CONSEQUENCES OF GAS EXTRACTION FROM THE BOWLAND-HODDER SHALE GAS PLAY 2021-2050

ESTIMATES OF HEAVY GOODS VEHICLE JOURNEYS, TRAFFIC & GHG EMISSIONS RESULTING FROM TRANSPORTATION OF WATER, PROPPANT AND WASTE

A REPORT BASED ON THE PERFORMANCE OF THE PENNSLVANIA MARCELLUS SHALE GAS PLAY

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GLOSSARY

1 US barrel = 0.1590 cubic metres
1 US barrel = 0.1590 tonnes water
1 US barrel = 0.1908 tonnes fracking fluid waste (used or unused) or produced fluid
1 US gallon = 0.0038 tonnes water
1 US ton (2,000 lbs) = 0.9072 tonnes
1 cubic foot = 0.02832 cubic metres
1 cubic metre = 35.3147 cubic feet

	REFERENCE
Density of water = 1 tonne m^{-3} = 1,000 kg m^{-3}	
Density of quartz = 2,650 kg m^{-3}	1
Density of pure methane = 0.671 kg m^{-3} at STP (15°C & 100 kPa)	2,3
Typical density of dry natural gas = 0.703 kg m^{-3} at STP (15°C & 100 kPa)	2,3
methane = 96.50%	2
ethane = 1.80%	2
propane = 0.45%	2
other hydrocarbons = 0.35%	2
carbon dioxide = 0.60%	2
nitrogen = 0.30%	2

1 tonne water = 219.969 imperial gallons
1 mcm = 1 thousand (10^3) cubic metres (m^3)
1 mmcm = 1 million (10^6) cubic metres (m^3)
1 mmcmd = 1 million (10^6) cubic metres (m^3) per day
1 bcm = 1 billion (10^9) cubic metres (m^3)
1 tcm = 1 trillion (10^{12}) cubic metres (m^3)

	REFERENCE
Density of Pennsylvania fracking fluid waste (used or unused) = 1,200 kg m^{-3}	4
Density of Pennsylvania produced fluid = 1,200 kg m^{-3}	4
Density of other Pennsylvania fluid wastes = 1,000 kg m^{-3}	4
Density of liquid natural gas (LNG) = 0.45 tonnes m^{-3}	5
1 tonne LNG = 2.2222 m^3 LNG	5
1 tonne LNG = 1,300 m^3 natural gas (at 0°C and 1 atmosphere or 101.325 kPa)	5
1 m^3 LNG = 585 m^3 natural gas = 0.0007692 tonnes LNG	5
Greenhouse Gas (GHG) Conversion Factors (CVs) for Transport of Freight	6
A 0% laden rigid diesel HGV >17 tonnes = 0.76605 kg km^{-1} (see Table 16, p.31)	
A 100% laden rigid diesel HGV >17 tonnes = 1.09607 kg km^{-1} (see Table 16, p.31)	
An LNG tanker with > 200,000 m^{-3} (90,000 tonnes) LNG capacity = 0.00943 kg $tonne^{-1}$ km^{-1} (see Table 17, p.32)	

ASSUMPTIONS

1. The projections for UK gas imports: For the 15 years 2021 to 2035 and the 30 years 2021 to 2050 the projections are 768 and 1,641 billion cubic metres (bcm), respectively.

2. The level of replacement of imported gas that could justify the creation of a new industry: Replacement in the range 50 to 100% is considered to be the required ambition.

3. Targets for replacement: Based on the above assumptions, four target replacements are considered in this report:
TARGET (1) 384 bcm (50% for the 15 years 2021 to 2035); **TARGET (2)** 768 bcm (100% for the 15 years 2021 to 2035)
TARGET (3) 820 bcm (50% for the 30 years 2021 to 2050) and **TARGET (4)** 1,641 bcm (100% for the 30 years 2021 to 2050).

Frack

4. The Bowland-Hodder shale gas resource: The upper bound of the technically recoverable resource is 1,200 bcm.

5. The Bowland-Hodder Estimated Ultimate Recovery of gas per well: The most likely modelled 30-year estimate is 6.5 million cubic feet.

6. The numbers of wells required to meet shale gas targets: TARGET (1) 2,086, **TARGET (2)** 4,172, **TARGET (3)** 4,456 and **TARGET (4)** 8,913.

7. The amount of water required for hydraulic fracturing: 54,350 tonnes per well assuming a 2,500 metre lateral.

8. The amount of proppant required for hydraulic fracturing: 16,003 tonnes per well assuming a 2,500 metre lateral.

9. The amount of waste created concomitantly with gas extraction: 73,067 tonnes per billion cubic metres of gas or 10.39 tonnes per 100 tonnes of gas.

10. 40.0 km (25 miles) is assumed as a nominal average journey distance for estimates of HGV traffic and greenhouse gas emissions arising from the removal of waste and delivery of water and sand to well sites.

REFERENCES

1. Rutley's Elements of Mineralogy, H H Read, 25th Edition, p.381, 1953.
2. Methane and natural gas mass densities: https://www.unitrove.com/engineering/tools/gas/natural-gas-density
3. Society of Petroleum Engineers and ISO 13443 definition of STP (Standard Temperature and Pressure).
4. Paul Howard, Office of Oil & Gas Management, Department of Environmental Protection, Harrisburg, Pennslvania PA17101
5. Natural Gas Conversion Guide, Liquid Natural Gas, Section 2.3, Table 1, p.23, Internatioal Gas Union, 2019
6. 2019 Government Greenhouse Gas Conversion Factors for Company Reporting (Condensed or Full Set), BEIS, 9 August 2019
https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2019

EXECUTIVE SUMMARY

1. The Government considers security of energy supply an important issue. This is reflected in its policy to replace imported gas with gas extracted from UK shale deposits by hydraulic fracturing. However, there is no sign of a credible immediate threat to the UK's gas imports. On the contrary, worldwide gas resources continue to rise and and there is no shortage of competitive suppliers. Long term, there is more credence in a threat to the UK's energy supplies from the Government's lack of progress on the deployment of nuclear power.

