions from the oil and gas industry. It also examined more recent studies of oil and gas sites in Pennsylvania, and the regulatory system which applied to them – showing that not only were large emissions of un-flared gas permitted by the state authorities, but those releases had been instrumentally demonstrated using FLIR (forward looking infra-red) cameras. They also addressed the debate over the use of 20- or 100-year global warming potentials

83 *Life Cycle Carbon Footprint of Shale Gas: Review of Evidence and Implications* [Weber 2012]

84 section 8.2.2, page 58, *Shale gas extraction in the UK: A review of hydraulic fracturing* [RoyalSoc 2012]

85 *Venting and Leaking of Methane from Shale Gas Development: Response to Cathles et al.* [Howarth 2012]

86 *Inventory Of U.S. Greenhouse Gas Emissions And Sinks: 1990-2009* [USEPA 2011]

(GWPs), stating that –

Our methane emission estimates compare well with EPA, although our high-end estimates for emissions from downstream sources (storage, transmission, distribution) are higher. Our estimates also agree well with earlier papers for conventional gas, including downstream emissions. Several other analyses published since April of 2011 have presented significantly lower emissions than EPA estimates for shale gas... We believe these other estimates are too low, in part due to over-estimation of the lifetime production of shale-gas wells.

We stress the importance of methane emissions on decadal time scales, and not focusing exclusively on the century scale. The need for controlling methane is simply too urgent, if society is to avoid tipping points in the planetary climate system. Our analysis shows shale gas to have a much larger GHG footprint than conventional natural gas, oil, or coal when used to generate heat and viewed over the time scale of 20 years. This is true even using our low-end methane emission estimates.

They conclude –

We reiterate that all methane emission estimates, including ours, are highly uncertain. As we concluded in Howarth et al. (2011), "the uncertainty in the magnitude of fugitive emissions is large. Given the importance of methane in global warming, these emissions deserve far greater study than has occurred in the past. We urge both more direct measurements and refined accounting to better quantify lost and unaccounted for gas."

Arguably the MacKay-Stone report fails, in a balanced way, to reflect these criticisms of Cathales. More importantly, they have criticised Howarth's data while excluding any discussion about how this evidence challenges the methodology for the assessment of impacts which the MacKay-Stone report supports – and how studies such as Pétron's confirm these criticisms by highlighting disparities between instrumental- and inventory-based data. This is particularly true of Appendix A of their report, which is clearly critical of Howarth without addressing the criticisms of Cathales' case; and which therefore fails to communicate the relevance of these criticisms to the debate over emissions from the oil and gas sector generally.

In November 2012, O'Sullivan and Paltsev published their *study of potential versus actual greenhouse gas emissions from shale gas*[87]. This was supplemented with an additional report providing more data and analysis[88]. It should be noted that, although the report talks of "actual" emissions, the information on which this study is based is, once again, the industry's own emission estimates (in this case, the data has been created using the "authors' calculations based on HPDI[89] 2012") – and thus suffers the same flaws inherent in all emission inventory assessments, as outlined by Howarth and Pétron.

The conclusion of O'Sullivan and Paltsev was that –

Taking actual field practice into account, we estimate that in 2010 the total fugitive GHG emissions from US shale gas-related hydraulic fracturing amounted to 216 Gg CH_4. This represents 3.6% of the estimated 6002 Gg CH_4 of fugitive emissions from all natural gas

87 *Shale gas production: potential versus actual greenhouse gas emissions* [O'Sullivan 2012a]

88 *Shale Gas Production: Potential versus Actual GHG Emissions* [O'Sullivan 2012b]

89 'HPDI' is a database of oil and gas operation maintained by the Drillinginfo consultancy.

production-related sources in that year... it is also clear is that the production of shale gas and specifically, the associated hydraulic fracturing operations have not materially altered the total GHG emissions from the natural gas sector.

The data in this study needs some unpacking – but I will leave that until the following subsection when I specifically examine the influence of methodology on results.

In December 2012 the Secretary of State for Energy commissioned MacKay and Stone to compile a report on shale gas and climate. It was good timing by the Government, as this was becoming a controversial area of research – as outlined by another article in *Nature* in January 2013[90] –

Scientists are once again reporting alarmingly high methane emissions from an oil and gas field, underscoring questions about the environmental benefits of the boom in natural-gas production that is transforming the US energy system.

That article reviewed early information from the study carried out in the wake of Pétron research, being conducted as part of a long-term project by the National Oceanic and Atmospheric Administration (NOAA), which involved extensive field sampling. The next study to be published from this research was produced by Peischl et al. in May. An aircraft was flown over Los Angeles and was able to identify significant leakage from both the oil and gas industry, and the gas distribution network – and then differentiate those emissions from landfills and agricultural sources. However, the study could not differentiate the level of contribution from the extraction of oil and gas and the leakages from natural gas supply systems –

We conclude the most probable source for the excess atmospheric CH_4 is likely due to a combination of primarily leaks, not accurately represented in the current CARB GHG inventory, from natural gas pipelines and urban distribution systems and/or from local geologic seeps, and secondarily leaks of unprocessed natural gas from local oil and gas production centered in the western L.A. basin. This finding is based on the characteristic enhancement ratios of CH_4 and the various C_2-C_5 alkanes consistently observed in the L.A. atmosphere...

Also in May 2013, Laurenzi and Jersey published their life-cycle analysis of Marcellus shale gas[91]. Although carried out by Exxon, one of the companies with shale gas interests, the paper outlines many of the sensitivities in relation to environmental/climate impacts and the selection of fugitive emissions and the estimated ultimate recovery (EUR) of the well. The paper observed –

Therefore, for all practical purposes, the life cycle GHG emissions from shale gas and conventional gas are statistically indistinguishable. That said, wells are defined as "conventional" if the permeability of the gas-yielding formation exceeds a certain number. This definition neglects geological and chemical properties of the reservoir that in turn may affect the EUR. Considering the strong effect of EUR upon life cycle emissions, we conclude that there may be differences between the life cycle GHG emissions of "conventional" gas and Marcellus shale gas if there are significant differences in the EURs of their wells.

The next study in the NOAA's project was published in August 2013, a month before the MacKay-

90 *Air sampling reveals high emissions from gas field* [Tollefson 2012]

91 *Life Cycle Greenhouse Gas Emissions and Freshwater Consumption of Marcellus Shale Gas* [Laurenzi 2013]

Stone report was published. That study[92], by Karion et al., was an airborne survey of a natural gas field. By refinements to the method of data collection, this study produced more accurate results than Pétron's pilot study. Despite its late publication, the MacKay-Stone report did comment upon it[93] –

> *A similar study by Karion et al. (2013) 30 sampling methane emissions over one day found that an oil and gas production field in Utah produced methane emission rates corresponding to 6-12% of the average production during one day of sampling.*

This is an inaccurate review of the research carried out. In fact, according to the paper –

> *Twelve flights averaging four hours each were made over the basin during the month-long campaign. On February 3, 2012, a well-defined boundary layer and steady winds led to ideal meteorological conditions for the mass balance calculation. On February 7, 2012, low and variable winds allowed for the confirmation of fluxes measured on February 3 but with much higher uncertainties.*

The most significant aspect of this study was the use of more accurate sampling techniques which were able to clearly identify the discrepancies between the industry's sampling, carried out as part of regulatory emissions inventories, and the actual emissions which were sampled in the field –

> *While the WRAP III-based analysis concluded that 5% of production was lost to venting and flaring in the Uintah Basin, operators in this basin reported annual production losses of only 0.24% to the US Department of Interior Oil and Gas Operations Report (OGOR). Our independent measurement-based estimate of 8.8±2.6% is nearly twice the WRAP and almost 38 times the OGOR reported volumes (possibly more, as those include both flaring and venting). This discrepancy highlights the value of our study, which provides the first atmospheric measurement-based estimate of CH_4 emissions from a producing gas and oil field to date that does not rely on atmospheric transport models or bottom-up inventory information. Such independent verification of inventory-based estimates is essential for evaluating inventory methodologies, quantifying the effectiveness of future regulatory efforts, and accurately determining the climate impact of natural gas over other fossil fuels.*

The fact that the Karion study highlighted discrepancies between the emission inventories compiled as part of the regulatory process was not discussed in the MacKay-Stone review. Nor the fact that this data correlates to previous studies which highlighted such discrepancies between inventories and the level of fugitive emissions, going right back to the Armendariz study in 2009[94].

At the beginning of September 2013, the MacKay-Stone report was published. In the weeks following a number of studies would be published which raised more doubts over the position taken in the MacKay-Stone report on the scale of fugitive emissions; and more importantly, how the underlying method by which emissions are calculated make the results very sensitive to the assumptions about the differences between conventional and shale gas sources.

Of particular significance was the publication of studies which highlighted the importance of leakage across the natural gas system, and which questioned the general assumption that natural gas is a "low carbon" source of energy compared to other fossil fuels. Burnham's study, for the US Argonne

92 *Methane emissions estimate from airborne measurements over a western United States natural gas field* [Karion 2013]

93 paragraph 46, page 19, *Potential Greenhouse Gas Emissions Associated with Shale Gas...* [MacKay 2013]

94 *Emissions from Natural Gas Production in the Barnett Shale Area* [Armendariz 2009]

National Laboratory[95], led to revisions to certain emissions factors used in the calculation of climate impacts, for both conventional and unconventional sources of gas. But that in turn was thrown into doubt by Miller's study of the *anthropogenic emissions of methane in the United States*, which highlighted the role of conventional natural gas production and supply on greenhouse gas emissions, again questioning the reliability of emissions inventories –

> *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%.*

The results of this study, and the other studies based upon sampling in the field, demonstrate that the actual emissions of greenhouse gases from the oil and gas industry – irrespective of whether that is conventional or unconventional – are likely to be much higher than the levels indicated by emission inventories. For unconventional oil and gas operations, it also suggests that the emissions can be higher still because of their higher fugitive emissions.

In just four years, the assumption that natural gas is a "low carbon" source of energy, and that the methane emissions from the gas industry were "insignificant", has been challenged by both modelled and instrumental research studies. That in turn has led to new research which is identifying significant discrepancies between the industry's inventory-based assessment of emissions, and the emissions which can be measured in the field. The effect of this is to push the impacts of the industry towards the type of profile identified by Howarth, Wigley and the Tyndall Centre Manchester – where the significance of methane emissions negates the benefits of natural gas over other fossil fuel energy sources. It also casts doubt on the studies by Cathales, O'Sullivan and Skone – given prominence in the MacKay-Stone review – which are based upon demonstrably uncertain emissions inventory estimates.

That brings us once again to the latest verdict from the IPCC in their AR5 mitigation review – that, *"recent empirical research has not yet resolved these uncertainties."*

The purpose of using a chronological review of the evidence on unconventional gas and climate change is that it illustrates the lack of hard information underpinning our current knowledge about the emissions from oil and gas production – and therefore the lack of certainty regarding their impacts upon the climate. As noted above, before Howarth's June 2011 paper, the climate impacts of natural gas due to fugitive emissions were considered "insignificant". *In the space of just four years*, a whole new field of scientific exploration has developed around the issue of climate and fugitive emissions – and reading across the evidence, we find that there is no certainty about climate impacts, but there is much concern about the potential damage which might be caused by the exploitation of unconventional gas. The fact that this was not discussed or explained within the MacKay-Stone report must be considered a serious flaw in that review.

95 *Updated Fugitive Greenhouse Gas Emissions for Natural Gas Pathways in the GREET Model* [Burnham 2013]

C. The influence of methodology on calculated emission rates

The MacKay-Stone report presents the disagreement between different studies in terms of poor data – criticising those results (primarily Howarth's 2011 paper) which they consider to be "unrealistic"[96].

In my view this contention over 'end results' masks the fundamental – and quite obvious – differences in methodology and assumptions which exist in these studies. And within these different viewpoints on methodology, we can also see how those writing in support of unconventional gas are using the uncertainties in data in a manner which suits their particular case.

In this process it is not the partisan argument over method which is problematic. That's the inherent nature of such technical debates on complex and contentious issues of public policy. It's that the reasons for the conflicts within methodology, and how this influences outcomes, is not being effectively communicated to the public and decision-makers – to allow them to make their own judgements over which method they consider to be the most appropriate.

In the MacKay-Stone report, figure 3 compares results from a number of studies in order to provide a comparison of the emissions from well flowback – to visually demonstrate that the result from Howarth's study for the Haynesville shale is far higher than results from other studies. ***This graph is misleading***. For example, if two wells produce the same level of gaseous venting, but one of the wells produces twice the amount of gas over its operating life, it will have a much lower impact overall. Consequently if we graph the emissions "per well" without scaling that figure by the production from that well over its life – taking into account other life-cycle emissions such as leakages from the supply network – the relationship implied in the graph will misrepresent the true relationship to global climate impacts.

The method by which individual well leakage rates translate into a global value for the impact upon climate is far more complex than the relationship in this graph implies. Furthermore, MacKay-Stone's own method hides an arguably deliberate understatement of climate impacts. There are certain assumptions within the calculation of climate impacts which, if manipulated, can skew the headline results of the study towards certain ends.

This tendency within the method, and how it is used by certain studies, was not explained in the MacKay-Stone report – although it has been explained in other papers, such as Howarth's response to Cathales[97].

The MacKay-Stone report relies heavily on the O'Sullivan and Paltsev paper[98] in its criticisms of Howarth. The difficulty with the O'Sullivan and Paltsev paper is that its assumptions skew the results, giving low figures for level of emissions from shale gas. That in turn, given that the MacKay-Stone fails to discuss these problems within method, could be argued to unduly sway their conclusions – and thus the decisions of the Government ministers commissioning their review.

For example, O'Sullivan and Paltsev's paper uses a well lifetime of either 30 or 15 years, and the supplementary data for their paper[99] gives a production figure for Marcellus shale wells of $104.7{\times}10^6$

96 paragraph 50, page 22, *Potential Greenhouse Gas Emissions Associated with Shale Gas...* [MacKay 2013]

97 *Venting and Leaking of Methane from Shale Gas Development: Response to Cathles et al.* [Howarth 2012]

98 *Shale gas production: potential versus actual greenhouse gas emissions* [O'Sullivan 2012a]

99 *Shale gas production – supplementary electronic data* [O'Sullivan 2012c]

m^3 to 76.4×10^6 m^3 (converted[100], that's 3.7bcf to 2.7bcf respectively) on a 30/15 year life. These assumptions about well life and production are questionable, since they relate to the production pattern of conventional gas wells rather than unconventional shale gas or coal-bed methane wells.

On the issue of the volume of gas produced, Burnham's study for the US Argonne National Laboratory states[101] –

> *After our analysis, several studies have estimated the EUR of shale plays such as Logan et al. analyzing the Barnett play and Laurenzi et al. analyzing the Marcellus play. The average estimates of those studies 1.4 Bcf for the Barnett and 1.8 Bcf for the Marcellus are more in line with INTEK results, 1.4 Bcf for both plays, as compared to the industry estimates, 3.0 Bcf and 5.2 Bcf respectively.*

Arguably then, industry figures are much higher, and that lowers the calculated impacts upon the climate in industry-backed studies (a good example of this tendency would be Cathales' papers[102]).

Another issue is that the performance of unconventional gas wells is highly variable. That, in part, is one of the reasons why the US shale gas industry has economic problems – because the view that gas production would be homogeneous across the field was not demonstrable in practice[103], and so those involved have had to write-down the value of their assets[104]. For example, a recent US Geological Survey report noted[105] –

> *This publication uses those 132 continuous oil and gas assessments to show the variability of well productivity within and among the 132 areas. The production from the most productive wells in an area commonly is more than 100 times larger than that from the poorest productive wells.*

As the MacKay-Stone report states, the significance of the variability of the *estimated ultimate recovery* (EUR) for each well is that it influences the carbon footprint of the gas produced[106] –

> *...the more productive a well is, the less pre-production and post-production emissions will influence the overall specific (per kWh) emissions. Halving the EUR would almost double the specific emissions.*

In which case the problem for the Government is that the MacKay-Stone review, as in the case of O'Sullivan and Paltsev, uses unrealistically high recovery rates compare to the shale gas EUR figures produced by Burnham. The MacKay-Stone figures were[107] –

> *Finally, to obtain emission intensities per kWh of gas shown in Figures 4 and 5, three well productivity scenarios were used (see paragraph 35).*
>
> - *“Low EUR” – 2 bcf (57 million m^3);*
> - *“Central EUR” – 3 bcf (85 million m^3); and*
> - *“High EUR” – 5 bcf (140 million m^3).*

100 To convert million cubic metres (Mm^3) to billion cubic feet (bcf), the Mm^3 figure is divided by 28.3.

101 section 2.8, page 7, *Updated Fugitive Greenhouse Gas Emissions for Natural Gas Pathways* [Burnham 2013]

102 *A commentary on “The greenhouse-gas footprint of natural gas in shale formations”* [Cathales 2012a]

103 *Drill Baby Drill : Can Unconventional Fuels Usher in a New Era of Energy Abundance* [Hughes 2013a]

104 *US shale gas and tight oil industry performance: challenges and opportunities* [OIES 2014]

105 *Variability of Distributions of Well-Scale Estimated Ultimate Recovery for Continuous (Unconventional) Oil and Gas Resources in the United States* [USGS 2012]

106 paragraph 73(b), page 27, *Potential Greenhouse Gas Emissions Associated with Shale Gas...* [MacKay 2013]

107 paragraph 68, page 25, ibid.

The central EUR figure is twice that of Burnham's statistics for the US Argonne National Laboratory study – therefore the figures for carbon footprints which MacKay and Stone present, by their own admission, would only be half of the figure it should be.

This understatement of impacts should also be considered in relation to the life-time of the well. O'Sullivan and Paltsev used 15 and 30 years as the lifetime of the well; Burnham's study used 30 years. In fact the life of the well is much shorter – arguably four or five years. This means, as seen in the USA, very high drilling and development rates must be maintained in order to maintain gas flows. This problem was outlined by Hughes in an article for *Nature*[108] –

> *When a play is discovered, a leasing frenzy ensues. This is followed by a drilling boom because the lease assignments, often 3–5 years long, can be terminated if the site is not producing gas. Sweet spots — small areas with high productivity — are identified and drilled off first, with marginal areas targeted next... In four of the top five shale-gas plays, average well productivity has been falling since 2010. In the Haynesville play, an average well delivered almost one-third less gas in 2012 than in 2010. The exception is the Marcellus: supply is rising in this young, large play as sweet spots are still being found and exploited.*

This means a large part of the resource is developed quickly, and as development progresses the falling rate of recovery raises the impacts upon the climate – further accentuating the short-term effect upon emissions, and its potential to accentuate damaging greenhouse gas concentrations.

