NAEI Briefing Note: Shale Gas Exploration and Production and impacts on the UK GHG Inventory

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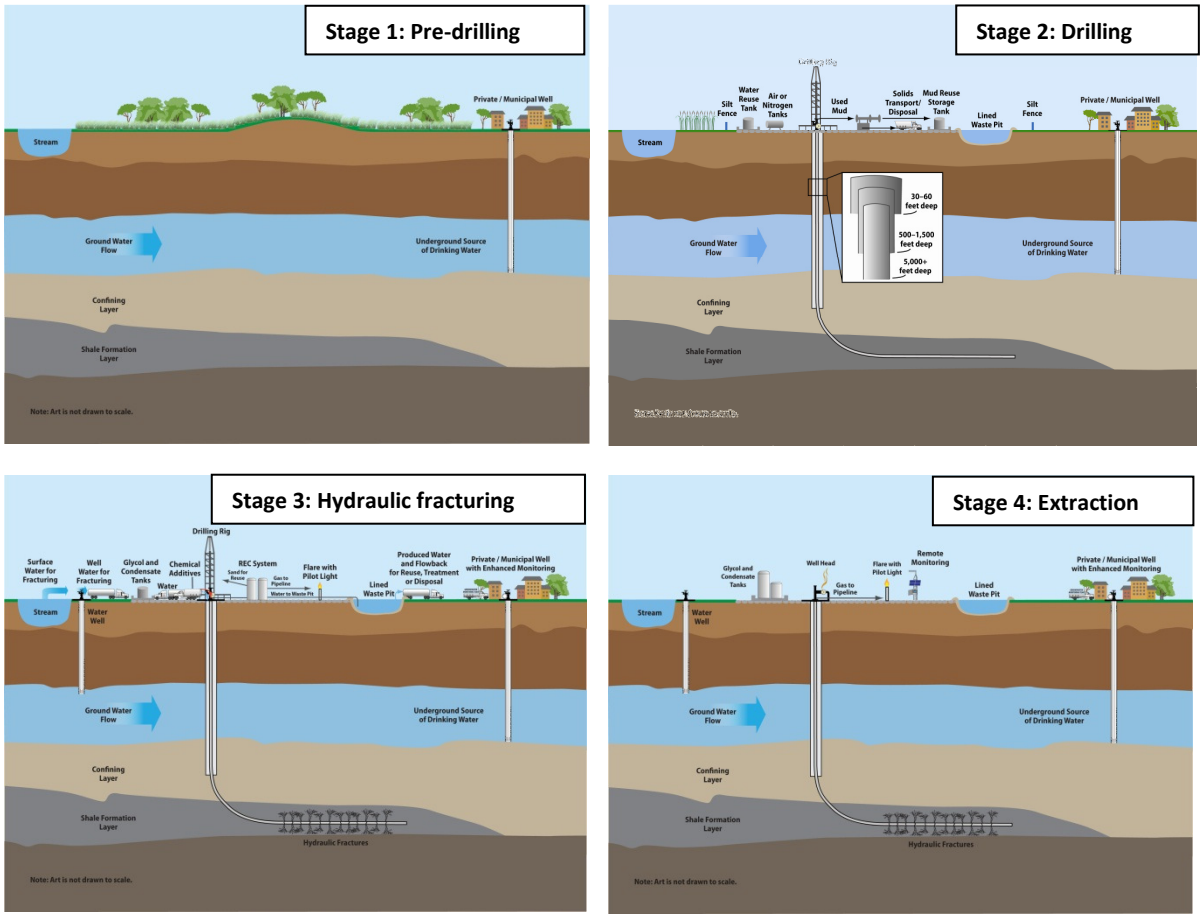
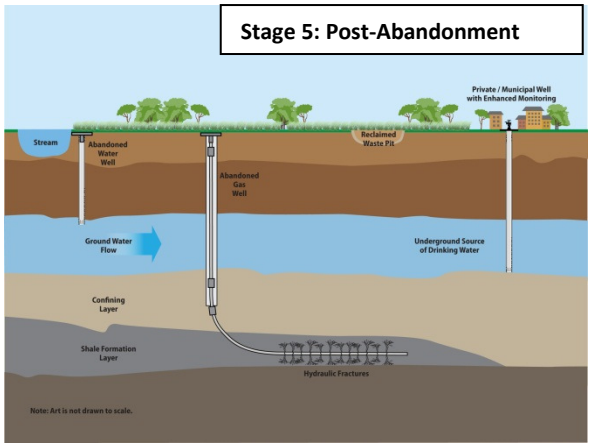
Executive Summary

Natural gas occurs from both conventional and unconventional sources. The main difference between these sources is that conventional gas is usually free gas trapped in porous zones within a rock formation, whereas unconventional gas (shale gas) is found in low porous rock formations and therefore the rock must be fractured to allow the gas to escape. Several process stages in shale gas extraction and processing (E&P), such as processing and compressing the gas for distribution require the same steps as with conventional gas. The additional emissions, specific only to unconventional extraction occur from hydraulic fracturing and management of flow back waters.

Hydraulic fracturing is the process by which liquid, under pressure, is pumped into the rock, causing it to crack open. It is used to extract gas from shale formations and the process is illustrated in Figure ES1 below.

Figure ES1: Stages in the hydraulic fracturing process.





There is currently no shale gas extraction in the UK and drilling at the test site in Lancashire has been suspended since mid-2011. However, initial estimates of total emissions from shale gas extraction and process activities at 100 fracking operations per year, based on US EPA data leads to a range of 1700 to 17,000 tonnes of methane (35 to 350 kt CO_2e) per year. These data are highly uncertain and exclude any addition emissions from ancillary operations to the main extraction activities, such as waste water treatment and road transport.

Overall, the main recommendation is that further research is required in order to obtain relevant emission factors for calculation of emissions from this sector. Currently there is little data for fugitive methane emissions arising during the fracking and flow back stage of the process, and data that are available are very uncertain and highly variable.

Contents

1 Introduction

Shale gas extraction has become established in the United States and Canada over the past 10 to 15 years. In contrast, shale gas activity is in its earliest stages in Europe. At present, no wells are in commercial production in Europe and in the UK, shale gas exploration is currently on hold pending investigation of potential seismicity risks. It is expected that investigation may restart in the short term. The UK has substantial shale gas reserves[1], which may be greater than originally thought,[2] although only a proportion of these reserves could be commercially or technically viable for production[3]. Current estimates indicate that shale gas reserves may amount to a total of approximately 6 trillion cubic metres, of approximately 10% - 30% may be commercially and technically viable for recovery.