2. The UK shale gas industry remains in an embryonic state and has yet to successfully construct and operate a test production well. This requires a well to be drilled, hydraulically fractured and gas to be extracted from it for six months in ideally one continuous operation. The results obtained provide valuable information concerning both scale-up and the impacts of scale-up. This report is focussed on the numbers of heavy goods vehicle journeys required for removal of waste from well sites and the delivery of water and sand to well sites. These are expected to cause the greatest negative impacts of fracking on the communities within and surrounding the area where well sites are located.

3. In the absence of hard evidence, the report sets out estimates of the magnitude of these impacts based on assumptions summarised in the Glossary and explained in detail throughout the report. Estimates based on the historical record of the Pennsylvania Marcellus shale gas industry will need to be adjusted as the impact of development of the Bowland Hodder shale gas play becomes apparent.

4. For a range of target replacements of imported gas with shale gas, the average weight of water and sand consumed and waste generated has been estimated to be between 32,000 and 68,000 tonnes per day and between 12 and 25 million annually . The total weight accumulated over the duration of the gas extraction process has been estimated to be between 175 and 747 million tonnes.

5. The transportation of water, sand and waste requires journeys by heavy goods vehicles, both with and without a payload. For this report a rigid 32 tonne 4-axle vehicle with a payload of 18 tonnes or 4,000 imperial gallons of water has been chosen for illustrative purposes. The number of empty journeys has been minimised by assuming that all journeys that remove waste are carried out by vehicles that leave well sites empty following delivery of water or sand. It has also been assumed that journeys on public roads will be restricted by a transport management plan that allows travel for 59.5 hours a week: Monday to Friday 0730 to 1830 and Saturday 0730 to 1200.

6. These boundary conditions indicate that between 351 and 751 journeys will be required for every hour of the 59.5 hour week, equivalent to between 1.1 and 2.3 million journeys a year. If the journeys were occurring on 10 roads across the area, an enumerator on each road would observe a vehicle on one of these journeys between every 1 minute 43 seconds and every 48 seconds.

7. Estimates of traffic, the product of Fracking road tanker by Spencer Platt/ Getty Images (https://www.gettyimages.co.uk/)
calculated using an average journey distance of 40.0 km. Depending upon the shale gas production target, hourly traffic (during work hours) ranges from 14 to 30 thousand vehicle km and annual traffic from 43.5 to 92.9 million vehicle km.

8. Estimates of greenhouse gas (GHG) emissions resulting from vehicular traffic have also been calculated. Again depending upon shale gas production targets, hourly emissions (during work hours) range from 22.6 to 48.3 tonnes and annual emissions from 70.0 to 149.5 thousand tonnes (CO_2 equivalent).

9. The Table below provides a summary of the main numerical findings of the report.

10. There is evidence that the Government will have difficulty supporting a UK shale gas industry beyond its current embryonic state:

(a) Current projections for carbon reduction are not on track to meet the fourth (2023-2027) and fifth (2028-2032) carbon budgets[1].
(b) The Climate Change Act 2008 carbon reduction target for 2050 is not certain to be met[1].
(c) The 2015 Paris Agreement requires efforts to limit a global temperature increase to 1.5^{o}C, more demanding than the 2^{o}C implicit in the 2008 Act.
(d) The UK's committment to meet a target of net zero emissions by 2050, signed into law on 27 June 2019.

11. Amongst the measures set out in the Government's 2017 Clean Growth Strategy policy document[2] are the need "to drive a significant acceleration in the pace of decarbonisation" and the need for domestic policies that "keep us on track to meet our carbon budgets". The Government[3] anticipates that by 2050 "emissions from the power sector could need to be close to zero" and recognises the "need to reduce the emissions created by heating our homes and businesses."

12. The major source of these emissions is gas. For 2021-2050 the National Grid estimates that gas will contribute 268.68 bcm (billion cubic metres) to electricity generation and 791.35 bcm to residential heat demand. The total contribution of 1,060.03 bcm is 64.6% of gas imports for 2021-2050. If the Government was successful in implementing these measures by 2050 it would reduce the need to import gas to levels that would render a UK shale gas industry redundant.

13. Shale gas extraction by hydraulic fracturing is an impressive technology but there is no denying that its commercial exploitation has created an unsightly, noisy and polluting heavy industry that is accepted elsewhere but has no place in rural England. Existing industries that are vital to the sustainable growth of the UK economy are continually seeking academically and professionally qualified technicians, engineers, technologists and scietists. It would be counterproductive to divert the UK's limited pool of talent into an industry that is neither sustainable nor is its product renewable.

REFERENCES

1. UK Carbon Budgets, Briefing Paper CBP7555, House of Commons Library, 20 February 2019.
2. The Clean Growth Strategy, HM Government, 12 October 2017, p.9.
3. Ibid., pp.8,95.