The problem is that, given the assumptions used in studies which support the development of unconventional gas, this is not apparent because of: the use of the 100-year methane factor; the use of excessively long production lifetimes used for each well; and the use of high recovery rates per well – all of which combine to produce a lower calculated value for the impact upon the climate. Arguably then, the studies which favour the industry fail to reflect the short-term nature of this resource.

In terms of the carbon footprint, this highly intense, short-term profile of development has implications for the time-scale over which the impact is assessed in order to properly reflect the effects upon climate. In Britain, if we look at the Department for Energy and Climate Change's recent strategic environmental appraisal report[109], the resource may be developed over as little as 20 or 30 years. Therefore it is appropriate to use the short-term 20-year impact for methane, not the longer 100-year value, in order to fully consider this short-term nature of this “hump” in emissions – and how that might be instrumental in breaching critical climate tipping points.

As argued in a number of the papers listed in the previous subsection, due to the currently critical need to reduce carbon emissions[110], and the likelihood of breaching tipping points in the climate system over the next few decades[111], we should be assessing the carbon footprint over the 20-year period as well as the longer-term 100-year. But as stated in the MacKay-Stone report, in their assessment of the carbon footprint the assumption they use is[112] –

> *...the global warming potential for methane compared to carbon dioxide is 25, based on a 100*

108 *A reality check on the shale revolution* [Hughes 2013b]

109 *Strategic Environmental Assessment for Further Onshore Oil and Gas Licensing: Environmental Report* [DECC 2013a]

110 *Climate forcing growth rates: doubling down on our Faustian bargain* [Hansen 2013]

111 *Early warning of climate tipping points* [Lenton 2011]

112 paragraph 64, page 24, *Potential Greenhouse Gas Emissions Associated with Shale Gas...* [MacKay 2013]

year time horizon.

Therefore the carbon footprint of UK shale gas, assessed in terms of its most damaging short-term impacts, will be much higher than that stated in the conclusions to the MacKay-Stone report. However that fact is lost upon the public and decision-makers because the issue of differences in methodology is not clearly discussed in their report.

This is a general issue with such assessments at the moment. The proponents of shale gas are using very high rates of production (EUR) for each well – which might be correct for just a few wells *within* a field, but which are much higher than can be substantiated by the average value *across* the field. At the same time they use a 100-year climate impact assessment – which fails to reflect the essentially short-term nature of this resource. This situation was discussed by Hughes[113], using the Skone's presentation[114] as a specific example –

> *An analysis of fugitive methane emissions presented by Skone reveals that they are likely understated, as they are 31% lower than those reported by the EPA inventory of emissions from natural gas for 2009. A further analysis of the impact of the assumed EUR for the Barnett Shale used by Skone on the percentage of fugitive methane emissions over production lifetime reveals that it is likely overstated, at 3 bcf, compared to other recent analyses that suggest the EUR's are likely to be much lower. This further raises the percentage of fugitive emissions in the Skone presentation. It should be pointed out that it is still early in determining how the EUR's of many shale plays will turn out, but the Barnett Shale is the most mature play at this point.*
>
> *Correcting the emissions estimates of Skone to match the EPA Inventory data, and adjusting for the likely average EUR in the Barnett Shale, reveals that they are comparable to the Howarth et al. estimates. On an overall basis, recognizing that 70% of natural gas is currently used for non-electric applications, shale gas has higher emissions than coal on a 20-year basis and equal or lower emissions on a 100-year basis.*

If we examine the methodology behind various studies, we see a divergence depending on whether the case is being made in support of shale gas development or not. Those supporting shale gas use high well recovery rates, long well production lifetimes, and a 100-year baseline for assessing climate impacts. This arguably distorts the true environmental impacts due to the demonstrable fact that: average well production is much lower; well productive lifetimes are far shorter; and, when we consider the short-term nature of how this resource will be developed, the "hump" in emissions will have a clear short-term impact, just at the time we are trying to prevent a peak in emissions that will breach tipping points in the climate system. This divergence in method, and its implications for the results of these studies, has not been clearly explained to the public and decision-makers.

113 *Life Cycle Greenhouse Gas Emissions from Shale Gas Compared to Coal* [Hughes 2011]

114 *Life Cycle Greenhouse Gas Inventory of natural Gas Extraction, Delivery and Electricity Production* [Skone 2011]

D. Conclusions of the MacKay-Stone review

Before moving on to consider later information, comment must be made upon the conclusions to the MacKay-Stone review. This is contained in three paragraphs[115]. The first states –

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

The MacKay-Stone review presents calculations claiming to show that the emissions from shale gas development are likely to be low – in the region of those from existing conventional gas production. These data tables, part of a spreadsheet, are presented in the appendices of their report. The spreadsheet model presented in the MacKay-Stone report was not made available – nor were any worked examples provided. To evaluate the model fully I have replicated the spreadsheet from the description provided in the text of their report – as outlined in Appendix B of this report.

The essence of the MacKay-Stone model is the computation of fugitive emissions from well drilling. This figure for emissions is then divided by the quantity of gas produced in order to produce a figure for emissions per unit of energy (in kilowatt-hours) produced – to allow comparison with other energy sources. Using a LibreOffice spreadsheet, the results produced under the various scenarios presented in the MacKay-Stone report were replicated almost precisely (the small differences in the data are most likely due to rounding error from the figures presented in the MacKay-Stone results).

Once the spreadsheet model was validated against the results of the MacKay-Stone report, different values could be used to assess the sensitivity of the model to certain assumptions. In particular, the selection of the 'estimated ultimate recovery' (EUR) value was found to have a significant effect on the output from the model. For example, halving the EUR to a more reasonable 0.9 to 1.9bcf, nearer to values indicated by recent USGS research[116], increases the emissions per unit of gas by between 200% (the '90% captured/flared' scenario) and 350% (if 100% is vented).

What this suggests is that the assumptions in the model are sensitive to both to accurate information about the level of fugitive emissions (as discussed in subsection 2B earlier), and that the EUR value (discussed in previously in subsection 2C). Given that – especially in relation to our current knowledge of US operations – both of these factors are uncertain, this suggests that the confidence we can have in accurately modelling the impact of shale gas emissions is low.

Therefore the assertion of “relatively small” impacts from greenhouse gas emissions misleads both the public and decision-makers as to the true state of the knowledge about unconventional fossil fuels. There no clear evidence to validate the assumptions of the MacKay-Stone report; as stated in the IPCC mitigations study, which commented upon our confidence in the data used in these assessments[117] –

> *Recent empirical research has not yet resolved these uncertainties.*

Arguably the true impacts of unconventional gas in Britain are highly uncertain, and, given the report's expressed certainty of minimal effects, the conclusions drawn by the MacKay-Stone review appear over-confident.

115 pages 37/38, *Potential Greenhouse Gas Emissions Associated with Shale Gas...* [MacKay 2013]

116 *Variability of Distributions of Well-Scale Estimated Ultimate Recovery for Continuous (Unconventional) Oil and Gas Resources in the United States* [USGS 2012]

117 pages 18/19, chapter 7, *Climate Change 2014: Mitigation of Climate Change*, IPCC WGIII AR5 [IPCC 2014]

The second paragraph of the conclusion states –

The production of shale gas could increase global cumulative GHG emissions if the fossil fuels displaced by shale gas are used elsewhere. This potential issue is not specific to shale gas and would apply to the exploitation of any new fossil fuel reserve.

This is arguably incompatible with European law – as I will outlined in section 5B later.

At the launch of the MacKay-Stone report, energy and climate minister Ed Davey stated[118] –

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.

The final paragraph of the conclusions to MacKay-Stone report states –

The potential increase in cumulative emissions could be counteracted if equivalent and additional emissions-reduction measures are made somewhere in the world. Such measures are well established in the scientific and policy literature and include: carbon capture and storage; carbon offsetting through additional reforestation or negative emissions technologies that reduce CO_2 *concentrations; and other measures that would lead to fossil fuel reserves, that would have been developed under business-as-usual, remaining in the ground. The view of the authors is that without global climate policies (of the sort already advocated by the UK) new fossil fuel exploitation is likely to lead to an increase in cumulative carbon emissions and the risk of climate change. We would strongly encourage continued efforts from the UK and internationally to address this issue, proportionate to the emissions involved*

What this statement ignores is the growing body of evidence that natural gas is not only unsuitable as a “bridge fuel”[119] in the transition to low carbon economy[120]; it also fails to consider the evidence that other technological options will fail to reduce carbon emissions quickly enough in order to avoid problematic disruption to the climate[121]. It also presumes that a global agreement on climate will be both effective and timely – which cannot be relied upon if the recent actions of the UK government, increasing the support for fossil fuels development, were replicated by other states. For example, the recent House of Commons Energy and Climate Committee report on carbon capture and storage notes, in advocating strong support for CCS to provide a mechanism to allow the continued use of fossil fuels, that “the prospect of a global deal is highly uncertain”[122].

The boundaries of climate science are not precise; arguably, when we look of the possible outcomes of certain actions, the probabilities of potential impacts have imprecise “fat tails”[123] – which is the inevitable result of trying to manage the impacts of human activity upon a non-linear environmental system. That is why, whether there is a global climate agreement or not, a strongly precautionary approach to policy is so important. As outlined, for example, in the second paper from the Tyndall Centre Manchester[124].

118 *Edward Davey today made the case for the safe and responsible exploration of shale gas...* [DECC 2013b]

119 *A bridge to nowhere: methane emissions and the greenhouse gas footprint of natural gas* [Howarth 2014]

120 For example, *Coal to gas: the influence of methane leakage* [Wigley 2011]

121 For example, *Greenhouse gases, climate change and the transition from coal to low-carbon electricity* [Myhrvold 2012]

122 paragraph 28, *Carbon capture and storage* [ECC 2014]

123 *On Modelling and Interpreting the Economics of Catastrophic Climate Change* [Weitzman 2008]

124 *Shale gas: An updated assessment of environmental and climate change impacts* [Tyndall 2011b]

Thus the conclusions of the review could be construed as advocating a course of action which will lead to risks to the climate, and consequently human health, on the basis of processes and regulatory procedures which are highly uncertain. For example, the idea that the world's nations will be able to conclude a viable and effective treaty to manage carbon emissions. Consequently that lack of precaution, in the face of little evidence to the contrary, arguably fails the tests of European environmental law – as I will examine in section 5B.

Taken as read, we have to look upon the conclusions of the MacKay-Stone report as misleading because they fail to encapsulate both the high level of uncertainty about these impacts, and the problems which exist within the data upon which these assessments are made. Therefore, we cannot attach any validity to the outcomes of this report, or to the policy decisions which are based, unquestioningly, upon the results of this review.

E. The University of Texas/EDF study

Up until this point, I have tried to restrict my consideration of the evidence for the climate impacts of unconventional gas to those papers/reports which were produced before the results of the MacKay-Stone review were published. In commenting upon that report, it is only fair to frame the critique in terms of the evidence available at that time.

Given the lack of data to support the claims of "relatively small" impacts upon UK greenhouse gas emissions, their report made reference to an unpublished research paper[125] –

> *The University of Texas have undertaken a more detailed study on GHG emissions from the natural gas industry, which is scheduled for publication in 2013.*

This paper, by Allen et al., was published the week after the MacKay-Stone report – although the fact that they were aware of its contents before publication suggests some co-ordination within the pro-shale gas lobby. Subsequent Government/industry promotion of the MacKay-Stone report also championed this paper as a justification of MacKay and Stone's central claim of "relatively small" impacts. For example, the Government's response to the MacKay-Stone report states[126] –

> *The report is a significant step forward in establishing the range of emissions we might expect in the UK's regulatory context. Since the release of the MacKay-Stone report, the University of Texas at Austin produced a detailed study involving the monitoring methane emissions from various stages of shale production. It found that emissions from fracking are lower than previously thought.*

The Allen paper does not give up its details with a simple reading of the abstract, or of its conclusions. In order to understand the value of the paper it is necessary – as with the MacKay-Stone review – to probe the method and statistics of the research. In particular, as it is not a full life-cycle review, its conclusions are not directly comparable – and the statistics for climate impacts will appear to be much smaller – than the papers by Howarth and others.

The headline from this study is –

125 paragraph 46, page 19, *Potential Greenhouse Gas Emissions Associated with Shale Gas...* [MacKay 2013]

126 page 6, *The Government's response to the MacKay-Stone report: Potential greenhouse gas emissions associated with shale gas extraction and use* [DECC 2014]

This work reports direct measurements of methane emissions at 190 onshore natural gas sites in the United States. The measurements indicate that well completion emissions are lower than previously estimated; the data also show emissions from pneumatic controllers and equipment leaks are higher than Environmental Protection Agency (EPA) national emission projections. Estimates of total emissions are similar to the most recent EPA national inventory of methane emissions from natural gas production.

What we have to question is whether the nature of the data collected, and the way it is presented, necessarily support this statement.

The data collected for this study comprises –

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.

It is not stated whether these operations were carried out at shale gas, coalbed methane, tight gas or 'associated' oil and gas production sites – or a combination of all of these. Different types of source rock produce different rates of flowback, and without more detailed information on the precise source type and location it is not possible to integrate these results with other studies.

One of the difficulties of this study is that the sites do not represent a randomised sample. The sites were selected by their industry partners – *who are not identified in the study*. For example, the supplementary information appendix for the paper merely states[127] –

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.

What is more, the sites sampled represent only 0.1% of the on-shore conventional and unconventional wells in the USA. Therefore we must question whether such a small and non-randomised sample of the total population of on-shore wells can be considered as statistically significant – or whether these results are even applicable to the national US emissions profile, or that of other states such as the UK. As is stated in the paper[128] –

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.

This point is outlined further in the supporting information for this paper[129] –

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.

It is entirely possible that all the sites selected for this study by the industry represented those sites

127 page S-10, *Measurements of Methane Emissions... in the US: Supporting Information* [Allen 2013b]

128 page 5, *Measurements of Methane Emissions at Natural Gas Production Sites in the United States* [Allen 2013a]

129 page S-70, *Measurements of Methane Emissions... in the US: Supporting Information* [Allen 2013b]

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 these tests. For example, it is noted in the supporting information[130] that extra/non-standard construction methods were required on these sites to incorporate the flow monitoring equipment for emissions to be recorded. Therefore it is entirely possible that these non-standard construction methods, not typical of the measures ordinarily taken during site operations, may have resulted in lower emissions from the sites.

One general comment on the Allen paper itself. At no point does the paper tackle the disparity between the estimates of fugitive emissions based upon emissions inventories (such as in the Allen study), and those which utilise in-field air sampling from fixed sites or atmospheric sampling from aircraft – which have found an excess of atmospheric pollutants which indicate far higher emission rates. Without a plausible explanation for the discrepancies between accountancy-based inventory assessments, and those based on actual measurements of the environment, this paper does not address the current debate about fugitive emissions. Instead it seeks to reinforce the use of emissions inventory assessments – which tend to support lower fugitive emissions – without addressing the criticisms from instrumental studies of atmospheric emissions across oil and gas fields.

Finally, this paper represents a large collection of data, which needs careful processing. It is also important, for both public confidence and the value we might attribute to this study's findings, that there is full transparency in the data presented. The co-ordinators of this research programme, the Environmental Defense Fund, noted in their press release[131] at the launch of the paper that –

> *A key element of UT's study, and the other EDF-industry collaborative studies, is the focus on ensuring their scientific integrity.*

It is significant that a month after the paper's launch, PNAS issue a correction[132] –

> *The authors note that upon publication their conflict of interest statement was not complete. The updated disclosure statement is as follows, "Jennifer Miskimins holds a joint appointment with Barree & Associates and the Colorado School of Mines. She has also served as an advisor to Nexen in 2012. David T. Allen served as a consultant for the Eastern Research Group and ExxonMobil in 2012, and is the current chair of the Science Advisory Board for the EPA. John H. Seinfeld has served as a consultant for Shell in 2012. David T. Allen, Matthew Harrison, Charles E. Kolb, and Robert F. Sawyer variously serve as members of scientific advisory panels for projects supported by Environmental Defense Fund and companies involved in the natural gas supply chain. These projects are led at Colorado State University (on natural gas gathering and processing), Washington State University (on local distribution of natural gas), and the University of West Virginia (on CNG fueling and use in heavy duty vehicles)."*

On publication of the first version of the paper in September 2013, the 'conflict of interests' statement has read, "The authors declare no conflict of interest". If, on the date of publication, those involved in the production of the study could not get their affiliations correct, what guarantee is there that other elements of their analysis do not contain other such oversights? We must also consider that – given the significance that governments, lobbyists and the energy industry gave this paper on its

130 section S1, ibid.

131 *First academic study released in EDF's groundbreaking methane emissions series* [EDF 2013]

132 PNAS, vol.110 no.44 pp.18023, 29th October 2013 – the PNAS corrections page is appended to the PDF copy of the Allen paper maintained in the Free Range On-line Library [Allen 2013a]

launch – the failure to state their original affiliations might be interpreted as an attempt to manipulate the public's perceptions over the 'impartiality' of this paper.

On its own the Allen paper means very little. In order to understand it we have to look at it within the matrix of research studies and reports on the fugitive emissions from unconventional oil and gas production. The Allen paper itself cautions on the applicability of its “low emissions” finding –

> *Finally, an emissions intensity of 0.42% is reported in Table 2. The intensity expresses a methane emission per unit of gross gas production. This intensity should be interpreted with caution, because it includes only production operations and implicitly attributes all methane emissions from natural gas wells to natural gas production, although natural gas wells produce substantial amounts of natural gas liquids and oil.*

As noted above, the failure to specify the source type for the well sampled makes it difficulty to extend these results more generally across the gas industry. Therefore we have to consider the findings of this study in the context of other data which may confirm or confound its findings. For example, the problem of the innate variability of the fugitive emissions of different sources of unconventional fossil fuels, was considered recently as part of a study[133] on how IPCC methodologies should account for unconventional fossil fuels. This provides a more detailed review than the IPCC's recent *AR5* mitigation report[134], stating –

> *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.*

Therefore the findings of the Allen paper might appear spurious. That is especially true if we consider the range of studies which have emerged since the MacKay-Stone report, and the Allen paper, were published in September 2013.