A substantial review of shale gas extraction activities and environmental management issues was published by the New York State Department of Environmental Conservation in 2011.[4] The Tyndall Centre also completed a study of environmental and climate change impacts of shale gas in 2011.[5]

This briefing note aims to address the following issues:

- Is shale gas activity covered by current or future UNFCCC/IPCC inventory guidelines?
- What methodology is available for deriving an estimate of shale gas emissions in the U.K?
- Can an initial estimate of greenhouse gas (GHG) emissions from exploratory hydraulic fracturing carried out in the north-west of England during 2010 be calculated?

The findings of a review of available materials pertinent to onshore shale gas extraction in the UK are summarised in the note, along with the new demands on GHG data compilation and reporting that shale gas activity requires.

As DECC is aware, we have also been working concurrently on projects relating to shale gas exploration and production (E&P) for the Environment Agency and the EU (DG Clima). This briefing note has benefitted from some of the consultation and review activities performed under those contracts, but we have focused this report on the specific interests of the DECC CESA team.

[1] DECC, "The unconventional hydrocarbon resources of Britain's onshore basins: shale gas", British Geological Survey on behalf of DECC, 2010

[2] US Energy Information Administration, "*World Shale Gas Resources: An Initial Assessment of 14 Regions Outside the United States,*" April 2011

[3] Caudrilla Resources Ltd, quoted by The Guardian and others, September 2011 (e.g. see http://www.guardian.co.uk/business/2011/sep/21/gas-field-blackpool-dallas-sea?intcmp=239). These references are not very authoritative, but no direct feedback from the industry has been provided.

[4] New York State Department of Environmental Conservation, "*Revised Draft Supplemental Generic Environmental Impact Statement On The Oil, Gas and Solution Mining Regulatory Program*", September 2011

[5] Tyndall Centre, "*Shale gas: an updated assessment of environmental and climate change impacts,*" November 2011

2 Key Messages

UK and EU Overview

- There is currently no shale gas exploration & production (E&P) in the UK and very limited information on shale gas activities and emissions within the EU;
- Shale gas exploration and production may recommence in the UK in the short term. Industry forecasts indicate that there may be a steady increase in well construction up to approximately 200 new wells per year by 2020.[6] (This estimate is very uncertain, and more research is needed to be able to more fully engage with the industry and derive forecasts.)
- A preliminary estimate of 100-1000 tonnes of fugitive methane (2-21 kt CO_2e) from fracking operations in the UK during 2010 has been calculated based on limited activity data and emission factors for shale gas well completions[7] derived from US EPA information. The range of data reflects the limited information regarding vented and fugitive methane emissions from fracking activities, and the impacts of any mitigation. The estimate excludes any emissions from related activities such as waste water treatment.
- Elsewhere in Europe, shale gas exploration is on hold in a number of Member States, but proceeding in Poland. Projects in Poland are at a similar state to the UK at present, but likely to advance more quickly and in greater numbers over the next few years.[6]

Emission Sources, Inventory Data and Methods

- IPCC Guidelines do not specify how to calculate emissions from shale gas E&P sources, nor do they provide emission factors applicable to sources that are specific to shale gas E&P. However, if a country knows of an emission source and can estimate the GHG emissions, it should report them even if IPCC guidance does not exist for that source;
- UNFCCC reporting formats do not require that countries specify GHG emissions from shale gas E&P, or from any other specific technology or sub-sector; data are typically reported by countries at an aggregated level across all gas exploration and production sectors;
- Several process stages in shale gas E&P, such as processing and compressing the gas for distribution, require the same steps as with conventional gas; current IPCC Guidelines and UK GHGI methodologies could therefore be used for these processes, although development of appropriate emission factors may be required to reflect shale gas composition;
- Fugitive methane emissions from hydraulic fracturing and management of flow-back waters are sources of emissions that do not arise from conventional extraction, and for which methodological data and emission factors are only evident from reporting in the USA; if shale gas E&P begins in the UK, these are expected to be the most significant new sources of GHGs for the UK inventory to cover, and also the biggest challenge methodologically.
- A review of National Inventory Reports from several EU Member States has yielded no data or methodological information regarding emissions of fugitive methane from shale gas E&P sources; American and Canadian sources do provide some good examples of activity data, emission factors and estimation methods that may be applicable for use in the UK;

[6] Douglas-Westwood. "*Unconventional Gas: World Production & Drilling Forecast 2011-2020*," quoted by M Karabula, PGNiG to World Shale Gas conference and exhibition, Houston Texas, 7-11 November 2011

[7] Completion is the process of finishing a well so that it is ready for the production of shale gas

- Fossil fuel combustion emissions and fugitive emissions from other sources such as valve and flange leakage need to be considered to get a complete picture of the emissions arising from shale gas E&P sources;
- Combustion emissions occur during well construction, drilling & fracturing and completion.
- Transport will be a source of additional emissions, due to the transport of raw materials, equipment, water and waste water;
- Significant volumes of water are required for the hydraulic fracturing process, which is partly returned to the surface together with other waters produced as a result of the fracturing process. These liquids are referred to as "flowback". This water can in some cases be recycled for use in the fracturing process, but there may be significant volumes of waste water to be transported and treated; the UK GHGI estimation method for emissions from waste water treatment and disposal will need to be reviewed to ensure complete coverage. These additional emissions would be due to new shale gas E&P activity, and as such, they are directly related to the industry. In the case of the wastewater treatment emissions, some of these may occur directly on the site, depending on whether operators were required or opted to install their own treatment plant near to the wells, thereby reducing the need for transport of waste water, and also increasing the opportunity for re-use of flow-back water, once it had been cleaned on site;
- Chemicals are used during the fracturing process. Additional emissions from chemical manufacture would be due to the new shale gas E&P activity, and as such are directly related to the industry. However, emissions from chemical manufacture are already covered in the UK GHGI methodology for industrial processes, IPCC sector 2.