	REPLACEMENT OF IMPORTED GAS					JOURNEY DATA (see NOTE 1)				PAYLOAD	TRAFFIC	GHG EMISSIONS	
	Target Period												
	Inclusive Years	No. of Years	% of Imports	Volume (billion cubic metres)	No. of Wells Required	Time Period (see NOTE 2)	Journeys Without Payload (number)	Journeys With Payload (number)	All Journeys (number)	(see NOTE 3) Total Payload (tonnes)	Total Traffic (vehicle km)	Effective Conversion Factor (kg km-1)	Total Emissions CO_2e (tonnes)
TARGET 1	2021-2035	15	50	384	2,086	Hourly	142	209	351	3,766	14,053	1.60966	22.6
TARGET 2	2021-2035	15	100	768	4,172	Hourly	284	418	703	7,533	28,107	1.60966	45.2
TARGET 3	2021-2050	30	50	820	4,456	Hourly	152	224	375	4,024	15,012	1.60966	24.2
TARGET 4	2021-2050	30	100	1,641	8,913	Hourly	304	447	751	8,047	30,025	1.60966	48.3
TARGET 1	2021-2035	15	50	384	2,086	Annually	439,616	647,414	1,087,030	11,653,446	43,481,186	1.60966	69,990
TARGET 2	2021-2035	15	100	768	4,172	Annually	879,232	1,294,827	2,174,059	23,306,893	86,962,372	1.60966	139,980
TARGET 3	2021-2050	30	50	820	4,456	Annually	469,617	691,595	1,161,212	12,448,711	46,448,468	1.60966	74,766
TARGET 4	2021-2050	30	100	1,641	8,913	Annually	939,233	1,383,190	2,322,423	24,897,423	92,896,935	1.60966	149,532
TARGET 1	2021-2035	15	50	384	2,086	15 Years	6,594,239	9,711,205	16,305,445	174,801,697	652,217,788	1.60966	1,049,849
TARGET 2	2021-2035	15	100	768	4,172	15 Years	13,188,479	19,422,411	32,610,889	349,603,394	1,304,435,575	1.60966	2,099,698
TARGET 3	2021-2050	30	50	820	4,456	30 Years	14,088,499	20,747,852	34,836,351	373,461,340	1,393,454,029	1.60966	2,242,987
TARGET 4	2021-2050	30	100	1,641	8,913	30 Years	28,176,997	41,495,704	69,672,701	746,922,680	2,786,908,058	1.60966	4,485,975

NOTES

1. Journey numbers are based on a 32 tonne 4-axle rigid HGV with a payload of 18 tonnes or 4,000 imperial gallons of water.
2. Hourly numbers are based on a 59.5 hour week: Weekdays Monday to Friday 0730 to 1830 and Saturday 0730 to 1200.
3. A Total Payload in the Table is, on average, by weight, 64.9% water, 19.1% proppant and 16.0% waste but each type of material is required to be transported separately.

EXPLANATORY NOTES .

1. The Government considers security of energy supply an important issue. This is reflected in its current determination to replace imported gas with gas extracted from UK shale deposits by hydraulic fracturing.

2. A concern for UK gas imports first arose in 2004 at the time of gas pipeline disputes between Russia and the Ukraine. This had a lasting effect until 2017 when, for the first time, 98.6 million cubic metres of identifiable Russian gas imports arrived in the form of liquid natural gas or LNG (0.2% of gas imports for that year). The biggest exporter of gas to the UK in 2018 was Norway: 34,086 million cubic metres by pipeline and 300 million cubic metres shipped as LNG. Together these represent 72.9% of total gas imports for 2018. Recently, gas imports have been drawn into the Brexit controversy with a claim that disgruntled EU bureaucrats, quite legally, could delay gas supplies through the gas interconnectors between the UK, The Netherlands and Belgium.
The UK imported 5,906 million cubic metres of gas (12.5% of total imports) by this means in 2018. If delays should happen there are many enthusiastic gas exporters ready to fill the gap, such as our longtime friend and ally Norway, not a member of the EU, and Qatar which exported 2,906 million cubic metres to the UK in the form of LNG in 2018 (6.2% of UK imports for that year).

2. An historical record of UK gas imports, gas exports and gas demand for the years 2000 - 2018 is shown in Table 1. It indicates that for that period Norway supplied 62.6% of the UK's gas imports (of which 62.1% was gas and 0.5% LNG). Qatar supplied 17.7% (all LNG) and The Netherlands and Belgium (shown as "Continent") supplied 15.9% (all gas). For the 4 years 2000-2003 the UK was a net exporter of gas. For the 10 years 2004-2013 net imports increased steadily from 1.4 to 52.3% of gas demand. For the 5 years 2014-2018 net imports have been stable. For example, in 2018 the gas demand was 80.0 bcm (billion cubic metres) of which 39.5 bcm or 49.4% were net imports. In contrast, the National Grid's "Consumer Evolution" future energy scenario (see below) predicts that in 2050 the demand for gas will be down to 66 bcm of which 88% or 58 bcm will need to be imported.

3. In July 2018 National Grid published four scenarios for future demand and supply of energy of all types in the UK : "Community Renewables", "Two Degrees", "Steady Progression" and "Consumer Evolution". Tables 1.1 and 1.2 summarise the role that gas plays in each of these scenarios and provide quantitative data for the amount of gas that would need to be replaced. Consumer Evolution is the focus of this report since it predicts the greatest need for imported gas.

4. The Bowland-Hodder shale formation in Northern England has been identified as a potentially rich source of shale gas, with some similarities to the Marcellus formation in the Appalachian basin of the United States. The role that the Bowland-Hodder formation might play as a source of home-produced gas is set out in Table 4. It can be noted that no estimate, including Cuadrilla's upper bound value of 1,200 bcm, meets National Grid's Consumer Evolution requirement for 1,641 bcm to be imported for the 30-year period 2021-2050.

5. The Bowland-Hodder resource estimates shown in Tab Fracking road tanker by Spencer Platt/ Getty Images (https://www.gettyimages.co.uk/)
A more reliable estimate of resource can be expected before too long for a specific well site. On 15 October 2018 the developer Cuadrilla commenced hydraulic fracturing at its two horizontal shale gas exploration wells located at Preston New Road, Westby-with-Plumptons, Fylde, Lancashire. In a press release dated 12 October 2018 Cuadrilla announced that the fracturing process was expected to take three months. Gas flow rates would be measured over the following six months, with the first results being published in the first quarter of 2019. However, substantial data have yet to be published.

6. The characteristics of shale gas extraction by hydraulic fracturing typically result in an exponential or hyperbolic decline in the rate of production. Six months of operation is sufficient to provide a useful prediction of (1) the rate of decline for up to 30 years (2) when it would be necessary to drill a new well to maintain an overall required rate and (3) the amount of gas that the well can produce over its lifetime (commonly assumed to be 30 years), known as the well's EUR or Estimated Ultimate Recoverable amount of gas.