The Allen report received extensive media coverage on its launch, and the MacKay-Stone report relied upon its findings in order to justify its own claims of the “relatively small” impacts of greenhouse gas emissions. However, when we look deeper into the method and statistical analysis used we find that no such claim can be objectively supported by the Allen paper. It is a small, non-randomised sample of sites selected by the industry. We must also be sceptical of its impartiality because, on publication, the authors failed to identify their links to the oil and gas industry. It is also wholly silent on the issue as to why large inconsistencies exist between instrumental records of fugitive emissions from such sites, and emissions inventory-based assessments – such as the Allen paper. Therefore we cannot give great weight to the evidence provided by the Allen paper, particularly when its method specifically fails to address the contrary findings in many other peer-reviewed studies.

133 *Quantifying Fugitive Emission Factors from UNG Production Using IPCC Methodologies* [Glancy 2013]

134 *Climate Change 2014: Mitigation of Climate Change* [IPCC 2014]

F. Recent studies of the climate impacts of extreme fossil fuels

Our understanding of the impacts of unconventional gas development did not stop with the publication of the MacKay-Stone report – although we might infer from the recent publication of the Government's response to their report that this might be the case (as outlined in the next section). Research continues to be published; and that evolving body of evidence casts doubt on the both the evidence cited by MacKay and Stone, and the nature of their conclusions.

This is not just an issue of climate change. The over-emphasis on carbon emissions as the single determinant of environmental sustainability not only detracts from a more balanced view of human ecological impacts, but also undervalues the toxic and air, water and waste discharges from unconventional fossil fuels as part of their overall environmental impact. For example, shortly before the MacKay-Stone and Allen papers, Vengosh et al. published a highly critical paper[135] on the impacts of wastewater disposal from the shale gas industry in Pennsylvania, highlighting the effect this was having on local and regional water quality. That was followed-up in March 2014 by an equally critical paper[136] which further developed the analysis of the waste management impacts of shale gas.

The general issue of the significance of methane to climate change was highlighted in a paper by Miller et al.[137] published shortly after the MacKay-Stone report. This paper looks at methane emissions from all human sources, and in particular notes the evolving nature of the debate on emissions from the oil and gas sector, and the uncertainty regarding the scale of these emissions –

> *Bottom-up inventories from US EPA and the Emissions Database for Global Atmospheric Research (EDGAR) give totals ranging from 19.6 to 30 TgCy^{-1}. The most recent EPA and EDGAR inventories report lower US anthropogenic emissions compared with previous versions (decreased by 10% and 35%, respectively); this change primarily reflects lower, revised emissions estimates from natural gas and coal production. However, recent analysis of CH_4 data from aircraft estimates a higher budget of 32.4 ± 4.5 TgCy^{-1} for 2004. Furthermore, atmospheric observations indicate higher emissions in natural gas production areas; a steady 20-y increase in the number of US wells and newly-adopted horizontal drilling techniques may have further increased emissions in these regions.*
>
> *These disparities among bottom-up and top-down studies suggest much greater uncertainty in emissions than typically reported. For example, EPA cites an uncertainty of only ±13% for the for United States. Independent assessments of bottom-up inventories give error ranges of 50-100%, and values from Kort et al. are 47 ± 20% higher than EPA. Assessments of CH_4 sources to inform policy (e.g., regulating emissions or managing energy resources) require more accurate, verified estimates for the United States.*

The study concludes that there is a large inconsistency between the “bottom up” emission inventories for the US oil and gas sector and from agricultural sources, and the levels of emission which can be demonstrated from “top down” instrument-based studies –

> *The results indicate that drilling, processing, and refining activities over the south-central United States have emissions as much as 4.9 ± 2.6 times larger than EDGAR, and livestock operations*

135 *The effects of shale gas exploration and hydraulic fracturing on the quality of water resources in the US* [Vengosh 2013]

136 *A Critical Review of the Risks to Water Resources from Unconventional Shale Gas in the United States* [Vengosh 2014]

137 *Anthropogenic emissions of methane in the United States* [Miller 2013]

across the US have emissions approximately twice that of recent inventories. The US EPA recently decreased its CH_4 emission factors for fossil fuel extraction and processing by 25-30% (for 1990-2011), but we find that CH_4 data from across North America instead indicate the need for a larger adjustment of the opposite sign.

Although it is possible to control methane emissions in many ways, what the debate about methane emissions is masking is the greater problem of the disparity between inventory assessments and what the latest instrument-based surveys reveal. It cannot be denied that “reduced emissions completion” (REC) is having an impact in US oil and gas fields. However, that impact is not as significant as its supporters promote (although significantly reduced, the impact still accumulates in the environment). As outlined in the US EPA's recent national emissions inventory[138] –

Emissions from field production account for approximately 32.2 percent of CH_4 emissions and about 38.8 percent of non-combustion CO_2 emissions from natural gas systems in 2012. CH_4 emissions from field production decreased by 25.2 percent from 1990-2012; however, the trend was not stable over the time series – emissions from field production increased 23.5 percent from 1990-2006 due primarily to increases in hydraulically fractured well completions and workovers, and then declined by 39.4 percent from 2006 to 2012. Reasons for the 2006-2012 trend include an increase in plunger lift use for liquids unloading, increased voluntary reductions over that time period (including those associated with pneumatic devices), and increased RECs use for well completions and workovers with hydraulic fracturing. CO_2 emissions from field production increased 38.9 percent from 1990 to 2012 due to increases in onshore and offshore flaring.

As this extract indicates, although the greater problem of methane emissions is being addressed by RECs, this ignores the significant rise in carbon dioxide emissions which are the product of gas flaring from unconventional oil and gas operations.

The issue of the inconsistencies between instrument-based and inventory assessments, like the US EPA's national inventory report above, was developed in Brandt et al.'s paper[139], published in February 2014. This notes –

To improve understanding of leakage rates for policy-makers, investors, and other decision-makers, we review 20 years of technical literature on NG [natural gas] *emissions in the United States and Canada. We find (i) measurements at all scales show that official inventories consistently underestimate actual CH_4 emissions, with the NG and oil sectors as important contributors; (ii) many independent experiments suggest that a small number of “super-emitters” could be responsible for a large fraction of leakage; (iii) recent regional atmospheric studies with very high emissions rates are unlikely to be representative of typical NG system leakage rates; and (iv) assessments using 100-year impact indicators show system-wide leakage is unlikely to be large enough to negate climate benefits of coal-to NG substitution.*

The criticisms of the US EPA's inventory assessment methods continued with the publication of the review by Moore et al. the following month[140]. This looked at the issue of methane sources across a number of different studies, and reiterated the problems with inventory assessments, and the way in

138 page 3-62, 'Field Production', *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2012* [USEPA 2014]

139 *Methane Leaks from North American Natural Gas Systems* [Brandt 2014]

140 *Air Impacts of Increased Natural Gas Acquisition, Processing, and Use: A Critical Review* [Moore 2014]

which these assessments create uncertainties in assessing the climate impacts from oil and gas –

> *Each year since 1998, the U.S. Environmental Protection Agency (US EPA) has released an updated national inventory (NI) of greenhouse gas (GHG) sources and sinks and submitted it to the United Nations Framework Convention on Climate Change. National estimates for CH_4 emissions from natural gas systems are modelled and calculated annually from 1990 to two years prior to the release year based on 80 different emission factors... Additional emissions or activity data for the estimates are supplied by states and the industry.*
>
> *Uncertainties in this inventory approach are illustrated by a series of methodological changes that US EPA implemented during the past four years to estimate CH_4 emissions from natural gas systems. Based on the US EPA approach, leakage estimates for natural gas across the entire life cycle ranged from as high as 2.8% of domestic natural gas production to as low as 1.65% in the 2013 US EPA GHG NI release. This range in values is important because an analysis by Alvarez et al. concluded that CH_4 leakage of 3.2% or less would provide immediate net climate benefits for electricity production from natural gas compared to coal.*
>
> *Two recent scientific studies have found that U.S. total CH_4 emissions are underestimated in current inventories. Miller et al. published a top-down estimate of CH_4 emissions in the U.S. based on long-term aircraft and tower observations conducted by U.S. government laboratories in 2007 and 2008. The authors concluded that the US EPA inventory underestimated CH_4 anthropogenic emissions by ∼50%. Brandt et al. reached a similar conclusion of ∼50% underestimation by US EPA based on a meta-analysis of published results. Based in part on the distribution of emissions excess observed especially in the southern U.S. and on the content of propane in the air, both studies suggest that some of the missing emissions in the inventory could be explained by larger emissions from oil and gas production and processing.*

Again returning to the non-climate issues related to extreme energy sources – late 2013/early 2014 saw a number of papers published which question the benefits of unconventional gas. It must be noted that at no point in their study do MacKay and Stone objectively justify the benefits of unconventional gas. It is assumed that the benefits are positive, and/or we assume that there are no less polluting options available – such as energy conservation or renewable energy sources.

The French Institute for Sustainable Development and International Relations (IDDRI) published a report[141] on the economics of shale gas in Europe. This presented an analysis which contradicted many of the assertions made by those promoting shale gas in the EU:

- Despite very low and ultimately unsustainable short-term prices of natural gas, the unconventional oil and gas revolution has had a minimal impact on the US macro-economy;
- The unconventional oil and gas revolution has had a minimal impact on US manufacturing;
- Without wider policy actions, the US shale revolution will not lead to a significant, sustained de-carbonisation of the US energy mix nor will it assure US energy security; and
- It is unlikely that the EU will repeat the US experience in terms of the scale of unconventional oil and gas production.

141 *Unconventional wisdom: An economic analysis of US shale gas and implications for the EU* [IDDRI 2014]

The IDDRI's report developed a theme that had begun back in 2011 with Deutsche Bank's initial report[142] on the economics of shale gas in Europe, which was developed by Bloomberg New Energy Finance in their report[143] of September 2013 –

In summary, while it is not unimaginable that hundreds of drilling sites holding thousands of wells could be set up in the UK, it would require favourable geology, public acceptance and the establishment of a services industry and onshore gathering and midstream infrastructure. None of these can be done quickly. Our conclusion is that even under the most favourable case for shale gas production, with production reaching 4.5bcfd in the mid-2020s, and low demand driven by a power sector emissions target of 50gCO2/kWh, the UK will not be self-sufficient in gas. The reliance on continued imports will ensure that UK gas prices remain tied to European and world markets and so the direct impact of shale on the cost of electricity in the UK will be limited.

In March 2014 the Oxford Institute for Energy Studies published a review of shale oil and gas in the USA[144]. Although generally positive, the report noted problems with the assessment of the shale resource, and low rates of recovery, which meant many gas fields in the USA were operating at or below the economic cost of recovery – and that over the past decade or so the losses and asset write-downs across the US industry may exceed $35 billion. To put that figure into perspective, that's a little more than J.P Morgan's bank bailout, and a little less than Citigroup's bailout.

March 2014 also saw the publication of an economic study by Jacquet[145] which examined the impacts of unconventional fossil fuel developments on communities in the USA. This makes comparisons to similar resource development "booms" of the 1970s and 1980s, and identifies a number of trends initiated by sudden changes in economics development patterns –

Although shale energy development can bring infusions of money and jobs to local communities, an array of risks to community-level assets and institutions is also possible. Sociological research dating back to the 1970s links rapid oil and gas development with overburdened municipal services, upended social and cultural patterns, and volatile economic growth. Research on technological risk has demonstrated communities can come to be associated with pollution and contamination, resulting in out-migration, declining amenity-led development, and decreased financial investment. Emerging shale energy case studies in Wyoming, Pennsylvania, North Dakota, and Texas show a similar, although nuanced, picture of these concerns. Yet, little data exists on the prevalence or magnitude of these risks in the current context of shale gas development.

Another recent study by Adgate et al.[146] took a broader comparative view of risks from unconventional oil and gas. This study provides a critical counterpoint to the narrow, climate-related claim of "relatively small" impacts by MacKay and Stone's; and instead puts emphasis on the lack of qualitative data across many aspects of the environmental impacts of unconventional gas –

Given the lack of systematic tracking of exposure and health effects in communities, there are little data to inform risk mitigation and risk management activities. For air quality, key

142 *European Gas: A First Look At EU Shale-Gas Prospects* [Deutsche Bank 2011]

143 paragraphs 25/26, *The economic impact on UK energy policy of shale gas and oil* [Bloomberg 2013]

144 *US shale gas and tight oil industry performance: challenges and opportunities* [OIES 2014]

145 *Review of Risks to Communities from Shale Energy Development* [Jacquet 2014]

146 *Potential Public Health Hazards, Exposures and Health Effects from UNG Development* [Adgate 2014]

unknowns include characterization of baseline air quality prior to development in new areas as well as characterization of the variability in exposure during high emissions processes, specifically drilling, hydraulic fracturing, and well completion activities. For water quality, unknowns include characterization of baseline water quality and impacts during each of the process steps that use water, that is, chemical mixing, hydraulic fracturing, flowback, and storage of flowback and produced water and wastewater treatment and disposal. Research on other stressors, including noise and light, traffic, and other safety hazards needs to be conducted in the context of understanding the overall effect of the mixture of these chemical and physical stressors. The interaction with the stress created by rapid change and community disruption is a key research need for characterizing health effects in locales where development is encroaching.

April 2014 saw the publication of the US National Oceanic and Atmospheric Administration's (NOAA) plan[147] for the study of the emissions from oil and gas fields – which they describe as the "*Shale Oil and Natural Gas NEXus*" (SONGNEX). It was this work, beginning with Pétron's 2012 study, improved upon by Karion's 2013 study, which highlighted both the scale of emissions from unconventional fossil fuels, and the extent to which these differed from inventory assessments. To quote their project plan –

In the SONGNEX mission described here, we will quantify the atmospheric emissions from various components of the U.S. energy infrastructure. We will also study how these emissions transform chemically in the atmosphere, and how these transformations contribute to ozone and fine particle formation. Specifically, we intend to focus on the emissions from a number of different tight oil and shale gas basins in the western U.S. The basins are chosen to represent a significant fraction of the production as well as different stages of the development of a basin. In addition, we will study several other components of the energy infrastructure, including surface coalmines in Wyoming, coal and natural gas power plants, a major intersection of crude oil pipelines in Oklahoma, and biofuel refineries where ethanol is made from corn. The results of SONGNEX will give the information that is needed to (1) evaluate the effects of various energy sources and uses on climate, air quality and human health, and to (2) allow communities and society as a whole to make the best decisions to minimize these effects.

This research project is due to take place in early 2015, with the first results reported towards the end of that year. Full publication of peer reviewed papers is not likely until 2016.

The next study from the NOAA's project was also published in April 2014. Caulton et al.[148] looked at sites across the Marcellus shale in Pennsylvania. This again was an aircraft-based study, and it discovered a large regional methane flux associated with the shale gas industry. Perhaps the most significant discovery of this study was that there is a large methane release associated with well drilling – from wells which were still being drilled, had not yet been hydraulically fractured, and were not yet in production. This source of emissions is not considered the US EPA's inventory. Considering the implications of this discovery, the paper states –

Large emissions averaging 34gCH_4/s per well were observed from seven well pads determined to be in the drilling phase, 2 to 3 orders of magnitude greater than US Environmental Protection

147 *Shale Oil and Natural Gas Nexus* [NOAA 2014]

148 *Toward a better understanding and quantification of methane emissions from shale gas development* [Caulton 2014]

Agency estimates for this operational phase. The emissions from these well pads, representing ∼1% of the total number of wells, account for 4–30% of the observed regional flux. More work is needed to determine all of the sources of methane emissions from natural gas production, to ascertain why these emissions occur and to evaluate their climate and atmospheric chemistry impacts.

Overall, from their own study and in reviewing other recent research, they estimated that a significant proportion of gas production is leaking between the well head and the final point of consumption; certainly within a range which negates the perceived climate benefits of natural gas over coal. As the paper describes –

The current range of observed CH_4 emissions from US natural gas systems (2.3-11.7%), if it were representative of the national scale, applied to the reported 2011 unassociated gas production number yields a range of CH_4 emissions between 5.6 and 28.4 Tg CH_4 , whereas the EPA reports 6.7 Tg CH_4 from natural gas systems in 2011 and only 28 Tg CH_4 total anthropogenic emissions. Natural gas systems are currently estimated to be the top source of anthropogenic CH_4 emission in the United States, followed closely by enteric fermentation, but the top-down observations suggest that natural gas may play a more substantial role than previously thought. Inadequate accounting of greenhouse gas emissions hampers efforts to identify and pursue effective greenhouse gas reduction policies.

The end of April 2014 saw the publications of Newell and Raimi's analysis[149] of the net climate impacts of natural gas production. This modelled the effects of the changing patterns of energy use initiated by greater natural gas production. The results of this research do not confirm the common assumptions – also made by MacKay & Stone's report as well as the Royal Society/Royal Academy of Engineering – regarding the contribution of natural gas to lowering carbon emissions –

Shale gas will likely not substantially change global GHG concentrations on its own. Policy and a range of competitive low-GHG energy options are the key factors. Shale gas has led to modest GHG emissions reductions, but these are not sufficient to substantially alter the future path of global GHG concentrations. For this to happen, policies would need to provide stronger incentives to switch to existing and deploy new technologies fuelled by natural gas, renewables, nuclear, and fossil fuels coupled with carbon capture and sequestration. These technologies would in turn need to become more cost-competitive and more broadly deployed on an international scale.

For a number of the issues discussed in this paper, additional research is needed. Key areas include methane emissions from natural gas systems and other sources; the emissions profiles of natural gas versus electricity and oil-based heating systems; the GHG implications of changes in international trade patterns due to shale gas growth; and the likely magnitude of substitution of natural gas for coal versus zero-carbon electricity, both in the United States and internationally.