Data from the USA and data uncertainty

- North American sources of information provide most insight and data on the emission sources from shale gas E&P. Despite 50+ years of onshore gas exploration in the USA using hydraulic fracturing techniques, there remains a high degree of uncertainty in the dataset underpinning industry and inventory emission estimates for fugitive / vented methane from well drilling, exploration, fracking, completion and well work-overs.
- The US EPA has drafted GHG reporting guidance for the oil and gas industry (April 2012) which presents emission factors for shale gas well completions, with and without mitigation technology. The US EPA document presents 5 different approaches to deriving an aggregate emission factor from the industry source data.). There is a high degree of uncertainty and variability associated with these data which are subject to on-going challenges by industry and the scientific community. The uncertainty is primarily due to the large range of reported fugitive gas volumes at the well fracking to well completion phase of production, which the USEPA emission factors cover.
- The study team has derived a weighted average factor using the source data from the US EPA guidance note, of 11,025 Mcf / completion (312,000 m^3 /completion) for unmitigated completions, and 1,100 Mcf (31,000 m^3 /completion) per reduced emission completion. Converting these weighted-average factors to a mass basis, assuming a gas density of 0.68 kg/m^3 and methane content of the vented gas to be 78.8% mole fraction, gives factors of **167 tonnes methane per unmitigated completion** and **17 tonnes methane per reduced**

emission completion. These emission factors cover the whole process of gas extraction at source, including fugitive emissions and leakage. See annex B3 for more information.

Other Issues

- Shale gas exhibits a wider range of composition than conventional natural gas; the shale gas content of methane, other hydrocarbons and carbon dioxide vary between shale gas basins; this implies a need for more gas compositional analysis in deriving emission factors;
- There are on-going studies into upstream gas GHG emissions, including shale gas E&P sources, in Germany and Canada, that are due to report in 2012 and 2013 respectively;

3 Summary of Key Sources of GHG Emissions from Shale Gas Exploration and Production

GHG emission sources from shale gas E&P fall into three broad categories when considering their impact on UK data sources and GHG inventory methods:

(See also Figure 1 below for an overview of the main sources specific to shale gas E&P, the level of significance of emissions, and inventory methodological development summary. Emission estimates are taken from the Tyndall Centre report of 2011.[5]*)*

- **No additional work needed.** There are some emission sources for which the existing data provision and estimation methods used for the UK GHGI will adequately cover the shale gas industry emissions, such as: transport, manufacture of chemicals used in fracking manufacture, gas transmission and distribution (leakage[8]). The current approach for gas transmission and distribution includes use of UK-wide gas compositional analysis, and hence no inventory data/method development is needed.

- **New gas compositional data / new emission factors needed.** Additional gas sampling and analysis data will be required in order to derive emission factors that are representative of shale gas composition. This research is needed because shale gas composition is more variable than conventional gas composition. Composition of shale gas is specific to the geology of the area from which it is extracted and comprises of a mix of methane, heavier hydrocarbons and carbon dioxide. Generally, in comparison to gas extracted by conventional methods, shale gas contains a higher proportion of heavier hydrocarbons. Examples include: fugitive releases from equipment (flanges, compressors, pipelines), gas flaring, gas venting (where used, and where measured volumes are available), shale gas combustion, gas processing. Note that one of the largest areas of uncertainty, which is unique to unconventional gas extraction, is fugitive emissions from the fracking and flowback stages of the extraction process. This is the area in which additional work would need to focus in order to derive relevant emission factors. Another example is that the current method for estimating emissions from waste water treatment and disposal may

[8] Note that for an overall well completion, leakage would be expected to be significantly higher for unconventional gas extraction compared to conventional extraction due to the flowback and drill out stages of the process. However, note that there is no expected impact on current leakage rates within the GHGI once the gas has been treated and transported offsite for distribution.

need to be reviewed, depending on the level of operator reporting for off- and on-site waste water treatment. Specific work to derive emission estimates from this source may be needed, to supplement the current methods.

- **New methods and data required.** For emission sources that are unique to shale gas exploration and production, entirely new estimation methods and source data will be needed. The method options for the UK GHGI are likely to be determined by the scope, detail and accuracy of the operator reported estimates to the environmental regulators for site-specific annual emission estimates. Where data specific to shale gas activities become available, these data could be directly assimilated into the UK GHGI estimates, similar to the use of the EEMS dataset for offshore oil and gas installations. However, in the event that installation-specific, source-specific emissions data do not become available, that are transparent, comprehensive and consistently provided by all shale gas operators, then the inventory agency may need to seek alternative data sources (perhaps periodic UK industry studies) to supplement the operator data. The main emission source in this category is fugitive / vented releases of gas from drilling, exploration to well completion, including the management of fracking flow-back fluids that contain methane in bubbles and in solution. US information suggests that this is potentially a source of high methane emissions during the period of fracking and well completion, which can include 2 to 8 weeks of gas venting, prior to production commencing at a new or re-fracked well (Reference 4 page 5-136). These emissions can be abated by the use of “reduced emissions completion” procedures.

  The term “Reduced Emissions Completion” (also known as “green completion”) describes a practice that captures gas produced during well completions and well workovers following hydraulic fracturing. Portable equipment is brought on site to separate the gas from the solids and liquids produced during the high-rate flowback, and produce gas that can be delivered into the sales pipeline. These procedures help to reduce emissions of methane and other organic compounds during well cleanup, and can eliminate or significantly reduce the need for flaring.

Figure 1: Outline of Shale Gas E&P Processes, Emission Sources and GHG Inventory Impacts