7. Pennsylvania is the major beneficiary of Marcellus shale gas. An average EUR value of 0.10113 billion cubic metres has been calculated for all 5,119 Marcellus wells in Pennsylvania that were active between January 2010 and July 2014, a prerequisite being that every well in the analysis had to have an initial production period of at least 6 months between the two dates. An exponential curve was fitted to the production data to illustrate an average performance and this is reproduced in Figure 4.1.

8. Whilst waiting for actual extraction rates for the Bowland-Hodder shale, Cuadrilla's consultants Anderson Thompson modelled an estimated EUR of 0.18406 billion cubic metres. This has been used to calculate estimates of the numbers of wells that would be required to meet UK targets for replacing gas imports. The results are shown in Table 4. It would require 2,086 to replace 50% of imports for 15 years, 4,172 to replace 100% for 15 years, 4,456 to replace 50% for 30 years and 8,913 to replace 100% for 30 years.

9. A record of hydraulically fracked well development in the Pennsylvania Marcellus is shown in Table 5. From its early beginnings in the 1970s up to the end of December 2018 the Pennsylvania Department of Environmental Protection (PADEP) permitted 21,036 wells to be drilled. Of these 11,699 (55.6%) have actually been drilled and of these 8,553 (73.1%) produced gas in 2018. The annual number of new wells drilled peaked in 2011 at 1,958. Since then the number has been on an unsteady downward trend with a minimum of 503 in 2016. In 2018 the number was 781.

10. Table 6 provides a summary of gas production for the Pennsylvania Marcellus. From 2004, the first year of production, to the end of 2018, total production was 907 bcm but 79% of this (717 bcm) was produced during the 5 years 2014-2018. These figures can be compared with 387 to 1,461 bcm, the range of potential targets for the Bowland-Hodder to substitute for UK gas imports. From 2004 to 2007 the average per well per day shale gas production rate was low and erratic but from 2008 to 2013 it rose steadily from 3.58 to 52.43 mcm (thousand cubic metres). From 2014 to 2018 it remained steady at, on average, 55.2 mcm. Many variables could contribute to the establishment of such a dynamic equilibrium, perhaps the most important being the maintenance of a constant average age. This can be achieved if new wells become operational at a similar rate to that for wells reaching the end of their useful lives.

11. Table 6 also provides a summary of concomitant waste generation for the Pennsylvania Marcellus. Waste generation shows a similar pattern of behaviour to that for gas production. From 2004 to 2007 the amount of waste generated per unit of gas produced exhibited no stability. From 2008 to 2014 it fell continuously from 1,739 to 84 tonnes per million cubic metres. From 2015 to 2018 there are signs of stability with a range of 69 to 75 and an average of 73.067 tonnes The gas industry requires accurate measurements of gas flow. Waste measurements are not so important and PADEP, the authority responsible for waste regulation in Pennsylvania, has needed time to install a satisfactory reporting and inspection system. It is therefore considered reasonable to conclude that the accuracy of early waste data is in doubt but the figure of 73 tonnes per million cubic metres is acceptable as a representative waste generation rate for the Pennsylvania Marcellus.

12. Cuadrilla reported in a press release on 6 February 2019 that the gas it has been recovering from the Bowland-Hodder shale at Preston New Road "has a very high methane content". This is of interest because it allows an estimate to be made of the mass of waste produced by shale gas extraction per unit

mass of gas produced. The density of pure methane is 0.671 kg m^{-3} at STP (15^{o}C and 100 kPa)[3,4]. A typical high methane content natural gas with the following composition has a density of 0.703 kg m^{-3} at STP[4]: methane (CH_4) 96.5%, ethane (C_2H_6) 1.8%, propane (C_3H_8) 0.45%, other hydrocarbons 0.35%, carbon dioxide 0.6% and nitrogen 0.3%.

13. A typical waste generation rate for the Marcellus of 10.39 tonnes per 100 tonnes of natural gas produced can be derived from the typical waste generation rate of 73.067 tonnes of waste per million cubic metres of gas and the density of 703 tonnes per million cubic metres of a typical high methane content natural gas. This figure has been used for illustrative purposes in this report.

14. Details of waste generation and disposal for the Pennsylvania Marcellus from 2004 to 2018 are reported in Tables 8 - 11. The well operator is required to report to PADEP, currently every month, the amount of waste that has left a well, its destination and method of disposal. This requirement has resulted in the submission of 679,707 reports describing the disposal of 76,755,924 tonnes of waste. PADEP has codified 12 types of waste and has identified 21 methods of disposal. These are set out in Table 8. Table 9 is a summary of the annual amounts of waste by type and Table 10 is a summary of annual amounts of waste by method of disposal. Table 11 is subdivided into 32 small tables. 16 for waste amounts by type: one for each of the 15 years from 2004 to 2018 and one for the period 2004 - 2018. The remaining 16 are a repeat of the first 16 but with waste type replaced with disposal method. This format allows easier recognition of changes to amounts of waste and methods of disposal over the years.

15. Table 11.16a indicates that for 2004-2018 the contributions of Produced Fluid and Fracturing Fluid Waste to total waste are 67.7 and 16.9%, respectively. These figures are not accurate because Produced Fluid and Fracking Fluid Waste were required to be reported as one type of waste for 2017 and 2018. If the contributions are recalculated for 2004-2016 (i.e. data for 2017 and 2018 are omitted) the contribution is 58.7% for Produced Fluid and 24.7% for Fracturing Fluid Waste.