Finally, in May 2014 Howarth produced an updated paper[150]. This reviewed the range of research which had been produced since the 2011 and 2012 papers, and how this new evidence changed the analysis of those earlier papers. It notes –

149 *Implications of Shale Gas Development for Climate Change* [Newell 2014]

150 *A bridge to nowhere: methane emissions and the greenhouse gas footprint of natural gas* [Howarth 2014]

Since 2012, many new papers have produced additional primary data. Two of these found very high upstream methane emission rates from unconventional gas fields (relative to gross methane production), 4% for a tight-sands field in Colorado [Pétron's paper] *and 9% for a shale gas field in Utah* [Karion's paper]*, while another found emissions from a shale gas field in Pennsylvania to be broadly consistent with the emission factors we had published in our 2011 paper* [Caulton's paper]. *All three of these studies inferred rates from atmospheric data that integrated a large number of wells at the basin scale. The new Utah data are much higher than any of the estimates previously published for upstream emissions from unconventional gas fields, while the measurement for the Colorado tight-sands field overlaps with our high-end estimate for upstream unconventional gas emissions in Howarth et al.. The Utah and Colorado studies may not be representative of the typical methane emissions for the entire United States, in part, because they focused on regions where they expected high methane fluxes based on recent declines in air quality. But I agree with the conclusion of Brandt and his colleagues that the "bottom-up" estimation approaches that we and all the other papers in Table 1 employed are inherently likely to lead to underestimates, in part, because some components of the natural gas system are not included.*

More significantly, in this paper Howarth directly addresses the issue of the 'global warming potential' (GWP) of methane – not only noting that the 100-year GWP figure had recently increased, but also that the IPCC stressed the importance of using not just 20-year but also 10-year GWPs –

The most recent synthesis report from the IPCC in 2013 on the physical science basis of global warming highlights the role of methane in global warming at multiple time-scales, using GWP values for 10 years in addition to 20 and 100 years (GWP of 108, 86, and 34, respectively) in their analysis. The report states that "there is no scientific argument for selecting 100 years compared with other choices," and that "the choice of time horizon... depends on the relative weight assigned to the effects at different times". The IPCC further concludes that at the 10-year time-scale, the current global release of methane from all anthropogenic sources exceeds (slightly) all anthropogenic carbon dioxide emissions as agents of global warming; that is, methane emissions are more important (slightly) than carbon dioxide emissions for driving the current rate of global warming. At the 20-year time-scale, total global emissions of methane are equivalent to over 80% of global carbon dioxide emissions. And at the 100-year time-scale, current global methane emissions are equivalent to slightly less than 30% of carbon dioxide emissions.

This difference in the time sensitivity of the climate system to methane and carbon dioxide is critical, and not widely appreciated by the policy community and even some climate scientists. While some note how the long-term momentum of the climate system is driven by carbon dioxide, the climate system is far more immediately responsive to changes in methane (and other short-lived radiatively active materials in the atmosphere, such as black carbon). The model published in 2012 by Shindell and colleagues and adopted by the United Nations predicts that unless emissions of methane and black carbon are reduced immediately, the Earth's average surface temperature will warm by 1.5°C by about 2030 and by 2.0°C by 2045 to 2050 whether or not carbon dioxide emissions are reduced.

In conclusion, Howarth notes that the uncertainties over the use of natural gas, and the high significance of methane to the overall impacts of global warming, cast doubt upon its role as a "bridge" towards a low carbon economy –

> *Is natural gas a bridge fuel? At best, using natural gas rather than coal to generate electricity might result in a very modest reduction in total greenhouse gas emissions, if those emissions can be kept below a range of 2.4–3.2% (based on/adjusted for the latest information on radiative forcing of methane). That is a big "if," and one that will require unprecedented investment in natural gas infrastructure and regulatory oversight. For any other foreseeable use of natural gas (heating, transportation), the GHG is larger than if society chooses other fossil fuels, even with the most stringent possible control on methane emissions, if we view the consequences through the decadal GWP frame. Given the sensitivity of the global climate system to methane, why take any risk with continuing to use natural gas at all?*

Clearly, this goes to the heart of the assumptions of the MacKay-Stone review – and its assumption of the superiority of using natural gas rather than, for example, an accelerated transition to non-fossil fuel energy sources. The IPCC's 2013 review of the science does indeed note that the selection of a particular GWP is a "value judgement"[151], and that there is no scientific argument behind using a 100-year value rather than the 10- or 20-year. Given the short-term nature of unconventional gas development, and the fact that a large emission of methane might take place within a short period of time, it is arguable from the latest IPCC research that MacKay and Stone's review should have used the 20-year GWP – and that review must be updated to reflect this. The significance of methane to the overall climate equation is such that not considering the short-term implications of unconventional gas production must be considered irresponsible – and that the Government's policy is evidentially flawed.

Reviewing the information across this section of this report, and considering the implications of the Government's policies on unconventional oil and gas, the MacKay-Stone report represents a two-fold failure. Firstly it is a failure of assessment – as it did not outline the significant uncertainties demonstrated across a wide range of recent research on the impacts of unconventional oil and gas development. In failing to convey these uncertainties when most recent research describes them at great length, and instead concluding that development would have a "relatively small" impact on UK greenhouse gas emissions, we must consider that the report is – whether by design or unintentionally – misleading. Secondly, it represents a failure to protect the public's interests. As is made clear in the *Civil Service Code*, the job of Government advisers is to "provide information and advice, including advice to Ministers, on the basis of the evidence, and accurately present the options and facts"; and not to "ignore inconvenient facts or relevant considerations when providing advice or making decisions". It is arguable, given the evidence available, that the MacKay-Stone report fails to objectively weigh the evidence on the climate change implications of the Government's policies on unconventional gas. All Government policies or decisions which rely on this report must be considered flawed in their assumptions, and therefore open to challenge by the public.

151 page 711, chapter 8, *Climate Change 2013: The Physical Science Basis* [IPCC 2013]

3. The Government's response to the MacKay-Stone report

In April 2014, the Government published its response to the MacKay-Stone report[152]. It should be noted that the contents of the report were not subject to public consultation. Therefore the questions raised within this examination of that report and its policy implications could not be put to ministers – who proceeded to accept the MacKay-Stone report without any critical review of its content.

This failure of process was further compounded by the statements made in the Government's response to the report. Although the response accepted a number of recommendations from the report, the statements made in their response raise doubts as to the effectiveness of these measures; and to the technical viability of this entire policy. In fact, what was significant was how little the response engaged with the issues raised in the MacKay-Stone report, and instead used this statement as an opportunity to promote the wider policy of unconventional gas development.

For example, consider MacKay-Stone's statement's on the BGS' study of the Bowland shale[153] –

> *The BGS report estimates that the resource in the Bowland-Hodder shale formation is 1329 trillion cubic feet (tcf), about 38,000 billion cubic meters (bcm); the resource is an estimate of the gas in the ground; the BGS report did not estimate the reserves, the amount of gas which could in practice be produced economically from that resource. Until more exploration work has been performed in the Bowland-Hodder shale and in other geologically different shale gas prospects beneath the UK, it will not be possible to make any meaningful estimate of the likely shale gas reserves in the UK.*

It would appear that the Government are accepting the prospectivity for shale gas in Britain when no evidence exists to support these claims. The BGS study is a probabilistic assessment. What the 1,329tcf figure refers to is the "P50", or 50% probability value. That means there is only an "evens" chance of that gas existing. If we consider the "P90" value, which is considered far more reliable for financial investment in resource production, that figure is almost 40% lower than that quoted in the Government response. And of that figure, only a few percent may finally be produced.

That misapprehension over the scale of the resource is compounded further the MacKay-Stone report when it discusses the likely production from shale wells[154] –

> *The US Geological Survey reported that the average EUR for basins ranged between 0.04 and 2.60 bcf per well (1-74 million cubic meters). Due to the collapse in gas prices in the USA such small wells are now probably considered uneconomic. Economic factors such as equipment costs, access and environmental regulations in the UK are likely to result in the wells having an EUR in excess of 3.0 bcf (85 million cubic meters), with industry sources suggesting an even higher figure of 5.0 bcf (140 million cubic meters).*

This statement shows a complete misunderstanding of the geophysics of resource production; from a technical point of view, putting the cart before the horse. It is not the industry's expectations which determines how much oil or gas a well will produce – it is the characteristics of the source rock.

152 *The Government's response to the MacKay-Stone report: Potential greenhouse gas emissions associated with shale gas extraction and use* [DECC 2014]

153 paragraph 4, page 9, *Potential Greenhouse Gas Emissions Associated with Shale Gas...* [MacKay 2013]

154 paragraph 35, page 17, ibid.

That in turn means that – as demonstrated by the asset write-downs in the US[155] – the scale of the resource cannot be inferred by exploration drilling, but only by continued production drilling[156]. The variation in the levels of well production, even within the same field[157], is such that even in the "sweet spots"[158] a large number of the wells drilled may be uneconomic. If the Government are arguing that the industry will only accept very large estimated ultimate recovery figures, but the evidence suggests that these rarely exist in unconventional gas fields, then by implication the Government are stating that only a very small fraction of the total resource will ever be produced.

This is the problem with the Government's entire policy in this area. They commissioned a report from MacKay and Stone which, as outlined in the previous section, does not accurately reflect the uncertain nature of the impacts of unconventional gas development. They then respond to that report, commenting very little on the science reviewed by MacKay and Stone, and instead proceed to hype the production of shale gas – using statements which in fact reduce the scale of the producible 'reserve' to a minimal proportion of the available 'resource'.

The failure of the Government to appreciate the available evidence on the impacts of unconventional gas on the climate is illustrated in the following paragraph of their response[159] –

> *The report is a significant step forward in establishing the range of emissions we might expect in the UK's regulatory context. Since the release of the MacKay-Stone report, the University of Texas at Austin produced a detailed study involving the monitoring methane emissions from various stages of shale production. It found that emissions from fracking are lower than previously thought.*

As I have outlined in this report, given the sensitivity to assumptions of the model used by MacKay and Stone, their report does not demonstrate that the emissions from shale gas development in Britain would be "low". Likewise, the flaws described in the Allen study for the University of Texas mean the conclusions of that report have little statistical validity. More importantly, when we set the results of both these reports against the greater body of available evidence – as I sought to do in the previous section – it is clear that the Government's optimism is premature. No such certainty can be claimed or demonstrated.

In my view the Government's response to the MacKay-Stone report not only fails to test the assumptions in that report; it also demonstrates a lack of understanding of the geophysics of unconventional fossil fuels. The assertions made in the Government's response, coupled with the failures of the MacKay-Stone report, and the Allen study which was also referenced, demonstrate a clear failure of judgement by the Department of Energy and Climate Change – and by extension, by the Government as a whole. Their policy of promoting unconventional fossil fuels appears to be an ideological position, not supported by objective evidence.

155 *US shale gas and tight oil industry performance: challenges and opportunities* [OIES 2014]

156 *Drill Baby Drill : Can Unconventional Fuels Usher in a New Era of Energy Abundance* [Hughes 2013a]

157 *Variability of Distributions of Well-Scale Estimated Ultimate Recovery for Continuous (Unconventional) Oil and Gas Resources in the United States* [USGS 2012]

158 *A reality check on the shale revolution* [Hughes 2013b]

159 page 6, *The Government's response to the MacKay-Stone report* [DECC 2014]

4. The House of Lords Economic Affairs Committee inquiry

Before moving on to tie-up this review of the evidence supporting the Government's policy on unconventional oil and gas, and its implications on climate change, there is one further report which should be considered. The report from the House of Lords Economic Affairs Committee (EAC), *The Economic Impact on UK Energy Policy of Shale Gas and Oil*[160], published on the 8th May 2014.

What first has to be considered is the proposition within the report, encapsulated in the title; "*The Economic Impact on UK Energy Policy of Shale Gas and Oil*". To date, the British Geological Survey refused to put a figure on the potential reserve of unconventional oil and gas – there is not enough evidence to make such estimates with any certainty. There has been no large scale commercial unconventional oil and gas production in the UK. Yet despite this, the EAC's report assumes that shale gas and oil will have a positive and significant "economic impact" upon energy policy – when in fact no such impact can be reliably demonstrated at this time. What this report contains is many assertions about unconventional oil and gas which have very little evidence to back them up.

For example[161] –

> *In December 2012 DECC commissioned a study into the greenhouse gas emissions associated with shale gas extraction and use. This was published in September 2013. The MacKay report found that the carbon footprint of shale gas extraction and use is comparable to gas extracted from conventional sources and lower than the carbon footprint of liquefied natural gas (LNG).*

As outlined in the previous sections, and through an analysis of the figures put forward by MacKay and Stone earlier in the report, there is no unequivocal evidence to demonstrate this claim. The models used are highly sensitive to the assumptions made about production, and evidence from the US shows that these assumptions are themselves uncertain – with a wide range of probability – due to a lack of evidence. Therefore this assertion by the EAC cannot be shown to be true.

Let's take another example from the EAC report[162] –

> *WWF, Greenpeace and Friends of the Earth told us that research from Princeton University suggested that for shale gas to maintain a lower carbon footprint than coal, cumulative fugitive methane emissions should not exceed 3.2 per cent of the gas produced. Professor Muller disagreed and told us that the 3.2 per cent figure was "misinformation ... based on a simple calculation you can do that is mistaken... 15 per cent to 18 per cent has to leak before it is as bad as coal." He referred us to his explanatory article in the New York Times.*

It is not clear, from the evidence volume to this report[163], which estimate the WWF et al. are citing – but I would assume it is the study by Alvarez[164]. In this report I also cite other peer-reviewed journal papers which provide similar estimates – for example, Wigley[165]. What's interesting is that, rather than peer-reviewed evidence from journals, their Lordships choose to cite a blog post (not an "article") in

160 *The Economic Impact on UK Energy Policy of Shale Gas and Oil* [EAC 2014]

161 paragraph 109, page 43, ibid.

162 paragraph 112, page 44, ibid.

163 pp.178-209, *The Economic Impact on UK Energy Policy of Shale Gas and Oil: Oral and Written Evidence* [EAC 2014b]

164 *Greater focus needed on methane leakage from natural gas infrastructure* [Alvarez 2012]

165 *Coal to gas: the influence of methane leakage* [Wigley 2011]

the New York Times[166] which contains some interesting claims –

> *The number 25 represents the relative greenhouse effect of equal kilograms of CH_4 and CO_2. But molecule per molecule, methane is only 9 times more potent than CO_2. That's because a molecule of CH_4 weighs less than a molecule of CO_2 by a factor of 4/11. If a methane molecule is burned, it produces one CO_2 molecule. If it leaks, it adds one methane molecule to the atmosphere. The leakage causes 9 times as much greenhouse effect as it would have caused if burned.*

Arguably what this blog post from the New York Times represents is "pseudo-science". In essence this quote is claiming that the Intergovernmental Panel on Climate Change's (IPCC) research on the global warming potential (GWP) of methane and other gases is irrelevant – and that the scientific consensus around the current use of GWPs is flawed.

In fact the value of the GWP for methane has nothing to do with the energy created by burning it, or its weight, but rather the capacity of a specific mass of methane gas, relative to carbon dioxide, to reflect or absorb the energy of infra-red radiation. The more opaque that the gas is to differing wavelengths of infra-red radiation, the higher its GWP. We must also question why the EAC are prepared to accept the value of blog posts from newspaper web sites, rather than information which can be readily found across a number of different peer reviewed journal papers and IPCC reports.

The fact is that some members of the Lords EAC have a long-stated opposition to the science of climate change, and to attempts to tackle greenhouse gas emissions. For example, Lord Lawson of Blaby outlined his position on shale in a House of Lords debate on fracking in March this year[167] –

> *As for the environmental objections, not only are they entirely without substance but you have only to go, as my noble friend has, to the United States to see that there is not an environmental problem.*

Or another example from a Lords question on climate change in May this year[168] –

> *Is she aware that the latest IPCC report explicitly states that estimates of the aggregate economic impact of climate change are relatively small and that moderate climate change, which is what it predicts for the rest of this century, may be beneficial?*

What is significant about the quoted sections of the EAC's report – and many other examples that I might have chosen – is that they demonstrate a predetermination of the issues within their inquiry. For example, the "benefits" of climate change can be dismissed if we look at the IPCC's latest reports[169]. The EAC appear to have chosen the evidence they wished to hear because it confirmed their views, rather than weighing a wide range of evidence, and seeking to understand the substantive differences between the cases made, in order to arrive at conclusions which have objective validity.

It would be possible to write many pages on the flaws in the EAC's report – but it would add little to the consideration of the Government's policy. That's because, as I've outlined in the two extracts above, the EAC's report is poorly compiled, and is so biased in favour of the case for the oil and gas industry that it has no objective value. In my view this report is so full of errors that it must be disregarded as part of this debate.

166 *Climate Change: Two Climate Analysts Fault Gas Leaks, but Not as a Big Warming Threat* [NYT 2013]

167 *Energy: Fracking – Question for Short Debate* [Hansard 2014a]

168 *Climate Change: Question* [Hansard 2014b]

169 *Climate Change 2013: The Physical Science Basis* [IPCC 2013]
Climate Change 2014: Mitigation of Climate Change [IPCC 2014]

5. Extreme energy policy and administrative/environmental law

The Government's policies on unconventional fossil fuels do not exist in a vacuum. They must comply with the framework of laws and standards which direct government administration. In this case it is arguable that the errors of fact, and excess of exaggeration over the benefits of unconventional fossil fuels, breach this framework – thereby acting against the public interest.

There are three parallel issues here: Firstly, the misrepresentation of the facts about unconventional fossil fuels within the Government's promotion of their policy to the public. Secondly, a failure to meet the precautionary requirement within environmental law as part of the Government's unconventional fossil fuels project. And finally, bringing these threads together, actions by elected and unelected Government officials which arguably amount to misconduct in a public office.

A. Misrepresentation of the facts on unconventional fossil fuels within policy

If we read across the whole range of information and policy produced by the Government on unconventional fossil fuels, what we find is a partial and often conflicting view of the research about these technologies, and the policy framework governing their operation. That in turn creates uncertainty about regulation, which leaves gaps in protection of the environment and human health. As a result the Government's optimism bias creates opportunities where these processes might create severe harm to the environment and human health.