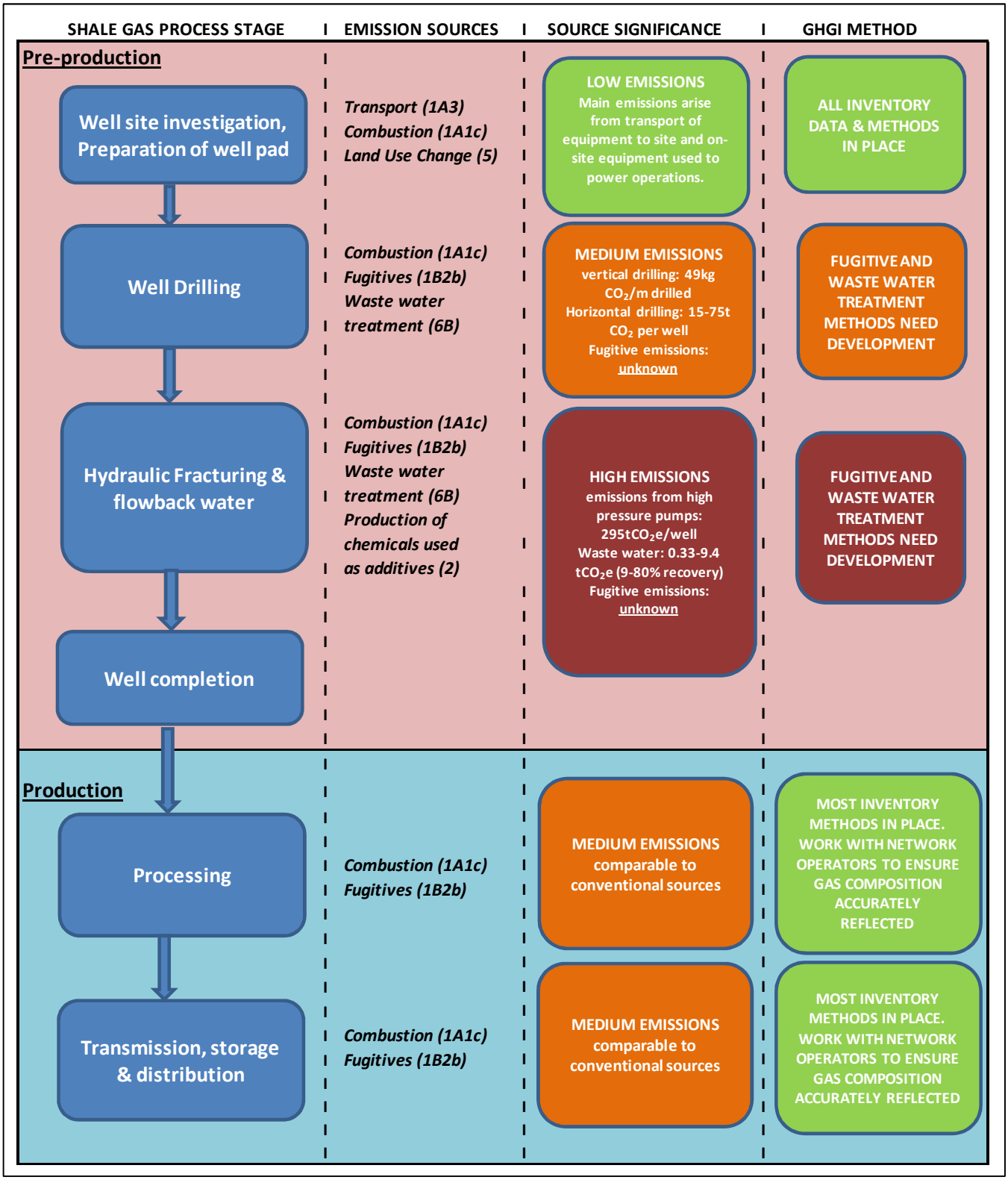


Table 1 below summarises GHG emission sources from shale gas activities, and provides information on whether the IPCC currently provides relevant guidance, highlighting where further work would be required in order to complete an estimate of shale gas emissions in the UK.

Table 1: ***Shale Gas E&P GHG Emission Sources, IPCC Sectors and Inventory Methods***

White: no action	Green: lower priority	Orange: medium priority	Red: high priority

Source	Comment: UK data and methods	Existing data, Further work and new source data requirements for GHGI reporting		
		Activity data	Emission factors	Methodology
Exploration and Production				
Drilling, fracking, well development and completion, well work overs	***1B2biii1: Exploration – All Other.*** There is general guidance given by the IPCC on how to select a calculation method, with calculation methods for each Tier set out. However, these are **not** specific to shale gas activity and so only those processes which occur during conventional gas exploration and production will be covered. IPCC GLs do not specify any default emission factors for unconventional gas E&P. The UK inventory agency will need to develop new estimation methods, the design of which will be partly dependent on the scope and detail of emissions data reported by industry to the Environment Agency.	New activity data will be needed. See section 4.2.1.	Require development.	New estimation methods required. Will require shale gas compositional data, ideally at site-specific level. The US EPA GHG reporting protocol presents method options for consideration for sources specific to shale gas.
Flaring	***1B2bii Gas Flaring*** IPCC GLs are not specific to shale gas, but existing guidance and methods could be applied to shale gas flaring activities.	May need to request more detail from operators where unconventional gas		Shale gas compositional analysis will be needed. Shale gas exhibits a wider range of composition, with variable hydrocarbon,

Source	Comment: UK data and methods	Existing data, Further work and new source data requirements for GHGI reporting		
		Activity data	Emission factors	Methodology
	Existing methods for the offshore oil & gas sector are available from EEMS, with operator guidance already applicable to the oil and gas sector. Flaring estimation methods typically use gas flow measurements or engineering calculations, combined with gas compositional data and methane oxidation assumptions. Annual gas flaring volumes will need to be reported to DECC as part of well drilling consents, together with reporting of production data, so activity data in volume terms will be available by site.	flaring may be co-located with other flaring activities (although unlikely).		carbon dioxide and other gas content. It may be necessary for operators to conduct more regular gas compositional analysis, rather than using industry-wide emission factors (as are agreed and used by the industry for conventional offshore gas flaring, for example).
Venting	***1B2bi: Gas venting*** IPCC GLs are not specific to shale gas, but existing guidance and methods could be applied to shale gas venting activities. There are methods available from other oil & gas industry sectors, as well as from other petroleum processes.			As above for gas flaring, there will be a need for additional gas sampling and compositional analysis to derive representative emission factors at the local (basin or well head) level.
Fugitives	***1B2biii2: Production – All Other*** *(fugitives, wellhead to processing plant to transmission system, well servicing, gas gathering, processing, waste water processing and disposal)* Current IPCC GLs offer guidance on	Activity specific to shale gas will be required, such as volumes of flow back water treated and number of fracks and well	New emission factors required.	New methodology required. For some sources the industry approaches of Leak Detection and Repair (LDAR), component inventories and use of American Petroleum

Source	Comment: UK data and methods	Existing data, Further work and new source data requirements for GHGI reporting		
		Activity data	Emission factors	Methodology
	calculation of fugitive emissions from conventional gas activities (sector 1B) but there is not anything specific to unconventional activities. For most of these sources, the industry methods that are available for onshore oil production, offshore production and gas processing at terminals currently will be applicable to shale gas activities also. However, there are some aspects of the well-head to gas gathering systems that will be specific to shale gas E&P, notably for the management of back-flow fluids, gas/water separation and then waste water treatment are involved. For these sources, further work to clarify with regulators and industry may be needed to ensure complete, consistent data reporting.	work-overs.		Institute (API) Compendium estimation methods and factors will be applicable. The US EPA GHG reporting protocols again cover the "new" sources.
Combustion	***1A1c: Other energy supply*** (Fuel Combustion in gas supply systems) Existing guidance and methods will be applicable to shale gas E&P activities.			Gas compositional data will be required, where produced gas is used to run combustion units.
Land Use Change	***5 LULUCF*** The activities to convert land areas to well pads are not expected to lead to significant LULUCF emissions. Existing inventory methods and data will provide the GHGI estimates.	Nothing specific to shale gas.	Nothing specific to shale gas.	Nothing specific to shale gas.