16. Tables 7.1 - 7.3 provide estimates of the amounts of waste generated and the numbers of heavy goods vehicle (HGV) journeys needed for their disposal that ararise from Bowland-Hodder gas production. The estimates are based on the average recorded waste generation rate for the Marcellus between 2014 and 2018 (either 73,067 tonnes per billion cubic metres of gas produced or 10.39 tonnes per 100 tonnes of gas produced). Table 7.1 indicates that the target Bowland-Hodder gas production range of 383.93 to 1,640.52 billion cubic metres is equivalent to a weight range of 269.9 to 1,153.3 million tonnes and the resulting range of generated waste is 28.1 to 119.9 million tonnes.

17. Storage space on a Bowland-Hodder well site is expected to be low and essentially waste has to be removed as fast as it is generated. The 28.1 million tonnes figure (para.16) refers to waste generated by 2,086 wells over 15 years. It is equivalent to an average of 5,120 tonnes for every day of every year or 35,965 tonnes per week. One current Cuadrilla Transport Management Plan restricts HGV journeys to 59.5 hours per week, that is, Monday to Friday 0730 to 1630 and Saturday 0730 to 1200. If this plan remains valid and 32 tonne 4-axle HGVs with a payload of 18 tonnes are employed, removal of 35,965 tonnes would require 34 HGV journeys every hour from Monday to Friday 0730 to 1630 and Saturday 0730 to 1200.

18. The 119.9 million tonnes figure (para.16) refers to waste generated by 8,913 wells over 30 years. It is equivalent to an average of 10,939 tonnes for every day of every year or 76,839 tonnes per week. To remove this amount in 59.5 hours using vehicles with a payload of 18 tonnes would require 72 journeys an hour.

19. The hydraulic fracturing of shale requires a fluid with three constituents: water, proppant and additives. A typical composition by volume is proppant (up to 10%), additives (up to 2%) and the balance water. The purpose of a proppant is to keep open the cracks created in the shale by the high pressure injection of fracturing fluid. Additives are chemicals added to the fracturing fluid in small amounts for a wide range of purposes.

20. The following assumptions have been made to arrive at estimates for water requirements for Bowland-Hodder shale gas extraction:

i Water is needed to hydraulically fracture 2,086 to 8,913 wells, as set out in Table 4.1.
ii The lateral length of each well is 2,500 metres.
iii The water requirement for a lateral length of 1 metre is 21.74 cubic metres. This figure is the average for over 5,000 Marcellus wells with an average lateral length of 1,203 metres.
iv The water requirement for each well is therefore 2,500 x 21.74 = 54,350 cubic metres or 54,350 tonnes.

Table 12 is based on the above assumptions and indicates the water requirements for the four targets for gas import substitution set out in Table 4. It also indicates the number of journeys needed to deliver the required water using 32 tonne 4-axle road tankers with a payload of 4,000 imperial gallons or 18 tonnes.

21. A proppant plays a vital role in determing the rate at which gas leaves fractured shale and enters the well bore. As small particles dispersed throughout the fracturing fluid, it enters the cracks created by high pressure injection of the fluid. The injection pressure must exceed the natural compressive stress that exists below the surface and put the shale into tension so that flaws in the shale will create a network of cracks through which trapped gas can escape. Following crack formation, the applied pressure is removed and the proppant holds the cracks open as the natural compressive force of the surrounding shale returns.

22. With a 95% share, silica proppant dominates the commercial market. Resin coated silica (2%) and alumina based ceramics (3%) make up the balance. Silica (SiO_2) is washed and sieved quartz sand. Its performance is generally satisfactory except in the deepest laterals where its crush resistance is inadequate. Resin coated silica has higher crush resistance because the resin spreads the load. This provides better performance at greater depths. Ceramic proppants offer best performance at greater depths but are the most expensive. Starting with the aluminium ore bauxite, complex processing procedures are used to produce uniform-sized, smooth spheres of up to 100% alumina (Al_2O_3) in the form of corundum - with a hardness second to that of diamond amongst natural minerals.

23. For the purposes of this report quartz sand has been used to illustrate the amounts of proppant required to meet import reduction targets. The fracturing fluid has been chosen to consist of a water/proppant mixture containing 90% water and 10% proppant together with unspecified types and amounts of additives. Weights of quartz sand proppant have been calculated using a density of 2,650 kg per cubic metre. Table 13 is based on the above assumptions and indicates the proppant requirements for the four targets for gas import substitution set out in Table 4. It also indicates the number of journeys needed to deliver the required proppant using 32 tonne 4-axle HGVs with a payload of 18 tonnes.

24. As already described, Tables 7.3,12 &13 provide estimates of the numbers of HGV journeys required to remove waste from well sites and to deliver water water and proppant to well sites. Each journey to remove waste has the potential to require an empty vehicle to drive to the site to carry out that task and each joutneyto deliver water or proppant has the potential to generate an empty return journey. The effect of these non-payload journeys on total journey numbers is set out in Table 12. Using import reduction Targets 1 & 4 as examples, when non-payload journeys are added to payload journeys, total hourly journey numbers are doubled from 209 to 418 and from 447 to 894, respectively.

25. However, the application of transportation logistics could reduce numbers of non-payload journeys significantly. For example, following delivery of water or proppant to a well site, there is potential for the empty vehicle to be directed to remove waste from, for example, the same well pad site or one close by. This eliminates the need to send an empty HGV to the well site for this purpose and concomitantly provides a payload for an otherwise empty vehicle. Since water and proppant delivery journeys far outnumber waste removal journeys it might be possible to reduce to zero the necessity to send empty trucks to remove waste.

26. Table 15 shows that if this were to be the case, the number of non-payload journeys would be reduced by 32.1 % and and all journeys by 16.0%. The majority of waste is fluid and road tankers that deliver water would appear to be the more appropriate for this task. Although not illustrated in the Table, clearly vehicles that deliver sand proppant would be the more appropriate for removal of solid waste.

27. It should be noted that journeys generated by water and proppant delivery and waste removal are additional to journeys generated (1) by the transportation of plant and equipment for drilling and fracturing between 2,086 and 8,913 wells, (2) for purposes of well and well site monitoring, maintenance and repair over the 15 to 30 year lifetime of a Bowland-Hodder shale gas play and (3) for the decommissioning of wells and well sites.