For example, Government policy cites the MacKay-Stone and Royal Society/Royal Academy of Engineering (RS/RAE) reports as authoritative studies. As I have attempted to show in this report, that is not the case. For example, consider one of the points made in the MacKay-Stone report[170] –

> *It is important to note that there has been little measurement of direct or indirect methane emissions from shale gas exploration and production anywhere in the world.*

This is not the case. As has been outlined in this report, there are a number of studies where direct measurement of emissions unconventional oil and gas operations has taken place. What is more, perhaps problematically for the Government's unconventional fossil fuels project, those studies have flagged-up a disparity between “bottom up” emission inventory assessments and “top down” measurements of emissions in the field. This, along with a number of the other observations made in recent research, invalidates some of the key assumptions in the MacKay-Stone and RS/RAE studies.

As well as problems with the factual basis of policy, the Government have also been carrying out arguably incompatible actions as part of creating a new policy framework to support unconventional fossil fuels. For example, in December 2013, the Department for Energy and Climate Change (DECC) published a strategic environmental appraisal (SEA) of the *14th Onshore Oil and Gas Licensing Round*[171]. This provided an analysis of the impacts of policy on the environment and human health, and was required under European law to be subject to a public consultation. At the same time though DECC also issued its “regulatory roadmap”[172] for unconventional gas developments – effectively pre-judging many aspects of the SEA consultation process.

170 paragraph 40, page 18, *Potential Greenhouse Gas Emissions Associated with Shale Gas...* [MacKay 2013]

171 *Strategic Environmental Assessment for Further Onshore Oil and Gas Licensing: Environmental Report* [DECC 2013a]

172 *Regulatory Roadmap: Onshore oil and gas exploration in the UK regulation and best practice* [DECC 2013c]

A few months before those documents were published, in July 2013, DECC had launched its "best practice" review of the regulatory processes governing unconventional gas. With regards to the public oversight of the process the document notes[173] *(my emphasis in bold)* –

> *The UK Government has been extremely active creating the right framework to accelerate shale gas development in a responsible way. The Office of Unconventional Gas and Oil (OUGO) has been set up to co-ordinate the activity of the regulatory bodies and Departments. OUGO is liaising with regulators* ***to create a streamlined planning and regulation system with a high degree of local scrutiny and prior consultation****. We want to ensure that regulation is fit for purpose, encourages growth whilst fully protecting the environment.*

This is a curious claim since, in June 2013, the Treasury issued an instruction to the Environment Agency to the effect that[174] *(my emphasis in bold)* –

> *Whilst maintaining environmental protection,* ***the Environment Agency will:***
>
> - *immediately extend the remit of its shale gas unit to include all onshore oil and gas exploration, ensuring a single point of contact for the industry;*
> - *publish draft technical guidance for consultation by the end of July, setting out its requirements of operators and giving them certainty;*
> - *significantly reduce the time it takes to obtain environmental permits for exploration. The Environment Agency will:*
> - *by August, develop a single application pack for mining waste and radioactive substances permits, to streamline the process;*
> - *by September, issue permits within the standard 13 week period. In some cases this could be as little as six weeks; and*
> - ***by February 2014, issue permits within 1-2 weeks****, by developing standard rules for onshore oil and gas exploration activities.*

Also in July 2013, new planning guidelines[175] issued by the Department for Communities and Local Government (DCLG), extending the restrictions imposed by the National Planning Policy Framework[176] published in March 2012, proscribed what issues could and could not be dealt with as part of the consideration of planning applications to local authorities – effectively fencing-off issues such as pollution and human health from the consideration of locally elected officials.

However, the "Regulatory Roadmap", launched in December 2013 some months **after** these policy actions took place, states under the heading "What opportunities are there for public consultation?" that[177] *(my emphasis in bold)* –

> ***Public consultation is part of every oil and gas application for planning permission****, which is required for each stage of exploration, appraisal and production.*
>
> *The Environment Agency will carry out public consultation for the issue of environmental permits.* ***The length of time for these consultations varies from 4 to 12 weeks****, depending on the*

173 section 5, page 5, *About shale gas and hydraulic fracturing (fracking)* [DECC 2013d]

174 paragraph 4.34, *Investing in Britain's future* (Cm8669) [HM Treasury 2013]

175 paragraph 29, *Planning practice guidance for onshore oil and gas* [DCLG 2013]

176 paragraph 122, *National Planning Policy Framework* [DCLG 2012]

177 page 9, *Onshore oil and gas exploration in the UK: regulation and best practice – England* [DECC 2013e]

complexity of the application. They would be advertised in the most appropriate way, depending on the circumstances. Often this will be done through local media and the Environment Agency's website, alongside targeted e-mails to interested parties.

Minerals planning authorities (MPAs) will also advertise and consult on individual planning applications.

The MPA gives notice that it has validated and accepted a planning application by writing to residents and businesses near the application site, putting up a site notice or placing an advertisement in a local newspaper. Information about the application must also be available on the relevant local authority website.

As a matter of best practice, UKOOG's charter also sets out that communities must be engaged from the very start of the planning application process, where shale gas is being developed. For a more specific indication of when, where and how consultation will take place, please check the relevant MPA's website or contact them directly. In addition, the Government encourages pre-application consultation for all kinds of developments, including shale gas.

These various conflicting documents – from the Treasury, DCLG and DECC – are describing the *same* public consultation process in very different terms. The public cannot have "from 4 to 12 weeks" consultation with the Environment Agency if the Treasury are forcing the Environment Agency to issue permits in two weeks. Likewise the public's concerns regarding pollution or public health cannot be considered by local minerals planning authorities if those matters have been specifically excluded by DCLG guidance from their responsibilities.

The MacKay-Stone report on climate change shares many general similarities with Public Health England's (PHE) recent study of the health impacts of shale gas[178] (as outlined in my previous report on the Government's extreme energy policies[179]). Both reports had methodological flaws; both poorly reviewed the available evidence on the issue under consideration; and as a result, both reached highly tenuous conclusions about the effects of these processes upon the environment.

Neither of these reports answer the public's criticisms because neither report is able to address the weight of evidence which puts the contrary position to their conclusions. Therefore the content of these reports will not assuage public criticism, and likely defiance in the face of an imposed policy, as a result of the changes to policy outlined above. As with the general information produced by the Government on this subject, the difficulties with the content of these reports exists because of, as I perceive it, the political pressure being placed upon those carrying out these reviews.

In the foreword to the current *Ministerial Code*[180], David Cameron states –

In everything we do – the policies we develop and how we implement them, the speeches we give, the meetings we hold – we must remember that we are not masters but servants. Though the British people have been disappointed in their politicians, they still expect the highest standards of conduct. We must not let them down.

178 *Review of the Potential Public Health Impacts of Exposures to Chemical and Radioactive Pollutants as a Result of Shale Gas Extraction* [PHE 2013]

179 *A critical review of Public Health England's report, "Review of the Potential Public Health Impacts of Exposures to Chemical and Radioactive Pollutants as a Result of Shale Gas Extraction – draft for comment"* [Mobbs 2014]

180 *Ministerial Code* [Cabinet Office 2010]

Arguably, with the way in which the policy agenda surrounding unconventional fossil fuels has been organised, and the way in which scientific evidence has been commissioned and presented, the objectives set by the Prime Minister have not been met.

For example, the *Principles Of Scientific Advice To Government* state[181] –

1. Clear roles and responsibilities

- *government should respect and value the academic freedom, professional status and expertise of its independent scientific advisers*
- *scientific advisers should respect the democratic mandate of the government to take decisions based on a wide range of factors and recognise that science is only part of the evidence that government must consider in developing policy*

Given the problems with the evidence reviewed and the conclusions put in both the MacKay-Stone and PHE reviews, it is difficult to believe that – given the weight of evidence to the contrary – that there was not some element of control in the research projects initiated by DECC/PHE. Returning once more to the Ministerial Code, two sections have relevance here –

1.2j Ministers must uphold the political impartiality of the civil service and not ask civil servants to act in any way which would conflict with the Civil Service Code

and –

5.2 Ministers have a duty to give fair consideration and due weight to informed and impartial advice from civil servants, as well as to other considerations and advice in reaching policy decisions, and should have regard to the Principles of Scientific Advice to Government.

As is made clear in the *Civil Service Code*[182], the job of Government advisers is to "provide information and advice, including advice to Ministers, on the basis of the evidence, and accurately present the options and facts"; and not to "ignore inconvenient facts or relevant considerations when providing advice or making decisions". What is at odds here is that both the MacKay-Stone and PHE reviews, by failing to assess the widest range of evidence and to fairly represent the nature of that evidence to ministers and the public, raise questions about the impartiality of their advice.

The issue is that while the weight of research suggest unknown or uncertain impacts from unconventional fossil fuels, that was not the reflected in the final conclusions of these studies. And since their publication, these significant and troubling uncertainties over the scale and range of environmental and health impacts have not been communicated to the public by Government.

If we look at the manner in which the Government has implemented its policies in relation to unconventional fossil fuels, and the scientific advice sought to justify those claims, there are clear gaps between the available body of evidence about these processes, and the statements of ministers and their advisers in promoting policies in support of their use. In my view – and given the serious consequences of this policy for human health, the climate and the environment – these actions mislead the public, and act against the public's interests. As a result of the serious impacts which might ensue, these actions arguably breach the *Civil Service Code*, the *Ministerial Code*, and the *Principles Of Scientific Advice To Government*.

181 *Principles of scientific advice to government* [GOS 2010]

182 *The Civil Service Code* [CSC 2010]

B. The precautionary principle

For some time it has been arguable as to the exercisability of the precautionary principle directly within UK law. As part of the harmonisation of European environmental and planning policy, Article 191 of the Treaty of Lisbon/the Treaty on the Functioning of the European Union modifies the general objectives at the root of European environmental law[183] –

> *Union policy on the environment shall aim at a high level of protection taking into account the diversity of situations in the various regions of the Union. It shall be based on the precautionary principle and on the principles that preventive action should be taken, that environmental damage should as a priority be rectified at source and that the polluter should pay.*

For a working definition of the precautionary principle we could take the definitions outlined in the UK Sustainable Development Strategy[184] –

> *In dealing with outputs of human activity which may have an impact on natural resources (e.g. emissions, waste, chemicals, GMOs), we are... integrating the precautionary principle – minimising the risk of harmful releases to the environment through better knowledge of potential impacts and better management.*

In this case, the policy expressed later in that report is also applicable[185] –

> *There are, however, still instances where decisions on managing natural resources will have to be taken on the basis of partial information. In these instances, and where, firstly, there is a risk of significant adverse environmental effects occurring and secondly, any possible mitigation measures seem unlikely to safeguard against these effects, the precautionary principle will be adopted.*

The first stage in the application of the precautionary principle is the acceptance that uncertainty exists; the characterisation of uncertainty – which is a practical aspect of all "science" rather than the statement of what is "certain" – then follows on from this acceptance. In my view the MacKay-Stone report, and the response of the Government to that report published in April 2014, seek to deny that any uncertainty exists; and therefore blindly adopt measures which fit the Government's views, rather than opening up the analysis of policy to identify the scope of these uncertainties.

What will be even more revealing is the Government's up-coming decision on the strategic environmental appraisal (SEA) of the *14th Onshore Oil and Gas Licensing Round*. Unlike general policy, the *Strategic Environmental Appraisal Directive*[186] specifies that policy measures subject to review must embody the general principles of European environmental law –

> *...the Treaty provides that Community policy on the environment is to contribute to, inter alia, the preservation, protection and improvement of the quality of the environment, the protection of human health and the prudent and rational utilisation of natural resources and that it is to be based on the precautionary principle.*

183 Article 191, *The Treaty of Lisbon* [EU 2007]

184 *Developing our vision for natural resources*, page 99, *Securing The Future: Delivering UK Sustainable Development Strategy* (Cm6467) [UKSDS 2005]

185 page 101, ibid.

186 *The Assessment of the Effects of Certain Plans and Programmes on the Environment* [Directive 2001/42/EC]

As we arguably move towards 'the ecological limits to growth'[187], there are great uncertainties as to the availability, and future economic viability of finite resources[188] – both in terms of fossil fuels[189] but also non-renewable resources generally[190]. The potential implications of climate change are also part of this package of future uncertainties, and could arguably have catastrophic consequences in the near-term for the global economy. Therefore, the current government policy of seeking the ongoing maintenance and growth in fossil fuel supply, while at the same time rolling back measures which might move us towards lowering consumption and securing renewable energy sources, represents a failure to enact the precautionary principle.

The use of the MacKay-Stone report to make certain arguments in relation to climate change and shale gas is another example of failure to consider uncertainty – since the arguments used in that report are based upon assumptions which fit the requirements of policy, not objectively quantified risks. Furthermore, the reliance of that report upon unrepresentative studies, to argue the case for the equivalence of conventional and unconventional gas production, represents a spurious argument – since it seeks to advance certainty where no such certainty can be demonstrated.

Note also the general mitigation point made in the conclusions of the MacKay-Stone report, which states that[191] –

> *...the potential increase in cumulative emissions could be counteracted if equivalent and additional emissions-reduction measures are made somewhere in the world*

This proposal could be interpreted as contrary to the position expressed in Article 191 of the *Treaty on the Functioning of the European Union*. That is because the root of EU environmental law requires that, “that environmental damage should as a priority be rectified at source”.

The MacKay-Stone report concludes that[192] –

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

In fact there is currently a very high degree of uncertainty as to the nature and extent of the climate impacts from unconventional oil and gas production – as there are uncertainties in the way the MacKay-Stone report evaluates those risks, both in the assumptions of its modelling, and in the dismissal of research which questions those assumptions. As the MacKay-Stone report makes no attempt to consider the precautionary approach, it stands in defiance to the objectives at the root of Community environmental law. As a result of the Government's failure to make appropriate corrections in their response to that report, those flaws have now been transposed into Government policy. Therefore any decisions made with reference to the MacKay-Stone report must be considered flawed, and open to challenge by the public.

187 *A Comparison Of The Limits To Growth With Thirty Years Of Reality* [CSIRO 2008]

188 *Tracking the ecological overshoot of the human economy* [Wackernagel 2002]

189 *Economic vulnerability to Peak Oil* [Kerschner 2013]

190 *The Need for a New, Biophysical-Based Paradigm in Economics for the Second Half of the Age of Oil* [Hall 2006]

191 paragraph 108, page 38, *Potential Greenhouse Gas Emissions Associated with Shale Gas...* [MacKay 2013]

192 paragraph 106, page 37, ibid.

C. Decision-making bias and likely misconduct in public office

The human species is arguably approaching a tipping point. Not just in relation to the "headline" environmental issues such as climate change – but across a number of less well publicised ecological and economic factors which are combining to make the future survival of human society as we know it untenable. If we look at the evidence which exists today – from agriculture, to economics, to energy policy, to ecotoxicology, and overarching all of these the ecological overshoot of the human system – we have sufficient knowledge of the factors involved, if not total certainty, to question the rationality of many currently totemic policies and the contemporary conception of the "Western lifestyle".

This in turn raises a question in the mind of many who are aware of these trends – *why is the political system incapable of action?*

There comes a point when, as citizens, we have to ask whether our political system has the capacity to adapt and change, and to address itself to foreseeable challenges; or whether that process has become so compromised by vested interests that it blindly enacts policies which exacerbate our objective ecological situation. This argument comes to a head with the issue of unconventional oil and gas development, as so many elements of our political processes are directly influenced by the fossil fuel lobby.

For example, consider the Prime Minister's special adviser (SPAD) on energy –

- David Cameron's first energy and climate change SPAD was Ben Moxham[193], who had been a vice president of Riverstone, the energy finance company which bought out a large portion of Cuadrilla, Britain's leading "fracking" company.
- In May 2013, Ben Moxham was succeeded by Tara Singh[194], a lobbyist with Centrica, who, shortly after her appointment, in addition to their other unconventional gas interests, also took a financial stake in Cuadrilla.

On the basis of past appointments, it would appear that one of the requirements of being the Prime Minister's special adviser on energy and climate requires that the person's corporate alma mater must have a stake in Britain's leading fracking company. This arguably violates the *Ministerial Code*.

Next let us consider The Chancellor. George Osborne's father-in-law is Lord Howell, former energy minister in the Thatcher government, recently retired minister at the Foreign Office where he promoted British energy interests around the globe and wrote William Hague's speeches on energy policy. More importantly, Lord Howell has extensive links to all sectors of the energy industry through his presidency of the British Institute for Energy Economics, and connections with other energy policy interests – such his chairmanship of the Windsor Energy Group, which specifically advertises itself as a body which, "bridges between the public and the private sectors"[195].

Over the course of this Parliament the Chancellor has become more directly involved in energy policy, giving greater tax breaks to fossil fuel companies while trying to reduce support for other competing sources of energy or energy efficiency programmes – and forcing through the Treasury's recent overhaul of environmental regulation surrounding unconventional fossil fuels[196].

193 *Key climate change adviser resigns from Cameron post* [Guardian 2013]

194 *No 10's new energy adviser is a former British Gas lobbyist* [Independent 2013]

195 See http://uk.linkedin.com/in/windsorenergygroup

196 section 4, *Investing in Britain's future* [HM Treasury 2013]

In April 2011, renewable energy minister Nick Boles was removed from his position[197] as renewable energy minister because his brother had a job with Siemens – a large multinational engineering and construction company who have interests in wind farm contracts, and this was perceived to be a conflict of interest. If we consider this case in parallel to the actions of the Chancellor – who has links to the largest fossil fuel interests in the energy sector via his father-in-law, who giving major financial assistance through tax reliefs and regulatory reforms, and on whose behalf he has lobbying for changes in law and policy – there is a clear inconsistency. The actions of the Chancellor, and the connections of his father-in-law to the industry, are also, arguably, a violation of the *Ministerial Code*.

Next let's consider Lord Browne, who is a non-executive minister at the Cabinet Office:

- Lord Browne is a managing director of Riverstone, who still have a major stake in Cuadrilla (Britain's leading shale gas company) as well as other global energy interests.
- Lord Browne is also the Chairman of Cuadrilla.
- It was recently revealed that environment minister Owen Paterson organised a meeting[198] between Lord Browne, chair of the Environment Agency Chris Smith, and other fracking interests in order to set up new regulatory agreements relating to the future roll-out of unconventional gas developments in England.