Source	Comment: UK data and methods	Existing data, Further work and new source data requirements for GHGI reporting		
		Activity data	Emission factors	Methodology
Waste Water treatment	***6B1 Industrial Waste Water*** (1996 GLs) ***4D2 Industrial waste water treatment and discharge*** (2006 GLs) In theory this is already covered by existing data and methods, but (i) the current method is somewhat uncertain due to limited access to source data and an assumption that industrial waste water treatment emissions are included within IPPC PI reporting (which technically they should be), and (ii) the potentially significant volumes of waste water from fracking activities may significantly increase the demands for waste water treatment, increasing the relative significance of the source.		Ensure that emission factors are current and appropriate.	Periodic research may be needed to supplement available data and assess the impact of fracking and the waste fluid composition, elution of methane etc.
Transport: raw materials to site, wastes off-site	***1A3 Transport*** All modes of transport are comprehensively covered within existing UK GHGI methods and data.	Nothing specific to shale gas – will be included within transport movement and fuel sales data already used to compile the inventory.	Nothing specific to shale gas.	Nothing specific to shale gas.
Fracking chemical manufacture	***2: Industrial processes*** Estimation methods are fully covered by existing guidance; there is nothing bespoke needed for shale gas activities.	Nothing specific to shale gas.	Nothing specific to shale gas.	Nothing specific to shale gas. Emissions from chemical manufacturing processes to

Source	Comment: UK data and methods	Existing data, Further work and new source data requirements for GHGI reporting		
		Activity data	Emission factors	Methodology
				supply fracking chemicals are already included in the inventory compilation source data.
Processing				
Gas treatment Fugitives Compression, injection to pipelines	***1B2biii3 Processing – All Other*** (fugitive emissions, gas processing) Existing guidance and methods will be applicable to shale gas E&P activities. Once the gas is through to gas treatment and injection into the main UK supply infrastructure, there is no difference between shale and conventional gas as regards data requirements and methods.			Ensure that variable composition of the source gas is reflected in the estimates (work with gas supply network operators).
Combustion	***1A1c: Other energy supply*** (Fuel Combustion in gas supply Existing guidance and methods will be applicable to shale gas E&P activities.			New gas compositional data for instances where produced gas is used.
Transmission and Storage, Distribution				
Combustion	***1A1c: Other energy supply*** (Fuel Combustion in gas supply Existing guidance and methods will be applicable to shale gas E&P activities.			New gas compositional data for instances where produced gas is used.
Gas network leakage Other fugitives	***1B2biii4 Transmission and Storage – All Other*** (fugitive emissions, pipeline leakage) Existing guidance and methods will be applicable to shale gas E&P activities. Once the gas is through to gas treatment and injection into the main UK supply infrastructure, there is no difference			Ensure that variable composition of the source gas is reflected in the estimates (work with gas supply network operators).

Source	Comment: UK data and methods	Existing data, Further work and new source data requirements for GHGI reporting		
		Activity data	Emission factors	Methodology
	between shale and conventional gas as regards data requirements and methods.			
Other sources				
Well blow outs Pipeline ruptures	***1B2biii6 Other– All Other*** (well blowouts, pipeline ruptures, dig-ins) Existing guidance and methods will be applicable to shale gas E&P activities.			Possibly new methods to generate emissions from well blow-outs. New gas compositional analysis required.

4 DECC & Environment Agency Regulatory Functions

4.1 Emissions inventory reporting

DECC regulates the licensing for all exploration and production from hydrocarbon fields in the UK, including the licensing of well drilling consents for conventional and unconventional gas under the Petroleum Act 1998. All offshore and onshore operators currently report annual data on gas venting and gas flaring volumes to the DECC energy statistics team (Personal communication, DECC, 2012), and it is likely that new onshore gas operators would also be required to report these data to DECC, along with monthly, quarterly and annual gas production data.

The DECC Offshore Inspectorate also regulates the atmospheric emissions from all offshore installations; the EEMS reporting system provides a template for emissions reporting by onshore operators, including the provision of operator guidance on emission estimation methodologies and default emission factors for specific sources where measured data are unavailable.

DECC shares the regulation of onshore oil and gas production sites with the Environment Agency of England and Wales, SEPA and NIEA. Onshore oil production in England is subject to EPR/IPPC regulation and the operators submit annual emission estimates of methane to the Pollution Inventory, where emissions exceed the reporting threshold of 10 tonnes per year. The same approach is expected to be applicable to onshore gas exploration and production and it is anticipated that onshore shale gas extraction wells will exceed the Pollution Inventory reporting threshold, based on emission estimates for methane from well completions and well work overs from the US EPA (see Section 4.2.2). Under EPR/IPPC regulation, site operators do not submit source-specific emission estimates, but report aggregate annual emission estimates for each pollutant across all sources on site.

Appendix A includes a summary of regulatory functions in the UK pertinent to onshore gas E&P.

4.2 Inventory methods and emission factors

In order that detailed, complete, accurate and comparable emission estimates are generated by onshore gas operators, the regulatory agencies should provide clear source-specific guidance on estimation methods. Ideally, onshore operators would be provided with an equivalent guidance note to the EEMS information for offshore operators, including protocols, factors and assumptions to generate emission estimates from all sources (including the well completion and other fugitive releases) in shale gas E&P.

4.3 Recommendation

The design of regulatory reporting for onshore gas operators and provision of guidance on estimation methods will have a significant effect on the options available to derive UK GHG inventory estimates. Source-specific estimates (rather than aggregated estimates across all sources on an installation) should ideally be made available, in order that national inventory reporting can

meet the UNFCCC reporting framework detail, matching the reporting detail achieved for the offshore oil and gas E&P sector.

5 Review of National Inventory Reports and Consultation with Inventory Agencies

We have reviewed several national GHG inventory reports and consulted with national experts to seek out available information on national methods for estimating GHG emissions from the upstream gas sector. The review has focused on: Netherlands, Germany, Poland, USA and Canada.