28. Table 16 sets out estimates of vehicular traffic and greenhouse gas (GHG) emissions that result from the HGV journeys identified in Table 15. Vehicular traffic is defined here as the product of the number of vehicles making a journey and the average journey length. For the purposes of this report a nominal 40 km has been chosen as the average journey length. GHG emissions are based on rates published by Government and are for a >17 tonne rigid diesel HGV: 0.76605 kg km^{-1} for 0% laden and 0.12125 kg $tonne^{-1}$ km^{-1} for 100% laden.

29. There is evidence that the Government will have difficulty supporting a UK shale gas industry beyond its current embryonic state. Current projections for carbon reduction are not on track to meet the fourth (2023-2027) and fifth (2028-2032) carbon budgets and the Climate Change Act 2008 carbon reduction target for 2050 itself is not certain to be met[1]. Beyond that, the 2015 Paris Agreement requires efforts to limit an average global temperature increase to 1.5^{o}C above pre-industrialisation levels. This is considerably more demanding than the 2^{o}C target implicit in the Climate Change Act 2008 and increases the urgency to reduce the use of fossil fuels. [1]UK Carbon Budgets, Briefing Paper CBP7555, House of Commons Library, 20 February 2019.

30. Amongst the measures set out in the Government's 2017 Clean Growth Strategy policy document[2] are the need "to drive a significant acceleration in the pace of decarbonisation" and set out domestic policies that "keep us on track to meet our carbon budgets". The Government[3] anticipates that by 2050 "emissions from the power sector could need to be close to zero" and recognises the "need to reduce the emissions created by heating our homes and businesses." The major source of these emissions is gas. For the years 2021-2050 the National Grid estimates that gas will contribute 268.68 bcm to electricity generation and 791.35 bcm to residential heat demand. The total contribution of 1,060.03 bcm is 64.6% of gas imports for 2021-2050. If the Government was successful in implementing these measures by 2050 it would reduce the need to import gas to levels that would render a UK shale gas industry redundant. [2] The Clean Growth Strategy, HM Government, 12 October 2017, p.9. [3] Ibid., pp.8,95.

31. Shale gas extraction by hydraulic fracturing is an impressive technology but there is no denying that its commercial exploitation has created a heavy industry in the Unites States that has no place in rural England. Existing industries that are vital to the sustainable growth of the UK economy are continually seeking academically and/or professionally qualified technicians, engineers, technologists and scietists. It would be counterproductive to divert the UK's limited pool of talent into an industry that, with a limited life in fossil fuel production, is neither sustainable nor is its product renewable.