It would appear that the Government is prepared to countenance a direct conflict of interest that clearly breaches both the *Ministerial Code* and, given the responsibilities of those under him, the *Civil Service Code*. It is incomprehensible that no one has challenged Lord Browne's apparent ability to change his responsibilities within the corridors of power to reflect his public and private interests.

If should be noted that the *Ministerial Code*[199] states that *(my emphasis in bold)* –

> *1.2f. Ministers must ensure that no conflict arises,* ***or appears to arise****, between their public duties and their private interests;*

Note the specific points that it is not required to prove a conflict of interest – *the appearance of such conflicts is a breach of the code*. Ministers, as quasi-judicial decision-makers, must act in a fair and unbiased way – a principle enshrined in both the *Ministerial Code* and the *Civil Service Code*[200]. They are required not only to act impartially, but to be seen to act impartially in the interests of justice.

In 2001, the House of Lords updated the definition of bias in public office with the “Porter test”[201] –

> *The question is whether the fair-minded and informed observer, having considered the facts, would conclude that there was a real possibility that the tribunal was biased.*

Bias on the part of a public body is a serious matter. It infringes the various codes of practice, discussed earlier in this report; and in the worse case it might lead to personal action against those involved for the criminal offence of “misconduct in a public office”[202]. For that reason it is important to be precise both about the claim of bias, and the evidence for that claim –

197 *Minister Nick Boles loses wind farm role because his brother works for turbine firm* [Telegraph 2013]

198 *Owen Paterson held urgent meeting for fracking boss, documents show* [Guardian 2014b]

199 *Ministerial Code* [Cabinet Office 2010]

200 *The Civil Service Code* [CSC 2010]

201 paragraph 103, *Porter v. Magill* [UKHL 2001]

202 *Prosecution Policy and Guidance: 'Misconduct in Public Office'* [CPS 2014]

In my view:

- **In evaluating the evidence reviewed by MacKay and Stone in the formulation of their report, it is not possible to correlate their conclusions to the weight of evidence which exists on this issue. The certainty of "relatively small" risks to the climate from developing unconventional fossil fuels in the UK cannot be proven if we look at the evidence available.**
- **Given the Government's current ideological drive in support of fossil fuels, and against renewable energy sources, there is a suspicion that MacKay and Stone – due to pressure from DECC – did not carry out the study in an impartial manner, and have reached a biased conclusion.**
- **In turn, the support given to the conclusions of the MacKay-Stone report by leading ministers and the Government, combined with the fact that financial interests close to the oil and gas lobby have influence within the Cabinet, leads to the conclusion that Government policy on this matter is biased in favour of those vested interests – in prejudice to the interests of the public.**

As a result – and given the potentially serious implications for the climate, the environment and human health if this policy is forced through – those involved in the promotion of this policy are arguably acting outside the law, and the various codes of conduct which apply to conduct of Government business. Therefore evidence exists to suggest that those involved in the promotion of this policy should be investigated for the offence of 'misconduct in a public office'.

6. Conclusions

It would appear, irrespective of any evidence to the contrary, that the Government believes shale gas development in Britain to be acceptable in terms of its impact upon the climate; and that this position is based upon assumptions, not upon facts.

Building upon the Royal Society/Royal Academy of Engineering review, the MacKay-Stone report makes various assertions about environmental risk, the regulation of environmental pollution, and the safety of the shale gas process. If we look at the evidence available – and in particular at more wide-ranging studies of the environmental risks of oil and gas development – this faith in the low risk of operation, and the way in which regulation can guarantee this, cannot be substantiated. More recent studies have identified significant environmental hazards from these operations.

Before Howarth's June 2011 paper, the climate impacts of natural gas due to fugitive emissions were considered “insignificant”. In the space of just four years, a whole new field of scientific exploration has developed around the issue of climate and fugitive emissions. Reading across the evidence, we find that there is no certainty about climate impacts; but there is much concern about the potential damage which might be caused by the exploitation of unconventional gas. The fact that this was not discussed or explained within the MacKay-Stone report must be considered a serious flaw in that review.

If we examine the methodology behind various studies, we see a divergence depending on whether the case is being made in support of shale gas development or not. Those supporting shale gas use high well recovery rates, long well production lifetimes, and a 100-year baseline for assessing climate impacts. This arguably distorts the true environmental impacts due to the demonstrable fact that: average well production is much lower; well productive lifetimes are far shorter; and, when we consider the short-term nature of how this resource will be developed, the “hump” in emissions will have a clear short-term impact, just at the time we are trying to prevent a peak in emissions that will breach tipping points in the climate system. This divergence in method, and its implications for the results of these studies, has not been clearly explained to the public and decision-makers.

Taken as read, we have to look upon the conclusions of the MacKay-Stone review as misleading because they fail to encapsulate both the high level of uncertainty about these impacts, and the problems which exist within the data upon which these assessments are made. Therefore, we cannot attach any validity to the outcomes of this report, or to the policy decisions which are based, unquestioningly, upon the results of this review.

The Allen report received extensive media coverage on its launch, and the MacKay-Stone report relied upon its findings, in advance of its publication, in order to justify its own claims of the “relatively small” impacts of greenhouse gas emissions. However, when we look deeper into the method and statistical analysis used we find that no such claim can be objectively supported by the Allen paper. It is a small, non-randomised sample of sites selected by the industry. We must also be sceptical of its impartiality because, on publication, the authors failed to identify their links to the oil and gas industry. It is also wholly silent on the issue as to why large inconsistencies exist between instrumental records of fugitive emissions from such sites, and emissions inventory-based assessments – such as the Allen paper. Therefore we cannot give great weight to the evidence provided by the Allen paper, particularly when its method specifically fails to address the contrary findings in many other peer-reviewed studies.

In summary, the MacKay-Stone report represents a two-fold failure. Firstly it is a failure of assessment – as it did not outline the significant uncertainties demonstrated across a wide range of recent research on the impacts of unconventional oil and gas development. In failing to convey these uncertainties when most recent research describes them at great length, and instead concluding that development would have a "relatively small" impact on UK greenhouse gas emissions, we must consider that the report is – whether by design or unintentionally – misleading. Secondly, it represents a failure to protect the public's interests. All Government policies or decisions which rely on this report must be considered flawed in their assumptions, and therefore open to challenge by the public.

In my view the Government's response to the MacKay-Stone report not only fails to test the assumptions in that report; it also demonstrates a lack of understanding of the geophysics of unconventional fossil fuels. The assertions made in the Government's response, coupled with the failures of the MacKay-Stone report, and the Allen study which was also referenced, demonstrate a clear failure of judgement by the Department of Energy and Climate Change – and by extension, by the Government as a whole. Their policy of promoting unconventional fossil fuels appears to be an ideological position, not supported by objective evidence.

It would be possible to write many pages on the flaws in the House of Lords Economic Affairs Committee's (EAC) report – but in this context it would add little to the consideration of the Government's policy on unconventional gas and climate change. That's because, as I've outlined, the EAC's report is poorly compiled, and is so biased in favour of the case for the oil and gas industry, that it has no objective value. In my view this report is so full of errors that it must be disregarded as part of this debate.

If we look at the manner in which the Government has implemented its policies in relation to unconventional fossil fuels, and the scientific advice sought to justify those claims, there are clear gaps between the available body of evidence about these processes, and the statements of ministers and their advisers in promoting policies in support of their use. In my view – and given the serious consequences of this policy for human health, the climate and the environment – these actions mislead the public, and act against the public's interests. As a result of the serious impacts which might ensue, these actions arguably breach the *Civil Service Code*, the *Ministerial Code*, and the *Principles Of Scientific Advice To Government*.

In fact there is currently a very high degree of uncertainty as to the nature and extent of the climate impacts from unconventional oil and gas production – as there are uncertainties in the way the MacKay-Stone report evaluates those risks, both in the assumptions of its modelling, and in the dismissal of research which questions those assumptions. As the MacKay-Stone report makes no attempt to consider the precautionary approach, it stands in defiance to the objectives at the root of Community environmental law. As a result of the Government's failure to make appropriate corrections in their response to that report, those flaws have now been transposed into Government policy. Therefore any decisions made with reference to the MacKay-Stone report must be considered flawed, and open to challenge by the public.

In my view:

- In evaluating the evidence reviewed by MacKay and Stone in the formulation of their report, it is not possible to correlate their conclusions to the weight of evidence which exists on this issue. The certainty of "relatively small" risks to the climate from developing unconventional fossil fuels in the UK cannot be proven if we look at the evidence available at this time.

- Given the Government's current ideological drive in support of fossil fuels, and against renewable energy sources, there is a suspicion that MacKay and Stone – due to pressure from DECC – did not carry out the study in an impartial manner, and have reached a biased conclusion.
- In turn, the support given to the conclusions of the MacKay-Stone report by leading ministers and the Government, combined with the fact that financial interests close to the oil and gas lobby have influence within the Cabinet, leads to the conclusion that Government policy on this matter is biased in favour of those vested interests – in prejudice to the interests of the public.

As a result – and given the serious implications for the climate, the environment and human health if this policy is forced through – those involved in the promotion of this policy are arguably acting outside the law, and the various codes of conduct which apply to conduct of Government business. Therefore evidence exists to suggest that those involved in the promotion of this policy should be investigated for the offence of 'misconduct in a public office'.

In conclusion, the issue of energy and the environment is complex, and is innately linked to the deeper economic values at the heart of society. Arguably the attraction of unconventional fossil fuels is that they offer a means of perpetuating the "normal" business of society, and therefore avoid the need to undertake painful structural changes to the operation of all aspects of society in order to deal with climate change, resource depletion, and environmental damage – and ultimately transition society to a far more stable and sustainable mode of operation.

It may be that those involved believe that they are acting in the public interest. However, given the uncertain evidence upon which they rely to justify this, and their infringement of various rules to perpetuate these policies in the absence of clear evidence, such beliefs cannot be objectively justified. Therefore, in the absence of clear evidence to support their actions, the Government's policies in support of unconventional fossil fuels must be suspended, and alternative options sought. Should that not be the case, then it requires public action to review, and ultimately halt, this misguided project.

7. References

This section lists the references cited in this report. To aid the reading of this report, web links have been provided for most of the sources cited.

Adgate 2014 — *Potential Public Health Hazards, Exposures and Health Effects from Unconventional Natural Gas Development*, John L. Adgate et al., Science of the Total Environment (undated preprint), March 2014 – http://www.fraw.org.uk/files/extreme/adgate_2014.pdf

Allen 2009 — *Warming caused by cumulative carbon emissions towards the trillionth tonne*, Nature, vol.458 pp.1163-1166, 30th April 2009 – http://www.fraw.org.uk/files/climate/allen_2009.pdf

Allen 2013a — *Measurements of methane emissions at natural gas production sites in the United States*, David T. Allen et al., PNAS, 16th September 2013 – http://www.fraw.org.uk/files/extreme/allen_2013.pdf

Allen 2013b — *Measurements of Methane Emissions at Natural Gas Production Sites in the United States: Supporting Information*, David T. Allen et al., 2013 – http://www.fraw.org.uk/files/extreme/allen_sup_2013.pdf

Alvarez 2012 — *Greater focus needed on methane leakage from natural gas infrastructure*, Ramón A. Alvarez, Stephen W. Pacala, James J. Winebrake, William L. Chameides, Steven P. Hamburg, PNAS, vol.109 no.17 pp.6435-6440, 24th April 2012 – http://www.fraw.org.uk/files/extreme/alvarez_2012.pdf

Armendariz 2009 — *Emissions from Natural Gas Production in the Barnett Shale Area and Opportunities for Cost-Effective Improvements*, Al Armendariz, Department of Environmental and Civil Engineering, Southern Methodist University, 26th January 2009 – http://www.fraw.org.uk/files/extreme/armendariz_2009.pdf

BGS 2002 — *Buckingham: Solid and Drift Geology Map* (1: 50 000 Series Geological Maps, England & Wales), Sheet 219, January 2002. ISBN 9780 7518 3043 9.

BGS 2004a — *Mineral Resource Information in Support of National, Regional and Local Planning: Buckinghamshire* (CR/04/62N), British Geological Survey, 2004 –
- report, http://www.bgs.ac.uk/downloads/start.cfm?id=2591
- map, http://www.bgs.ac.uk/downloads/start.cfm?id=2592

BGS 2004b — *Mineral Resource Information in Support of National, Regional and Local Planning: Oxfordshire* (CR/04/62N), British Geological Survey, 2004 –
- report, http://www.bgs.ac.uk/downloads/start.cfm?id=2601
- map, http://www.bgs.ac.uk/downloads/start.cfm?id=2602

BGS 2013 — *Bowland Shale Gas Study*, British Geological Survey/Department of Energy and Climate Change, July 2013 – https://www.gov.uk/government/publications/bowland-shale-gas-study

BGS 2014 — *Weald Basin Jurassic Shale Study*, British Geological Survey/Department of Energy and Climate Change, May 2014 – https://www.gov.uk/government/publications/bgs-weald-basin-jurassic-shale-reports

Bloomberg 2013 — *The economic impact on UK energy policy of shale gas and oil*, Bloomberg New Energy Finance, 30th September 2013 – http://www.fraw.org.uk/files/extreme/bloomberg_2013.pdf

Brandt 2014 — *Methane Leaks from North American Natural Gas Systems*, A.R. Brandt et al., Science, vol.343 pp.733-735, 14th February 2014 – http://www.fraw.org.uk/files/extreme/brandt_2014.pdf

Brown 2010 — *Abundant Shale Gas Resources: Some Implications for Energy Policy,* Stephen P.A. Brown et al., Resources for the Future/National Energy Policy Institute, April 2010 – http://www.fraw.org.uk/files/extreme/brown_2010.pdf

Brufatto 2003 — *From Mud to Cement – Building Gas Wells*, Claudio Brufatto et al., Oilfield Review, vol.15 no.3 pp.62-76, 2003 – http://www.fraw.org.uk/files/extreme/brufatto_2003.pdf

Burnham 2013 — *Updated Fugitive Greenhouse Gas Emissions for Natural Gas Pathways in the GREET Model*, A. Burnham et al., Energy Systems Division, Argonne National Laboratory, October 2013 – https://greet.es.anl.gov/files/ch4-updates-13

Cabinet Office 2010 — *Ministerial Code*, Cabinet Office, May 2010 – https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/61402/ministerial-code-may-2010.pdf

Cathales 2012a — *A commentary on "The greenhouse-gas footprint of natural gas in shale formations" by R.W. Howarth, R. Santoro, and Anthony Ingraffea*, Lawrence M. Cathles III, Larry Brown, Milton Taam, Andrew Hunter, Geochemistry-Geophysics-Geosystems (G3), vol.13 no.6, 3rd January 2012 – http://www.fraw.org.uk/files/extreme/cathales_2011.pdf

Cathales 2012b — *Assessing the greenhouse impact of natural gas*, L. M. Cathles, Geochemistry-Geophysics-Geosystems (G3), vol.13 no.6, 19th June 2012 – http://www.fraw.org.uk/files/extreme/cathales_2012.pdf

Caulton 2014 — *Toward a better understanding and quantification of methane emissions from shale gas development*, Dana R. Caulton et. al., PNAS (early edition), 14th April 2014 – http://www.fraw.org.uk/files/extreme/caulton_2014.pdf

CPS 2014 — *Prosecution Policy and Guidance: 'Misconduct in Public Office'*, Crown Prosecution Service (accessed May 2014) – http://www.cps.gov.uk/legal/l_to_o/misconduct_in_public_office/

CSC 2010 — *The Civil Service Code*, Civil Service Commission, November 2010 – http://www.civilservice.gov.uk/wp-content/uploads/2011/09/civil-service-code-2010.pdf

CSIRO 2008 — *A Comparison Of The Limits To Growth With Thirty Years Of Reality*, Graham Turner, CSIRO, June 2008. http://www.fraw.org.uk/files/limits/csiro_2008.pdf

Davies 2014 — *Oil and gas wells and their integrity: Implications for shale and unconventional resource exploitation*, Richard J. Davieset al., Marine and Petroleum Geology (preprint), March 2014 – http://www.fraw.org.uk/files/extreme/davies_2014.pdf

DCLG 2012 — *National Planning Policy Framework*, Department for Communities and Local Government, March 2012 – https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/6077/2116950.pdf

DCLG 2013 — *Planning practice guidance for onshore oil and gas*, Department for Communities and Local Government, July 2013 – https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/224238/Planning_practice_guidance_for_onshore_oil_and_gas.pdf

DECC 2011 — *The Hydrocarbon Prospectivity of Britain's Onshore Basins*, British Geological Survey/Department for Energy and Climate Change, October 2010 – http://www.fraw.org.uk/files/extreme/decc_onshore_2011.pdf

DECC 2012 — *The Unconventional Hydrocarbon Resources of Britain's Onshore Basins: Shale Gas*, British Geological Survey/Department for Energy and Climate Change, December 2012 – http://www.fraw.org.uk/files/extreme/decc_shale_2012.pdf

DECC 2013a — *Strategic Environmental Assessment for Further Onshore Oil and Gas Licensing: Environmental Report*, Department of Energy and Climate Change, 2013 – https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/273997/DECC_SEA_Environmental_Report.pdf

DECC 2013b — *Edward Davey today made the case for the safe and responsible exploration of shale gas in the UK, in line with UK's climate change targets*, DECC, 9th September 2013 – https://www.gov.uk/government/news/davey-uk-shale-gas-development-will-not-be-at-expense-of-climate-change-targets

DECC 2013c — *Regulatory Roadmap: Onshore oil and gas exploration in the UK regulation and best practice*, Department of Energy and Climate Change, 17th December 2013 – https://www.gov.uk/government/publications/regulatory-roadmap-onshore-oil-and-gas-exploration-in-the-uk-regulation-and-best-practice

DECC 2013d — *About shale gas and hydraulic fracturing (fracking)*, Department of Energy and Climate Change, 30th July 2013 – http://www.fraw.org.uk/files/extreme/decc_2013.pdf