5.1 EU Member States

The review of the NIRs from the EU, and subsequent consultation with the inventory agencies, has identified no data or methods that are directly of use for future UK GHGI estimation methodologies. There is no current shale gas exploration and production activity in the UK, and there is very limited information on this activity within the EU. There has been some limited activity in Germany (approximately 300 fracking operations in tight gas reservoirs over 30 years, becoming more common in recent years). In the Danish sector of the North Sea, stimulation using hydraulic fracturing has been carried out at approximately 130 wells in total. In the Netherlands, over 200 unconventional tight gas wells have been fractured since the 1950s, of which about half are onshore and half offshore. As part of this, between 2007 and 2011, 9 onshore wells and 13 offshore wells were fractured in the Netherlands. There is increasing activity in relation to shale gas in Poland, where very large shale gas resources are evident.

The estimates in the German inventory are currently only a Tier 1 method (i.e. using default emission factors from the Good Practice Guidance), but there is an on-going study which is aiming to deliver Tier 2 or Tier 3 estimates for the oil and gas sector in time for the 2013 inventory submission. Whether this study will derive any data that are specific to unconventional shale gas is unclear; in Germany the use of fracking is limited to a small number of sites, with only 300 fracking actions in the last 30 years.

The Dutch onshore gas industry (conventional only) is well established, with a reporting protocol in place developed in conjunction with the industry. This may include underlying methodological information pertaining to well completions, but not for the unconventional shale gas industry. PBL (the inventory agency for fugitive emissions from the oil and gas sector in the Netherlands) stated that annual operator emission estimates in the Netherlands are calculated at a very detailed level but the data are aggregated prior to any reporting due to commercial confidentiality.

We have consulted with the inventory agency and relevant competent authority for the oil and gas industry in Poland, but no useful feedback has been provided. There is no useful data within the NIR. We have also approached an expert in the Norwegian Pollution Control Authority (a co-author of the 2006 IPCC GL chapter on fugitive emissions from energy sector) and await a response.

- ➔ There are oil & gas reporting protocols in place for the UK (*offshore*: emissions, gas flaring and venting volumes, *onshore*: gas flaring and venting volumes) and Netherlands (*offshore and onshore*: emissions data). The Dutch protocols are not publicly available at a source-

specific level. None of the EU reporting protocols currently cover fugitive and vented methane emissions from the well drilling to completion phase needed to underpin emission estimates for shale gas.

5.2 USA and Canada

Shale gas exploration and production using fracking techniques is an established onshore gas extraction technology in the USA, with over 35,000 gas wells using hydraulic fracturing and the practice evident in the industry for over 50 years. There are shale gas E&P activities within Canada too, but the activity is less widespread than in the USA.

5.2.1 Canada

We have contacted the lead authors of the chapter in the Canadian National Inventory Report on fugitive emissions from the energy supply sector and reviewed the NIR text also. The Canada GHGI method does not provide any detailed factors specific to shale gas extraction. The Canadian inventory upstream oil and gas (UOG) estimates are derived from a detailed study in 2000, scaled across the time series using specific indicators for sub-sectors of the UOG sector. Environment Canada has recently commissioned a new UOG study, which will include consideration of shale gas fugitive emissions, and is due to report in 2013. We have consulted with the lead expert conducting that study (Dave Picard of Clearstone Engineering, who is also the lead author of the 2006 IPCC GLs chapter on fugitive emissions from the energy sector), but there is no information specific to unconventional gas E&P currently available.

Information from the British Columbia state regulators of oil & gas exploration and production also provides a useful insight into the type of activity data and emissions data that should be considered for collection in the UK, in order to inform future GHGI estimates. Regulator reports from the Oil & Gas Commission in British Columbia can be viewed at:

http://www.bcogc.ca/publications/reports.aspx

These reports give a useful insight into the type of data that is required to be reported by operators in Canada, which includes both conventional and unconventional natural gas extraction and has been used to help establish some of the data requirements listed in table 1 Data reported by site operators includes:

- Total flared gas volume (which in the UK we believe would be required to be reported to DECC, as is the case currently for onshore oil fields)
- Solution gas flaring volume (which is primarily aimed at gas produced at oil producing wells, but may also be applicable to unconventional gas well flow-back waters)
- Annual gas production from each well and across the installation
- Well clean-up and well testing flaring (which should include information on well work-overs and re-fracking activity in unconventional production)
- Total gas vented volume (also expected to be reported to DECC, as above for flaring)
- Number of wells drilled
- Pipeline km built
- Geophysical exploration programmes
- Public complaints
- Incident types and causes (e.g. blowouts due to fracking, unplanned gas releases, fires etc.)

Based on other resources, further activity data that would be useful for inventory compilation are:

- Number of fracking activities conducted (Number of fracturing stages per well; volume of fluid used for each stage)
- Number of well completions
- Number of well work-overs
- Volume of waste water treated (on-site or off-site)
- Fracking flow back fluid volumes
- Annual inventory of use of fracking fluids
- Description of any Reduced Emissions Completion methods used
- Any other information used by the operator to estimate methane emissions
- Annual report on LDAR programmes and progress on plant improvement and emission mitigation activities, including changes to plant design operation and abatement systems

5.2.2 USA

We have researched information from the US EPA Natural Gas STAR programme and GHG Reporting Protocol, as well as reviewing the NIR and consulting with US experts on shale gas.

Emission totals compiled in the US GHGI are calculating using regional production data and emission factors that vary according to the shale gas basin, reflecting the fact that the composition of shale gas is more variable than conventional gas; this infers that any future estimation method for methane emissions from shale gas extraction should include gas compositional analysis from all major producing areas, in order that factors derived and applied across the industry are representative of all shale gas sources.

US-sourced information on shale gas E&P activities provides data on fugitive methane emissions from the early phases of exploration to well completion and management of methane in flow-back fluids. There are a wide range of emission factors and emission estimates quoted in the industry and scientific literature, and evidently a high degree of uncertainty in the available data. During 2011, the US EPA finalised a "clean" version of emission estimation methods and factors for the oil and gas sector to use under the (new) GHG Reporting Protocol, which updates the industry factors used within previous national inventory estimates. The generation of the new guidance note included a substantial review and consultation with input from leading authorities across industry and Government, including the American Petroleum Institute, but the factors cited for well completions are the subject of on-going industry disputes with some organisations indicating that the factors may be over-estimating emissions by over 1000%. In April 2012, the US EPA published a technical guidance document[9] to summarise their analysis of industry submissions and present a final set of emission factors for operators to use in the GHGRP. The study team has reviewed the US EPA GHG Reporting Programme rule documents and the findings are summarised in Annex B3. In the initial estimates of UK emissions presented in this paper, we have used a weighted-average factor for shale and tight gas formations, based on the source data presented in the US EPA protocol documents. These data are subject to high uncertainty and are regarded as indicative only. (*See annex B3 for more details*.)