Table 1 UK ANNUAL NATURAL GAS DEMAND, IMPORTS AND EXPORTS 2000 - 2018

	COUNTRIES EXPORTING NATURAL GAS TO THE UK														TOTAL		TOTAL	NET	DEMAND	NET	TOTAL LNG	
	Qatar		Russia		Norway						Continent (NOTE1)		Other		UK IMPORTS		EXPORTS	IMPORTS		IMPORTS	10^6 m^3	% of
	**LNG		LNG (NOTE 3)		LNG		Gas		LNG & Gas		Gas only		(LNG only)		LNG & GAS			(NOTE 4)		as a % of	(gas	total gas
YEAR	***10^6 m^3	%*	10^6 m^3	%	10^6 m^3	%	10^6 m^3	%	10^6 m^3	%	10^6 m^3	%	10^6 m^3	%	10^6 m^3	%	10^6 m^3	10^6 m^3	10^6 m^3	DEMAND	equivalent)	imports
2000	0.0	0.0	0.0	0.0	0.0	0.0	1,030.9	79.2	1,030.9	79.2	270.1	20.8	0.0	0.0	1,301.0	100.0	12,297.4	-10,996.4	102,321.0	-10.7	0.0	0.0
2001	0.0	0.0	0.0	0.0	0.0	0.0	1,158.0	75.9	1,158.0	75.9	367.0	24.1	0.0	0.0	1,525.0	100.0	11,389.7	-9,864.7	101,805.5	-9.7	0.0	0.0
2002	0.0	0.0	0.0	0.0	0.0	0.0	3,392.0	84.7	3,392.0	84.7	611.3	15.3	0.0	0.0	4,003.3	100.0	12,317.6	-8,314.3	100,476.6	-8.3	0.0	0.0
2003	0.0	0.0	0.0	0.0	0.0	0.0	6,327.3	94.0	6,327.3	94.0	401.0	6.0	0.0	0.0	6,728.2	100.0	15,252.9	-8,524.7	100,734.2	-8.5	0.0	0.0
2004	0.0	0.0	0.0	0.0	0.0	0.0	8,459.6	78.3	8,459.6	78.3	2,339.1	21.7	0.0	0.0	10,798.7	100.0	9,325.6	1,473.0	102,944.5	1.4	0.0	0.0
2005	0.0	0.0	0.0	0.0	0.0	0.0	11,304.8	80.7	11,304.8	80.7	2,203.5	15.7	499.6	3.6	14,007.9	100.0	7,340.2	6,667.8	100,321.7	6.6	499.6	3.6
2006	71.4	0.3	0.0	0.0	0.0	0.0	14,003.1	66.5	14,003.1	66.5	3,627.5	17.2	3,370.7	16.0	21,072.7	100.0	10,128.2	10,944.5	95,143.8	11.5	3,442.1	16.3
2007	246.7	0.8	0.0	0.0	0.0	0.0	20,338.8	69.1	20,338.8	69.1	7,699.4	26.2	1,156.6	3.9	29,441.5	100.0	9,967.4	19,474.2	96,198.0	20.2	1,403.3	4.8
2008	0.0	0.0	0.0	0.0	0.0	0.0	25,686.1	71.2	25,686.1	71.2	9,566.4	26.5	834.8	2.3	36,087.2	100.0	10,072.4	26,014.9	98,753.4	26.3	834.8	2.3
2009	6,966.7	16.5	0.0	0.0	129.1	0.3	24,689.5	58.5	24,818.7	58.9	7,202.7	17.1	3,183.3	7.5	42,171.4	100.0	11,883.5	30,287.8	92,079.7	32.9	10,279.1	24.4
2010	14,951.3	27.0	0.0	0.0	832.1	1.5	26,869.3	48.6	27,701.5	50.1	9,408.8	17.0	3,248.2	5.9	55,309.8	100.0	15,242.9	40,066.9	99,412.4	40.3	19,031.6	34.4
2011	21,552.4	39.5	0.0	0.0	931.2	1.7	22,510.6	41.2	23,441.9	42.9	6,815.4	12.5	2,813.7	5.2	54,623.3	100.0	15,963.5	38,659.8	82,684.5	46.8	25,297.3	46.3
2012	13,482.5	26.6	0.0	0.0	159.7	0.3	28,288.6	55.8	28,448.3	56.1	8,606.8	17.0	178.2	0.4	50,715.8	100.0	11,964.8	38,751.0	77,627.4	49.9	13,820.4	27.3
2013	8,736.3	17.7	0.0	0.0	97.9	0.2	28,986.5	58.8	29,084.4	59.0	10,905.1	22.1	583.3	1.2	49,309.1	100.0	8,985.9	40,323.3	77,057.4	52.3	9,417.5	19.1
2014	10,387.4	23.7	0.0	0.0	0.0	0.0	25,561.1	58.3	25,561.1	58.3	6,932.1	15.8	940.0	2.1	43,820.6	100.0	10,560.6	33,260.1	70,727.6	47.0	11,327.4	25.8
2015	12,931.6	28.4	0.0	0.0	55.3	0.1	28,103.8	61.7	28,159.1	61.8	3,523.1	7.7	938.3	2.1	45,552.1	100.0	14,218.6	31,333.5	72,741.0	43.1	13,925.2	30.6
2016	9,906.7	20.5	0.0	0.0	259.2	0.5	31,707.6	65.7	31,966.9	66.3	5,789.3	12.0	580.1	1.2	48,243.0	100.0	10,298.2	37,944.8	81,448.2	46.6	10,746.1	22.3
2017	5,822.8	12.3	98.6	0.2	0.0	0.0	35,889.8	76.1	35,889.8	76.1	4,517.5	9.6	827.1	1.8	47,155.8	100.0	11,342.5	35,813.3	79,344.6	45.1	6,748.5	14.3
2018	2,905.9	6.2	1,530.1	3.2	299.8	0.6	34,085.5	72.3	34,385.3	72.9	5,906.1	12.5	2,433.0	5.2	47,160.4	100.0	7,621.5	39,538.9	80,022.4	49.4	7,168.8	15.2
2000-2018	**107,961.8**	**17.7**	**1,628.7**	**0.3**	**2,764.3**	**0.5**	**378,393.0**	**62.1**	**381,157.3**	**62.6**	**96,692.0**	**15.9**	**21,586.9**	**3.5**	**609,026.8**	**100.0**	**216,173.4**	**392,853.4**	**1,711,843.8**	**22.9**	**#133,941.8**	**22.0**

* % refers to imported gas as a % of total imports.

** LNG = liquid natural gas, boiling point -162°C.

*** $10^6 m^3$ = million cubic metres gas or gas ec Fracking road tanker by Spencer Platt/ Getty Image

NOTES

1. Only the current five major gas exporters are identified in Table 1: Norway, The Netherlands, Belgium, Qatar and Russia (the last two LNG only). The Netherlands and Belgium are shown as "Continent".
2. Table 2 shows some minor exporters to the UK in 2018 (LNG only).
3. Russia supplied 3.2% of the UK's imported gas, as LNG, in 2018. Also, it is known that Russian gas arrives in the UK via the Continent interconnectors but BEIS does not specify a figure (see Source 2).
4. With the decline in North Sea gas, the UK became a net importer of gas in 2004. Between 2004 and 2018 the UK imported 595.5 billion cubic metres (bcm) of gas including 133.9 bcm or 22.5% as LNG. Norway supplied 369.2 bcm or 62.0% of all imports and Qatar 108.0 bcm or 80.6% of all LNG.

Table 2 (NOTE 2)

Other UK Exporters to the UK in 2018		
Country	10^6 m^3	%*
1. USA	1,216.3	2.58
2. Trinidad & Tobago	613.9	1.30
3. Algeria	224.4	0.48
4. Egypt	140.3	0.30
5. Equatorial Guinea	79.5	0.17
6. Peru	79.8	0.17
7. Nigeria	78.8	0.17
TOTAL	2,433.0	5.16

SOURCES

1. Natural Gas Supply & Consumption, Table 4.1, Energy Trends, BEIS, 19 December 2019.
   NOTE: This reference does not show UK gas demand for the years 2000 to 2007 in units of $10^6 m^3$.
   For these years, data reported in GWh are converted to $10^6 m^3$ by a factor of 11 GWh per $10^6 m^3$.
2. Natural Gas Imports and Exports, Table 4.3, Energy Trends, BEIS 19 December 2019.
3. "Gas Production from the UK Continenantal Shelf" The Oxford Institute for Energy Studies, Marshall Hall, July 2019.
   www.oxfordenergy.org › wpcms › wp-content › uploads › 2019/07

#With reference to Tabel 17 (p.32), it can be estimated that the delivery by ocean tanker of 133.9 bcm of natural gas (as LNG) generated approximately 10.9 million tonnes of greenhouse gases at rates of 730 thousand tonnes per annum and 106 kg per tonne of LNG imported. In the light of the increasing urgency to reduce the UK's greenhouse gas emissions, the UK Government should endeavour to reduce LNG imports in favour of increased pipeline imports from the Continent and Norway. Although not quantified in this report, it is generally accepted that greenhouse gas emissions generated by onshore and, in particular, offshore pipeline transportation, are significantly less than those generated by transportation of LNG.