DECC 2013e — *Onshore oil and gas exploration in the UK: regulation and best practice – England*, Department of Energy and Climate Change, December 2013 – https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/265988/Onshore_UK_oil_and_gas_exploration_England_Dec13_contents.pdf

DECC 2014 — *The Government's response to the MacKay-Stone report: Potential greenhouse gas emissions associated with shale gas extraction and use*, Department of Energy and Climate Change, 24th April 2014 – https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/305811/140424_MacKay_Stone_Response_.pdf

Deutsche Bank 2011 — *European Gas: A First Look At EU Shale-Gas Prospects*, David Folkerts-Landau, Deutsche Bank, 20th October 2011 – http://www.fraw.org.uk/files/extreme/deutsche_bank_2011.pdf

Directive 2001/42/EC — *The Assessment of the Effects of Certain Plans and Programmes on the Environment*, European Parliament and Council, 27th June 2001. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32001L0042

Dusseault 2000 — *Why Oilwells Leak: Cement Behavior and Long-Term Consequences*, Maurice B. Dusseault et al., Society of Petroleum Engineers International Oil and Gas Conference, November 2000 – http://www.fraw.org.uk/files/extreme/spe_2000.pdf

EAC 2014a — *The Economic Impact on UK Energy Policy of Shale Gas and Oil*, 3rd Report of Session 2013-14 (HL172), Lords Economic Affairs Committee, 8th May 2014 – http://www.publications.parliament.uk/pa/ld201314/ldselect/ldeconaf/172/172.pdf

EAC 2014b — *The Economic Impact on UK Energy Policy of Shale Gas and Oil: Oral and Written Evidence* , 3rd Report of Session 2013-14 (HL172), Lords Economic Affairs Committee, 8th May 2014 – http://www.parliament.uk/documents/lords-committees/economic-affairs/EnergyPolicy/EAC-energy-ev-vol.pdf

ECC 2014 — *Carbon capture and storage* , Ninth Report of Session 2013–14 (HC742), Commons Energy and Climate Change Committee, 21st May 2014 – http://www.publications.parliament.uk/pa/cm201314/cmselect/cmenergy/742/742.pdf

EDF 2013 — *First academic study released in EDF's groundbreaking methane emissions series*, Environmental Defense Fund, 16th September 2013 – http://www.edf.org/media/first-academic-study-released-edf%E2%80%99s-groundbreaking-methane-emissions-series

EU 2007 — Article 191, *The Treaty of Lisbon* – http://www.lisbon-treaty.org/wcm/the-lisbon-treaty/treaty-on-the-functioning-of-the-european-union-and-comments/part-3-union-policies-and-internal-actions/title-xx-environment-climate-change/479-article-191.html

Ferrar 2013 — *Assessment of Effluent Contaminants from Three Facilities Discharging Marcellus Shale Wastewater to Surface Waters in Pennsylvania*, Kyle J. Ferrar et al., 4th March 2013 – http://www.fraw.org.uk/files/extreme/ferrar_michanowicz_2013.pdf

Glancy 2013 — *Quantifying Fugitive Emission Factors from Unconventional Natural Gas Production Using IPCC Methodologies*, R.P. Glancy, IGES, 2013 – http://www.fraw.org.uk/files/extreme/glancy_2013.pdf

GOS 2010 — *Principles of scientific advice to government*, Government Office for Science, 24th March 2010 – https://www.gov.uk/government/publications/scientific-advice-to-government-principles/principles-of-scientific-advice-to-government

Guardian 2013 — *Key climate change adviser resigns from Cameron post*, Fiona Harvey, Guardian On-line, Friday 10th May 2013 – http://www.theguardian.com/environment/2013/may/10/climate-change-adviser-resigns-cameron

Guardian 2014a — *UK defeats European bid for fracking regulations*, Damian Carrington, Guardian On-line, Tuesday 14th January 2014 – http://www.theguardian.com/environment/2014/jan/14/uk-defeats-european-bid-fracking-regulations

Guardian 2014b	*Owen Paterson held urgent meeting for fracking boss, documents show*, Damian Carrington, Guardian On-line, Friday 21st March 2014 – http://www.theguardian.com/environment/2014/mar/21/owen-paterson-urgent-meeting-fracking-cuadrilla-lord-browne
Hall 2006	*The Need for a New, Biophysical-Based Paradigm in Economics for the Second Half of the Age of Oil*, Charles A.S. Hall, Kent A. Klitgaard, International Journal of Transdisciplinary Research, vol.1 no.1 pp.4-22, 2006. http://www.fraw.org.uk/files/peakoil/hall_klitgaard_2006.pdf
Hansard 2014a	*Energy: Fracking – Question for Short Debate*, col. GC42, House of Lords debate, Hansard, 17th March 2014 – http://www.publications.parliament.uk/pa/ld201314/ldhansrd/text/140317-gc0001.htm
Hansard 2014b	*Climate Change: Question*, col. 1757, House of Lords, Hansard, 13th May 2014 – http://www.publications.parliament.uk/pa/ld201314/ldhansrd/text/140513-0001.htm
Hansen 2013	*Climate forcing growth rates: doubling down on our Faustian bargain*, James Hansen, Pushker Kharecha, Makiko Sato, Environmental Research Letters, vol.8 no.1 id.011006, March 2013 – http://www.fraw.org.uk/files/climate/hansen_2013.pdf
HM Treasury 2013	*Investing in Britain's future*, Cm8669, HM Treasury, June 2013 – http://www.fraw.org.uk/files/ukgov/hm_treasury_2013.pdf
Howarth 2011	*Methane and the greenhouse-gas footprint of natural gas from shale formations*, Robert W. Howarth et al., Climatic Change, vol.106 no.4 pp.679-690, June 2011 – http://www.fraw.org.uk/files/extreme/howarth_2011.pdf
Howarth 2012a	*Venting and Leaking of Methane from Shale Gas Development: Response to Cathles et al.*, Robert W. Howarth et al., Climatic Change, vol.113 no.2 pp.537-549, July 2012 – http://www.fraw.org.uk/files/extreme/howarth_2012.pdf
Howarth 2012b	*Venting and Leaking of Methane from Shale Gas Development: Response to Cathles et al. – Electronic Supplemental Materials*, Robert W. Howarth et al., Cornell University, January 2012 – http://www.fraw.org.uk/files/extreme/howarth_supp_2012.pdf
Howarth 2014	A bridge to nowhere: methane emissions and the greenhouse gas footprint of natural gas, Robert W. Howarth, Energy Science and Engineering, 15th May 2014 – http://www.fraw.org.uk/files/extreme/howarth_2014.pdf
Hughes 2011	*Life Cycle Greenhouse Gas Emissions from Shale Gas Compared to Coal: An Analysis of Two Conflicting Studies*, David Hughes, Post Carbon Institute, 30th June 2011 – http://www.fraw.org.uk/files/extreme/hughes_2011.pdf
Hughes 2013a	*Drill Baby Drill : Can Unconventional Fuels Usher in a New Era of Energy Abundance*, David Hughes, Post Carbon Institute, February 2013 – http://www.postcarbon.org/drill-baby-drill/
Hughes 2013b	*A reality check on the shale revolution*, J. David Hughes, Nature, vol.494 pp.307-308, 21st February 2013 – http://www.fraw.org.uk/files/extreme/hughes_2013.pdf

Hultman 2011 — The greenhouse impact of unconventional gas for electricity generation, Nathan Hultman et al., Environmental Research Letters, vol.6, 25th October 2011 – http://www.fraw.org.uk/files/extreme/hultman_2011.pdf

IDDRI 2014 — *Unconventional wisdom: An economic analysis of US shale gas and implications for the EU*, Thomas Spencer, Oliver Sartor, Mathilde Mathieu, Institut du Dévelopement Durable et des Relations Internationales, February 2014 – http://www.fraw.org.uk/files/extreme/iddri_2014.pdf

Independent 2013 — *No 10's new energy adviser is a former British Gas lobbyist*, Tom Bawden , Independent On-line, Thursday 23rd May 2013 – http://www.independent.co.uk/news/uk/politics/no-10s-new-energy-adviser-is-a-former-british-gas-lobbyist-8630040.html

Ingraffea 2013 — *Fluid Migration Mechanisms Due To Faulty Well Design And/Or Construction: An Overview And Recent Experiences In The Pennsylvania Marcellus Play*, Anthony R. Ingraffea, Physicians Scientists & Engineers for Healthy Energy, January 2013 – http://www.fraw.org.uk/files/extreme/ingraffea_2013.pdf

IPCC 2013 — *Climate Change 2013: The Physical Science Basis*, Assessment Report 5, Working Group I, Intergovernmental Panel on Climate Change, 2013 – https://www.ipcc.ch/report/ar5/wg1/

IPCC 2014 — *Climate Change 2014: Mitigation of Climate Change*, Assessment Report 5, Working Group III, Intergovernmental Panel on Climate Change, April 2014 – http://report.mitigation2014.org/drafts/final-draft-postplenary/ipcc_wg3_ar5_final-draft_postplenary_chapter7.pdf

Jackson 2013 — *Increased stray gas abundance in a subset of drinking water wells near Marcellus shale gas extraction*, Robert B. Jackson et al., PNAS, vol.110 no.28 pp.11250-11255, 24th June 2013 – http://www.fraw.org.uk/files/extreme/jackson_2013.pdf

Jacquet 2014 — *Review of Risks to Communities from Shale Energy Development*, Jeffrey B. Jacquet, Environmental Science and Technology (preprint), 13th March 2014 - http://www.fraw.org.uk/files/extreme/jacquet_2014.pdf

Jiang 2011 — *Life cycle greenhouse gas emissions of Marcellus shale gas*, Mohan Jiang et al., Environmental Research Letters, vol.6 no.034014, 5th August 2011 – http://www.fraw.org.uk/files/extreme/jiang_2011.pdf

Karion 2013 — *Methane emissions estimate from airborne measurements over a western United States natural gas field*, Anna Karion et al., Ceres, 27th August 2013 – http://www.fraw.org.uk/files/extreme/karion_2013.pdf

Kerschner 2013 — *Economic vulnerability to Peak Oil*, Christian Kerschner, Christina Prell, Kuishuang Feng, Klaus Hubacek, Global Environmental Change, 13th October 2013 - http://www.fraw.org.uk/files/peakoil/kerschner_2013.pdf

Lacazette 2013 — *Comment on Davies et al 2012 – Hydraulic Fractures: How far can they go?*, Alfred Lacazette, Peter Geiser, Marine and Petroleum Geology, vol.43 pp.516.518, May 2013 – http://www.refine.org.uk/media/4889/comment_on_hyd._fractures.pdf

Laurenzi 2013 — *Life Cycle Greenhouse Gas Emissions and Freshwater Consumption of Marcellus Shale Gas*, Ian J. Laurenzi, Gilbert R. Jersey, Environmental Science and Technology, vol.47 no.9 pp.4896-4903, 7th May 2013 – http://www.fraw.org.uk/files/extreme/laurenzi_2013.pdf

Lenton 2011 — *Early warning of climate tipping points*, Timothy M. Lenton, Nature Climate Change, vol.1 pp.201-209, July 2011 – http://www.fraw.org.uk/files/climate/lenton_2011.pdf

MacKay 2013 — *Potential Greenhouse Gas Emissions Associated with Shale Gas Extraction and Use*, David J.C, MacKay, Timothy J. Stone, Department of Energy and Climate Change, 9th September 2013 – http://www.fraw.org.uk/files/extreme/decc_2013-2.pdf

Meinshausen 2009 — *Greenhouse-gas emission targets for limiting global warming to 2C*, Nature, vol.458 pp.1158-1162, 30th April 2009 – http://www.fraw.org.uk/files/climate/meinshausen_2009.pdf

Miller 2013 — *Anthropogenic emissions of methane in the United States*, Scot M. Miller, et al., PNAS, 18th October 2013 – http://www.fraw.org.uk/files/climate/miller_2013.pdf

Mobbs 2014 — *A critical review of Public Health England's report, "Review of the Potential Public Health Impacts of Exposures to Chemical and Radioactive Pollutants as a Result of Shale Gas Extraction – draft for comment"*, Paul Mobbs, Mobbs' Environmental Investigations, April 2014 – http://www.fraw.org.uk/mei/archive/phe_shale_gas_and_health_report-critical_analysis.pdf

Moore 2014 — *Air Impacts of Increased Natural Gas Acquisition, Processing, and Use: A Critical Review*, Christopher W. Moore et. al., Science of the Total Environment (undated preprint), March 2014 – http://www.fraw.org.uk/files/extreme/moore_2014.pdf

Myers 2012 — *Potential Contaminant Pathways from Hydraulically Fractured Shale to Aquifers*, Tom Myers, Groundwater, vol.50 no.6 pp.872-882, 17th April 2012 – http://www.fraw.org.uk/files/extreme/myers_2012.pdf

Myhrvold 2012 — *Greenhouse gases, climate change and the transition from coal to low-carbon electricity*, N.P. Myhrvold and K. Caldeira, Environmental Research Letters, 16th February 2012 – http://www.fraw.org.uk/files/climate/myrhvold_2012.pdf

Newell 2014 — *Implications of Shale Gas Development for Climate Change* , Richard G. Newell, Daniel Raimi, Environmental Science and Technology (preprint), 22nd April 2014 – http://www.fraw.org.uk/files/extreme/newell_2014.pdf

New York 2009 — *Draft Supplemental Generic Environmental Impact Statement (SGEIS) on the Oil, Gas and Solution Mining Regulatory Program*, New York State Department of Environmental Conservation, September 2009 – ftp://ftp.dec.state.ny.us/dmn/download/OGdSGEISFull.pdf

NOAA 2014 — *Shale Oil and Natural Gas Nexus: Studying the Atmospheric Effects of Changing Energy Use in the U.S. at the Nexus of Air Quality and Climate Change*, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, April 2014 – http://www.esrl.noaa.gov/csd/projects/songnex/whitepaper.pdf

NYT 2013 — *Climate Change: Two Climate Analysts Fault Gas Leaks, but Not as a Big Warming Threat*, Andrew C. Revkin, New York Times blog, 1st August 2013 – http://dotearth.blogs.nytimes.com/2013/08/01/two-climate-analysts-fault-gas-leaks-but-not-as-a-big-warming-threat

O'Sullivan 2012a — *Shale gas production: potential versus actual greenhouse gas emissions*, Francis O'Sullivan, Sergey Paltsev, Environmental Research Letters, vol.7, 26th November 2012 – http://www.fraw.org.uk/files/extreme/osullivan_paltsev_2012.pdf

O'Sullivan 2012b — *Shale Gas Production: Potential versus Actual GHG Emissions*, Francis O'Sullivan, Sergey Paltsev, MIT Joint Program on the Science and Policy of Global Change, November 2012 – http://www.fraw.org.uk/files/extreme/osullivan_paltsev_rpt234_2012.pdf

O'Sullivan 2012c — *Shale gas production: potential versus actual greenhouse gas emissions – supplementary electronic data*, Francis O'Sullivan, Sergey Paltsev, Environmental Research Letters, November 2012 – http://iopscience.iop.org/1748-9326/7/4/044030/media/erl437454suppdata.pdf

OIES 2014 — *US shale gas and tight oil industry performance: challenges and opportunities*, Ivan Sandrea, OIES Research Associate, Oxford Institute for Energy Studies, March 2014 – http://www.fraw.org.uk/files/extreme/oies_2014.pdf

Pétron 2012 — *Hydrocarbon emissions characterization in the Colorado Front Range: A pilot study*, Gabrielle Pétron et al., Journal Of Geophysical Research, vol.117 no.D4, 27th February 2012 – http://www.fraw.org.uk/files/extreme/petron_2012.pdf

Peischl 2013 — *Quantifying sources of methane using light alkanes in the Los Angeles basin, California*, J. Peischl et al., Journal of Geophysical Research: Atmospheres, vol.118 no.10 pp.4974-4990, 27th May 2013 – http://www.fraw.org.uk/files/extreme/pieschl_2013.pdf

PHE 2013 — *Review of the Potential Public Health Impacts of Exposures to Chemical and Radioactive Pollutants as a Result of Shale Gas Extraction*, A. Kibble et. al, Centre for Radiation, Chemical and Environmental Hazards, Public Health England, October 2013 – http://www.fraw.org.uk/files/extreme/phe_2013.pdf

Queensland 2010 — *Investigation report: Leakage testing of coal seam gas wells in the Tara 'rural residential estates' vicinity*, Department of Employment, Economic Development and Innovation, State of Queensland, 1st June 2010 – http://www.fraw.org.uk/files/extreme/queensland_2010.pdf

Rogers 2013 — *Shale And Wall Street: Was The Decline In Natural Gas Prices Orchestrated?*, Deborah Rogers, Energy Policy Forum, February 2013 – http://www.fraw.org.uk/files/extreme/rogers_2013.pdf

Weitzman 2008 — *On Modeling and Interpreting the Economics of Catastrophic Climate Change*, Martin L. Weitzman, REStat, 6th May 2008 – http://www.fraw.org.uk/files/climate/weitzman_2008.pdf

RoyalSoc 2012 — *Shale gas extraction in the UK: A review of hydraulic fracturing*, Royal Society/Royal Academy of Engineering, June 2012 – http://www.fraw.org.uk/files/extreme/rs_rae_2012.pdf

Santoro 2011 — *Indirect Emissions of Carbon Dioxide from Marcellus Shale Gas Development*, Renee L. Santoro et al., Agriculture, Energy & Environmental Program, Cornell University, 30th June 2011 – http://www.fraw.org.uk/files/extreme/santoro_2011.pdf

Selley 2012 — *UK shale gas: The story so far*, Richard C. Selley, Marine and Petroleum Geology, vol.1 no.1 pp.100-109, March 2012 – http://www.fraw.org.uk/files/extreme/selley_2012.pdf

Skone 2011 — *Life Cycle Greenhouse Gas Inventory of natural Gas Extraction, Delivery and Electricity Production*, Timothy J.Skone, Office of Strategic Energy Analysis and Planning , US Department of Energy, 24th October 2011 – http://cce.cornell.edu/energyclimatechange/naturalgasdev/documents/pdfs/skone_ng_lc_ghg_profile_cornell_12may11_final.pdf