[9] http://www.epa.gov/airquality/oilandgas/pdfs/20120418tsd.pdf

In addition to regulatory reporting guidance, the US EPA hosts a voluntary industry reporting mechanism, the Natural Gas STAR programme, for oil and gas companies to share mitigation activity information. The data presented in the Gas STAR outputs are not independently validated but nevertheless give a useful insight into the typical achievable methane emission reductions for different mitigation options.

- ➔ The US EPA GHGRP protocol outlines the range of information from industry sources across the USA and derives an average factor for emissions of gas per unconventional gas well completion in gas volume terms. Based on industry data, the US EPA guidance indicates that around 90% of these emissions can be mitigated through implementation of Reduced Emission Completions technology. While there has been discussion over the basis of this calculation, and in the absence of UK data, it is the best available estimate of mitigation of methane emissions that can be achieved using Reduced Emission Completion technology. Based on the data presented in the US EPA GHG Reporting Programme guidance note[10], the study team has derived a weighted emission factor of **11,025 Mcf[11] per unmitigated completion (312,000 m^3/completion)** and **1,100 Mcf (31,000 m^3) per reduced emission completion**.

- ➔ Converting these weighted-average factors to a mass basis, assuming a gas density of 0.68 kg/m^3[12] and methane content of the vented gas to be 78.8%[13] mole fraction, gives factors of **167 tonnes methane per unmitigated completion** and **17 tonnes methane per reduced emission completion**. There is a high degree of uncertainty associated with these data and the US EPA guidance is subject to on-going challenges by industry and the scientific community in the USA.

- ➔ There are on-going studies in Canada (Environment Canada) and Germany (UBA) to research GHG inventory estimates for the upstream oil and gas industry, including consideration of shale gas E&P sources. These studies are due to report in late 2012 / early 2013 and we recommend that DECC retain a watching brief on these studies or perhaps consider a more active role to ensure that the UK might benefit from these studies.

6 Development of UK GHGI Emission Estimates

6.1 Reporting Structure and requirements

The UK GHGI reporting structure and the requirements for international reporting, as outlined in the IPCC guidelines and CRF table formats, does not enable explicit enquiry of all emissions relating to

[10] Data are taken from the US EPA and as such are considered typically achievable in the USA. Data are however, highly uncertain.
[11] Million cubic feet
[12] : http://cdm.unfccc.int/methodologies/inputsconsmeth/MGM_methane.pdf, where density is assumed to be 15 degrees C and 1.013 bar
[13] API Compendium 2009, Table 5-23

shale gas exploration and production; there are on-going EU-level studies that will present shale gas E&P emission estimates based on a Life Cycle Analysis from well to end user, and compare those emissions against alternative sources of gas and power.

In the future national GHGI outputs, no amendments would be needed to the reporting structure of the UK CRF submissions, but the inventory agency would need to:

(i) develop new (and amend existing) data compilation spreadsheets and all other data management systems (NAEI database tables etc.) to add new sources to the UK estimates; and
(ii) add text to the NIR to outline the data and methods used to derive the new source estimates.
(iii) Access activity data, emission factors and methods as per Table 1.

6.2 New Source Estimates

If shale gas exploration and production begins in the UK, there will be new sources of GHGs for inclusion in the UK inventory, as indicated in Table 1. For many sources, the current data provision and estimation methods will be sufficient to ensure that the UK GHGI remains a comprehensive and accurate record of UK emissions. As outlined in Table 1, the main challenges to the inventory agency will arise for:

- fugitive and vented methane emissions at the well drilling, exploration to completion phase and from any gas well work-overs; (sector 1B2b) and
- GHG emissions from (on- or off-site) waste water treatment and disposal (sector 6B1).

In order to derive GHGI estimates for fugitive / vented methane (the most significant potential new source of emissions), the inventory agency will be reliant on either:

(i) detailed and comprehensive source-specific emission estimates (including sector emission estimates for combustion, fugitive emissions, process emissions, venting and flaring) reported by site operators (analogous to the current level of detail reported by offshore oil & gas operators through the EEMS reporting system); or
(ii) detailed periodic industry studies to derive emission factors for shale gas extraction sources and annual activity data for each of those sources (as outlined in section 4.2.1).

For option (i) here, if source-specific estimates become available, then the inventory compilation method will reflect that used for offshore installations in the UK currently:

Emissions = ∑ installation reported data, by source

Quality checking of emission estimates could include checking of activity data on gas venting and flaring volumes, numbers of fracking activities, shale gas well completions and work-overs, and volume of waste water treated, to compare against equivalent data from US-based industry reporting.

For option (ii) above, the inventory compilation method will be reliant on accessing detailed activity data (as outlined above) and deriving emissions using emission factors:

Emissions = Activity Data x Emission Factor

In applying this approach, it may be necessary to distinguish between different groups of sources, (e.g. sources with/without reduced emissions completion, sources from different gas basins), and calculate estimates separately for these groups, followed by aggregation of the estimated emissions.

In all cases there is a need to ensure that local gas compositional data is obtained through gas sampling and analysis, in order that emission estimates or emission factors are representative of the shale gas basin gas quality.

The scale of additional GHG emissions arising from on- or off-site waste water treatment and disposal are unknown, but in other regulatory regimes this is not determined to be a major source. We note, however, that the volume of water used in hydraulic fracturing activities is very high and the current UK GHG inventory method for (municipal) waste water treatment and disposal is based on a limited dataset from UK water companies; the UK GHGI approach reflects the current low significance of the wastewater source in the UK context, but this may alter over time if shale gas E&P activities greatly increase the demand for waste water treatment. The UK GHGI approach to estimating emissions from industrial waste water treatment assumes that emissions are included within annual operator returns to the IPPC inventory reporting systems (PI, SPRI, ISR); further research may be needed to determine the extent to which these operator emission estimates include this source.

6.3 Indicative UK estimates of fugitive methane emissions

6.3.1 Potential future shale gas emissions in the UK

North American sources of information provide most insight and data on the emission sources from shale gas E&P activities. Despite 50+ years of onshore gas exploration in the USA, there remains a high degree of uncertainty in the dataset underpinning industry and inventory emission estimates for fugitive / vented methane from well drilling, exploration, fracking, completion and well work-overs. As outlined in section 5.2.2, the US EPA has drafted GHG reporting guidance for the industry (April 2012) from which the study team has utilised data on unconventional well completion emissions to derive weighted average emission factors for unmitigated well completions (**167 tonnes methane** per completion) and reduced emission completions (**17 tonnes methane** per completion). These emission factors are regarded as highly uncertain, reflecting the limited evidence base from the industry to date, but appear to be the best available data for use in deriving initial estimates of emissions from historic and projected shale gas extraction in the UK.

The estimates presented here for the UK are regarded as indicative only. At this stage, in advance of monitoring of shale gas exploration and extraction in the UK, we do not know whether the estimates based on US data will be representative for the UK. Significant additional research is needed to develop a more comprehensive evidence base to reduce uncertainties in emission estimates for this source.

Emission estimates have been made for the UK based on the US EPA emissions data. Industry forecasts indicate that there may be a steady increase in well construction up to approximately 200 new wells per year by 2020.[6] This is consistent with the Tyndall Centre estimate of approximately 150 wells per year in the UK to sustain an anticipated output of 9 billion cubic metre of natural gas per year.[5] These estimates are highly uncertain, and recent trends suggest that progress is, if anything, likely to be slower than forecast.

Table 2 presents a range of possible emissions which could occur from the shale gas industry, based on the number of new well completions or well work-overs per year. A range of well completions has been used to give an indication of the associated emissions which could be attributed to this sector for context with future emissions estimates.

Table 2: Estimated future emissions from the shale gas industry in the U.K.

Number of wells	With mitigation technology			Unmitigated		
	CH_4 emissions ($ktCO_2e$)	% of 2010 oil & gas sector emissions	% of total net UK GHGI emissions in 2010	CH_4 emissions ($ktCO_2e$)	% of 2010 oil & gas sector emissions	% of total net UK GHGI emissions in 2010
100	35	3%	0.006	351	30%	0.06%
1000	351	30%	0.06	3,513	300%	0.6%

Based on these data, an indicative estimate of the range of total emissions from this source in the UK from 2012 to 2030[14] has been calculated. For the purposes of this calculation it has been assumed that there will be 100 fracking operations per year between 2012 and 2030. These assumptions lead to the following total new UK emissions of GHGs from shale gas well completions:

- Emissions with mitigation technology: 31,800 tonnes methane (668 $ktCO_2e$)
- Emissions without mitigation technology: 318,000 tonnes methane (6,675 $ktCO_2e$)

These data are highly uncertain and exclude any additional emissions from ancillary operations to the main extraction activities, such as waste water treatment, additional road transport activities and so on.

6.3.2 Estimated emissions from exploratory fracturing during 2010

The Tyndall Centre report[5] (Table 2.4) indicates that the fracking activity at the exploratory well in Weeton, Lancashire, operated by Cuadrilla Resources and completed in December 2010, comprised a 6-stage fracking process, using 8,600 m^3 of fracturing fluid. Based on the factors derived from the US EPA source data, the fugitive methane emissions from this activity are expected to be in the range of 100-1000 tonnes of methane (2-21 kt CO_2e), depending on the level of mitigation that Cuadrilla implemented. The Cuadrilla website explains how flowback and produced water is handled at the site, but does not refer to the use of reduced emissions completion techniques.[15] If there was no mitigation, then the upper estimate equates to around 1.8% of the annual upstream oil and gas sector methane emissions, and in UK GHGI terms is less than 0.005% of the 2010 net UK GHGI emissions total.

[14] Time range based on initial DECC request for an estimate of additional emissions to 2030

[15] Cuadrilla Resources, http://www.cuadrillaresources.com/protecting-our-environment/water/water-disposal/

Research is being carried out in the USA to derive and verify estimates of methane loss per unit of production; the findings vary considerably, but are typically in the range of 2-4% gas loss per unit production.[16]

7 Conclusions

The aim of this briefing note was to investigate shale gas exploration and production in the UK and the impacts that this would have on the UK GHG inventory and to try to address three issues:

- Is shale gas activity covered by current or future UNFCCC/IPCC inventory guidelines?
- What methodology is available for deriving an estimate of shale gas emissions in the U.K.?
- Can an initial estimate of greenhouse gas (GHG) emissions from exploratory hydraulic fracturing carried out in the north-west of England during 2010 be calculated?

Currently shale gas activity is not explicitly covered in the UNFCCC/IPCC guidelines, although some methodology exists for helping to derive an estimate of shale gas emissions in the U.K. Where processes with conventional gas extraction are the same as for unconventional extraction, existing methodology for conventional gas sites could be used. The main challenges for estimating shale gas emissions in the U.K. would arise from fugitive and vented methane emissions at the well drilling, exploration and completion phase and from any gas well work-overs and estimating emissions from waste water treatment and disposal. Work would also be required to establish site specific emission factors as well as information on the gas composition, as shale gas varies from conventional gas. Where emissions fall into other reporting categories (such as LULUCF and transport), these would automatically be captured within the inventories for those sectors.

Estimates for emissions from the exploratory fracturing which took place in the UK in 2010 range from 2-21 $ktCO_2e$, depending on the level of mitigation used by Cuadrilla. Estimates for future emissions from the shale gas industry in the UK range from 35 -3,513 $ktCO_2e$ depending on the level of mitigation and the number of wells completed per year. All estimates are highly uncertain.

Further research into emission factors and activity data is required in order to more accurately estimate emissions from this sector.

[16] Pétron G, Frost G, Miller BR Hirsch AI, Montzka SA, Karion A, Trainer M, Sweeney C, Andrews AE, Miller L, Kofler J, Bar-Ilan A, Dlugokencky EJ, Patrick L, Moore CT Jr., Ryerson TB, Siso C, Kolodzey W, Lang PM, Conway C, Novelli P, Masarie K, Hall B, Guenther D, Kitzis D, Miller J, Welsh D, Wolfe D, Neff W and Tans P (2012) "*Hydrocarbon emissions characterization in the Colorado Front Range: A pilot study*", J. Geophys. Res., 117, D04304