Sy 2012 — *Evaluation of the CO2 Leakage Risk Along the Abandoned Wells in the French Context*, S. Sy et al., Energy Procedia, vol.23 pp.480-486, 2012 – http://www.fraw.org.uk/files/extreme/sy_2012.pdf

Telegraph 2013 — *Minister Nick Boles loses wind farm role because his brother works for turbine firm*, Christopher Hope and Rowena Mason, Telegraph On-line, 1st August 2013 – http://www.telegraph.co.uk/earth/energy/windpower/10217727/Minister-Nick-Boles-loses-wind-farm-role-because-his-brother-works-for-turbine-firm.html

Tollefson 2012 — *Air sampling reveals high emissions from gas field*, Jeff Tollefson, Nature, vol.482 pp.139-140, 9th February 2012 – http://www.fraw.org.uk/files/extreme/tollefson_2012.pdf

Tyndall 2011a — *Shale gas: A provisional assessment of climate change and environmental impacts*, Tyndall Centre Manchester, January 2011 – http://www.fraw.org.uk/files/extreme/tyndall_coop_2011-1.pdf

Tyndall 2011b — *Shale gas: An updated assessment of environmental and climate change impacts*, Tyndall Centre Manchester, The Co-operative, November 2011 – http://www.fraw.org.uk/files/extreme/tyndall_coop_2011-2.pdf

Tyndall 2012 — *Has US Shale Gas Reduced CO2 Emissions?: Examining recent changes in emissions from the US power sector and traded fossil fuels*, Tyndall Centre Manchester, October 2012 – http://www.fraw.org.uk/files/extreme/tyndall_coop_2012.pdf

UKSDS 2005 — *Securing The Future: Delivering UK Sustainable Development Strategy*, Cm6467, March 2005 – https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69412/pb10589-securing-the-future-050307.pdf

USEPA 2011 — *Inventory Of U.S. Greenhouse Gas Emissions And Sinks: 1990-2009* (EPA 430-R-11-005), U.S. Environmental Protection Agency, 15th April 2011 – http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2011-Complete_Report.pdf

USEPA 2014 — *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2012* (EPA 430-R-14-003), U.S. Environmental Protection Agency, 15th April 2014 – http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2014-Main-Text.pdf

USGS 2012 — *Variability of Distributions of Well-Scale Estimated Ultimate Recovery for Continuous (Unconventional) Oil and Gas Resources in the United States*, Open-File Report 2012–1118, U.S. Geological Survey, U.S. Department of the Interior, June 2012 – http://www.fraw.org.uk/files/extreme/usgs_eur_2012.pdf

Vengosh 2013 — *The effects of shale gas exploration and hydraulic fracturing on the quality of water resources in the United States*, Avner Vengosh et. al., Procedia Earth and Planetary Science, vol.7 pp.863-866, June 2013 – http://www.fraw.org.uk/files/extreme/vengosh_2013.pdf

Vengosh 2014 — *A Critical Review of the Risks to Water Resources from Unconventional Shale Gas Development and Hydraulic Fracturing in the United States*, Avner Vengosh et al., Environmental Science and Technology (preprint), 7th March 2014 – http://www.fraw.org.uk/files/extreme/vengosh_2014.pdf

Vidic 2013 — *Impact of Shale Gas Development on Regional Water Quality*, R.D. Vidic et al., Science, vol.340 item 1235009, 17th May 2013 – http://www.fraw.org.uk/files/extreme/vidic_2013.pdf

Wackernagel 2002 — *Tracking the ecological overshoot of the human economy*, Mathis Wackernagel et al., PNAS, vol.99 no.14 pp.9266-9271, 9th July 2002 – http://www.fraw.org.uk/files/limits/wackernagel_2002.pdf

Warner 2013 — *Impacts of Shale Gas Wastewater Disposal on Water Quality in Western Pennsylvania*, Nathaniel R. Warner et al., Environmental Science and Technology, vol.47 no.20 pp.11849-11857, 2nd October 2013 – http://www.fraw.org.uk/files/extreme/warner_2013.pdf

Weber 2012 — *Life Cycle Carbon Footprint of Shale Gas: Review of Evidence and Implications*, Christopher L. Weber, Christopher Clavin, Environmental Science and Technology, 30th April 2012 – http://www.fraw.org.uk/files/extreme/weber_2012.pdf

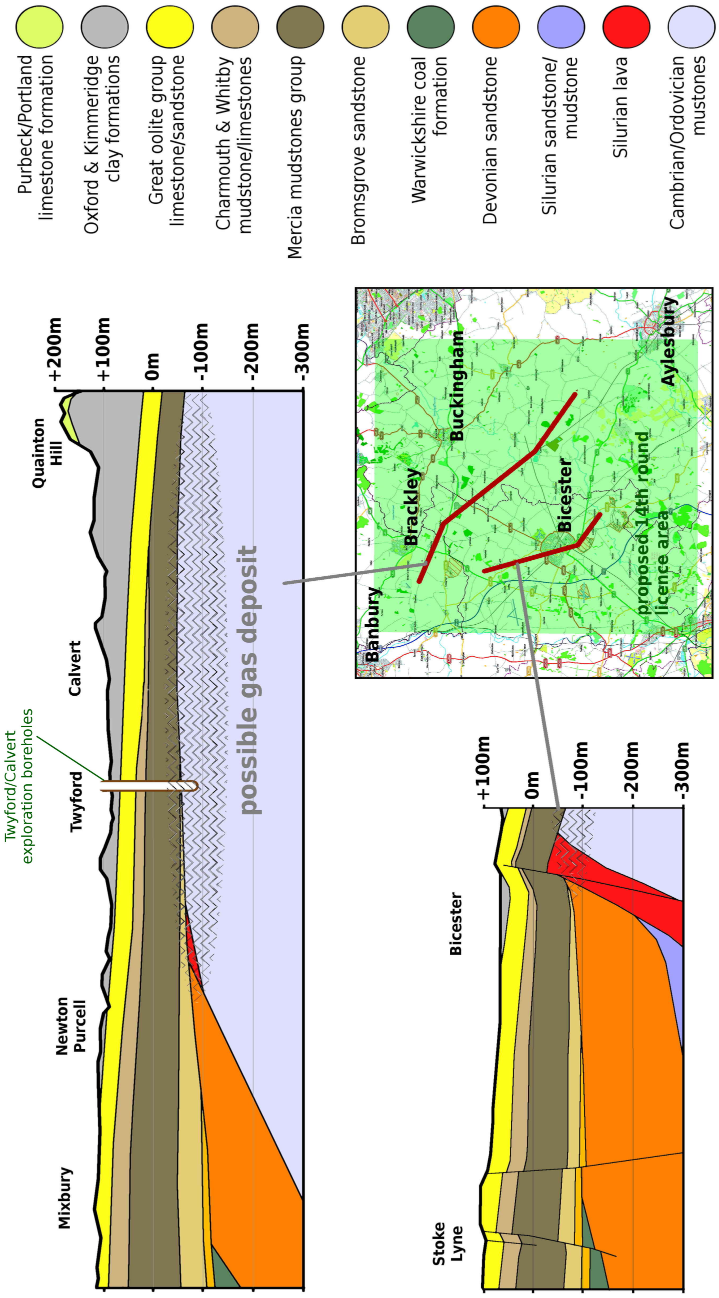
Wigley 2011 — *Coal to gas: the influence of methane leakage*, Tom M. L. Wigley, Climatic Change, vol.108 pp.601-608, 26th August 2011 – http://www.fraw.org.uk/files/extreme/wigley_2011.pdf

Witter 2008 — *Potential Exposure-Related Human Health Effects of Oil and Gas Development: A White Paper*, Roxana Witter et al., Colorado School of Public Health, 15th September 2008 – http://www.fraw.org.uk/files/extreme/witter_2008.pdf

8. Appendices

8A. Geological section of the proposed licence area in Oxfordshire/Buckinghamshire

The following geological section was created from the British Geological Survey's published mapping and memoir for sheet 219, *Buckingham*. Further discussions of the unconventional gas potential of this area are also available in other references cited in this report[203].



203 For further information on the unconventional gas potential of this area see:
Mineral Resource Information in Support of National, Regional and Local Planning : Buckinghamshire [BGS 2004a]
Mineral Resource Information in Support of National, Regional and Local Planning : Oxfordshire [BGS 2004b]
Buckingham: Solid and Drift Geology Map [BGS 2002]
The Hydrocarbon Prospectivity of Britain's Onshore Basins [DECC 2011]
The Unconventional Hydrocarbon Resources of Britain's Onshore Basins: Shale Gas [DECC 2012]
UK shale gas: The story so far [Selley 2012]

8B. An evaluation of the MacKay-Stone emissions model

The spreadsheet model presented in the MacKay-Stone report was not made available – nor were any worked examples provided, merely the results. In order to evaluate the model an attempt was made to replicate the model from the description provided in the text of their report.

The essence of the model is the computation of fugitive emissions from well drilling. This figure for emissions is then divided by the quantity of gas produced in order to produce a figure for emissions per unit of natural gas produced – to allow comparison with other energy sources. The data in the MacKay-Stone report were replicated by deriving the following equation from the text –

$$E_{gas}(x,y) = \frac{[\, E_{sp} + E_{df} + E_c + E_{ww} + (\, W_{wo} \times E_{wc} \times A(y)\,)\,] + [\, EUR(x) \times E_p \,]}{[\, EUR(x) \times (\, G_{vr} \div G_{vp}\,) \times G_{cv} \times V_{cf} \times N\,] \div M_{cf}}$$

where:

- $A(y)$ = emissions abatement factor for assumption 'y',
- E_c = fracturing chemicals manufacturing emissions, 300 tCO_2e per well,
- E_{df} = drilling and fracturing emissions, tCO_2e per well,
- $E_{gas}(x)$ = equivalent CO_2 emissions per unit of gas, gCO_2e/kW-h(th) for scenario 'x',
- E_p = gas processing emissions, tCO_2e per lifetime well production = 100tCO_2e/Mm^3,
- E_{sp} = site preparation emissions, tCO_2e per well,
- E_{wc} = well completion emissions, tCO_2e per well,
- E_{ww} = water and wastewater transport and treatment emissions, 21 tCO_2e per well,
- $EUR(x)$ = estimated ultimate recovery for well over lifetime, Mm^3, for scenario 'x' *(note, to convert billion cubic feet to million cubic metres multiply bcf figure by 28.3)*,
- G_{cv} = methane calorific value, $40MJ/m^3 \div 3.6MJ/kW\text{-}h = 11.1\ kW\text{-}h/m^3$,
- G_{vp} = proportion of methane in produced gas = 100%,
- G_{vr} = proportion of methane in raw gas = 86%,
- M_{cf} = mass conversion factor, tCO_2 to gCO_2 = 1×10^6,
- N = 'unknown' correction factor = 1.21,
- V_{cf} = gas volume conversion factor, m^3 to Mm^3 = 1×10^6,
- W_{wo} = number of well fracturing plus work-over operations = 2.

The values for the variables not listed can be sourced from the text of the MacKay-Stone report:

- *E_{sp}, site preparation emissions –*
  The site preparation emissions were derived from three studies, listed in Table A1 of the report. To obtain the values in the MacKay-Stone report the range figures from the Jiang study must both be entered. Therefore the array of site preparation emissions values upon which to calculate the mean, median and percentile values is (300, 360, 158, 15).

- *E_{df}, drilling and fracturing emissions –*
  The values for drilling and fracturing are obtained from five studies, listed in Table A2 of the report. Again, where the study presents a range of values, the maximum and minimum are enters as two figures. Therefore the array of drilling and fracturing emissions values upon which to calculate the mean, median and percentile values is (840, 1790, 1426, 711, 344, 369, 656).

- *E_{WC}, well completion –*
  The data for well completion is listed in Table A3 of the report. Note that in the MacKay-Stone review, the scenarios chosen either include or exclude the 102,000 tCO_2e/well figure from Howarth's study. Therefore the array of drilling and fracturing emissions values upon which to calculate the mean, median and percentile values is (9100, 3900, 18000, 4100, 4400, 6100, 7300, 5600, 102000).
- *EUR(x), estimated ultimate recovery –*
  The MacKay-Stone review uses three separate scenarios for the life-time gas production from a well, based upon different 'estimated ultimate recovery' (EUR) values – *high*, 5bcf; *central*, 3bcf; and *low*, 2bcf.
- *A(y)*, emissions abatement factor –
  To apply differing levels of emissions abatement, factors were calculated representing the different assumptions about reductions in fugitive/methane emissions. These are:
  - 100% vented = 1,
  - 90% captured/flared = 0.239,
  - 90% captured/injected = 0.2,
  - 100% captured/injected = 0.

Using a LibreOffice spreadsheet[204], the results produced under the various scenarios presented in the MacKay-Stone report were replicated almost precisely. Once the spreadsheet model was validated against the results of the MacKay-Stone report, different values could be used to assess the sensitivity of the model to certain assumptions:

- What the creation of this model immediately threw up was an unknown factor – 'N' (value, 1.21) – which was required in order to create the same data output. It is not clear from the text of the report what this value represents. It is an issue because, by multiplying the energy produced by this figure, it diminishes the value of the emissions per unit of gas produced by around 20%.
- The selection of the 'estimated ultimate recovery' (EUR) figure has a significant effect on the output values from the model – which is significant due to the arguably high EUR figures selected for use in the original MacKay-Stone model. For example, halving the EUR to a more reasonable 0.9-1.9bcf increases the emissions per unit of gas by between 200% (captured/flared) and 350% (100% vented).
- The model is most sensitive to changes in 'well completion' emissions – other factors, such as the emissions from gas processing or drilling/fracking, have a lower impact upon results.

In order to provide another viewpoint, an 'alternate assumptions' model was created which:

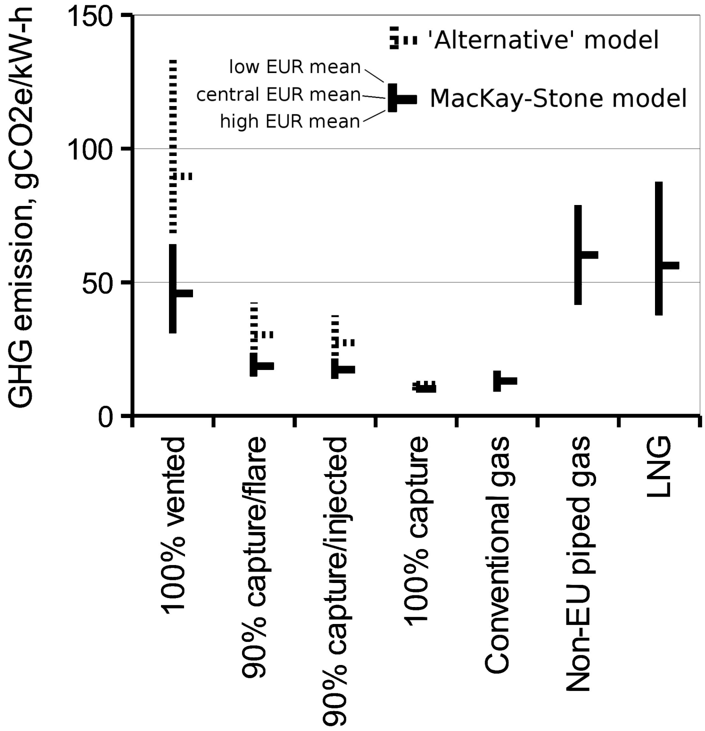
- Used a value for the EUR nearer to recent USGS research[205] – a 'low' case of 0.9bcf, 'central' of 1.4bcf, and a 'high' of 1.9bcf;

204 A copy of the spreadsheet model – in the original LibreOffice format and as an exported 'XLSX' Excel file format – is available from the 'work archive' of my web site – http://www.fraw.org.uk/mei/archive/mackay_stone_shale_gas_review_spreadsheet.ods http://www.fraw.org.uk/mei/archive/mackay_stone_shale_gas_review_spreadsheet.xlsx

205 *Variability of Distributions of Well-Scale Estimated Ultimate Recovery for Continuous (Unconventional) Oil and Gas Resources in the United States* [USGS 2012]

- Relied on the 'including Howarth' options – because recent studies which have shown large deviations between inventory assessment and instrumental measurements lend support to the results of Howarth's original study[206];
- Excluded the NYS DEC figure for site preparation due to the fact that it only represented rig transport – although this made a negligible difference to the model output; and,
- In the absence of information on its role/function, the 'N' value used in the original model was retained to make the new model compatible with MacKay-Stone's model – even though it arguably reduced emissions by 20%.

To illustrate the difference this makes to the output, the following graph replicates figure 4 of the MacKay-Stone report.



One of the difficulties of the MacKay-Stone model is that it does not specify the proportions of captured and flared/injected emissions which enter the environment as methane or carbon dioxide. It should also be noted that there are other significant sources of flared hydrocarbons – such as the gas liquids produced during well-head and compressor station gas processing.

As a result it has not been possible to perform a wholesale recalculation of the MacKay-Stone model with a 20-year global warming potential. Nor are values provided for the 20-year impact LNG and piped gas supplies.

However, if we assumed:

- a blanket increase in emissions of 250% relative to the 100-year baseline; then
- add 190gCO_2e/kW-h to represent the carbon produced when the gas is burnt; and
- multiply by 2.22 to represent a combined-cycle gas turbine generation efficiency of 45% –

then the figure for MacKay and Stone's "captured and flared, maximum, central EUR, plus Howarth" scenario of 62gCO_2e/kW-h becomes 766gCO_2e/kW-h. Using same scenario for the 'alternative model', the figure of 120gCO_2e/kW-h becomes 1,087gCO_2e/kW-h. This is comparable to the figures for coal generation used in the MacKay-Stone report – 837gCO_2e/kW-h to 1,130gCO_2e/kW-h.

What these results suggest is that the assumptions in the model are sensitive both to accurate information about the level of fugitive emissions, but that the selection of the EUR for the model is also significant. Given that – especially in relation to our current knowledge of US operations – both of these factors are uncertain, this suggests that the confidence we can have in accurately modelling the impact of shale gas emissions is low.

206 *A bridge to nowhere: methane emissions and the greenhouse gas footprint of natural gas* [Howarth 2014]