2 A COMPARISON OF THE GAS SUPPLY PATTERNS FOR NATIONAL GRID's FOUR FUTURE ENERGY SUPPLY SCENARIOS

Table 2.1 GAS SUPPLY PATTERN FOR THE 15 YEARS 2021 - 2035

GAS SUPPLY SOURCE	CONSUMER EVOLUTION SCENARIO	STEADY PROGRESSION SCENARIO	RENEWABLES SCENARIO	TWO DEGREES SCENARIO
	billion cubic metres			
UK Continental Shelf	351.5	388.7	206.4	300.4
Shale	0.0	0.0	0.0	0.0
Green gas	15.9	8.2	31.9	19.3
Norway	483.7	409.3	288.1	391.4
Continent	74.0	70.0	66.0	54.7
Liquid natural gas (LNG)	114.0	122.8	112.6	94.3
Generic imports*	96.1	111.8	188.3	78.6
Demand	1,135.3	1,110.8	893.2	938.7
Import dependency %	67.6	64.3	73.3	65.9
50% (gross) Imports	383.9	357.0	327.5	309.5
100% (gross) Imports	767.9	713.9	655.0	619.0

Table 2.2 GAS SUPPLY PATTERN FOR THE 30 YEARS 2021 - 2050

GAS SUPPLY SOURCE	CONSUMER EVOLUTION SCENARIO	STEADY PROGRESSION SCENARIO	RENEWABLES SCENARIO	TWO DEGREES SCENARIO
	billion cubic metres			
UK Continental Shelf	451.1	388.7	216.6	346.9
Shale	0.0	0.0	0.0	0.0
Green gas	72.3	29.8	164.5	91.1
Norway	902.5	695.9	372.6	675.5
Continent	174.7	170.7	142.2	134.9
Liquid natural gas (LNG)	275.3	276.1	233.7	218.4
Generic imports*	288.0	454.4	355.8	385.1
Demand	2,163.9	2,119.0	1,485.4	1,852.0
Import dependency %	75.8	75.4	74.3	76.3
50% (gross) Imports	820.3	798.5	552.2	707.0
100% (gross) Imports	1,640.5	1,597.1	1,104.4	1,413.9

*A generic import is one for which the source cannot be identified specifically.
It is either the Continent, LNG or a mixture of both.

NOTES

1. "Consumer Evolution" is the scenario that predicts the greatest need for imported gas and hence the greatest demand for shale gas. Since a policy for creating a new industry must take into account the maximum projected demand that is expected of it, this scenario has been made the focus of this report.

2. The above scenarios, published by National Grid in July 2018, are updated versions of similar scenarios published in July 2017. A significant difference between them is the absence of shale gas in the current versions, because of uncertainties concerning the future of hydraulic fracturing in the UK. "Consumer Evolution" replaced "Consumer Power" which estimated that shale gas production for 2021 - 2035 would be 312.0 billion cubic metres and replace 35.5% of UK gas imports. For 2021 - 2050 shale gas production was estimated to be 790.5 billion cubic metres and replace 42.1% of gas imports.

3. It should be noted that the gas demand figures in TWh (terawatt hours) shown in Source 1, specify inclusion of gas connector exports and gas shrinkage. These are identical to the gas demand figures in bcm (billion cubic metres) shown in Source 2, that does not explicity make this specification. However, for the purposes of this report it is assumed that the specification is implicit and applies to the demand figures shown in Source 2. It can be noted that supply and demand are in balance in Figures 5.10, 5.11, 5.14 and 5.15 (Source 2).

SOURCES

1. Future Energy Scenarios Data Workbook, Version 2, Chapter 4: Energy Demand, National Grid, July 2018:
   Figure GD1 Annual Gas Demand (including interconnector exports and shrinkage).

2. Future Energy Scenarios Data Workbook, Version 2, Chapter 5: Energy Supply, National Grid, July 2018:
   Figure 5.10 Gas Supply Pattern in Community Renewables
   Figure 5.11 Gas Supply Pattern in Two Degrees
   Figure 5.14 Revised Gas Supply Pattern in Steady Progression
   Figure 5.15 Revised Gas Supply Pattern in Consumer Evolution (no shale gas sensitivity).

3 PUBLISHED ESTIMATES FOR THE BOWLAND-HODDER SHALE GAS RESOURCE AND PROJECTIONS FOR MEETING TARGETS TO REPLACE GAS IMPORTS REPORTED IN NATIONAL GRID'S "CONSUMER EVOLUTION" SCENARIO

	Table 3.1 PUBLISHERS OF ESTIMATES FOR TECHNICALLY RECOVERABLE RESOURCE[1]						
	Energy Contract Company		British Geological Survey and Department for Business, Energy & Industrial Strategy		US Energy Administration information	Cuadrilla	
Bowland-Hodder technically recoverable resource estimate*	lower bound	upper bound	lower bound	upper bound	mean	lower bound	upper bound
billion cubic metres (bcm)	60	110	80	200	540	900	1,200
	Table 3.2 IMPORT DATA FOR "CONSUMER EVOLUTION" SCENARIO[2]						
Target 1: 50% of imports for the period 2021-2035 (bcm)	383.9	383.9	383.9	383.9	383.9	383.9	383.9
15-year annual requirement (bcm)	25.6	25.6	25.6	25.6	25.6	25.6	25.6
Number of years supply	**2.3**	**4.3**	**3.1**	**7.8**	**21.1**	**35.2**	**46.9**
Target 2: 100% of imports for the period 2021-2035 (bcm)	767.9	767.9	767.9	767.9	767.9	767.9	767.9
15-year annual requirement (bcm)	51.2	51.2	51.2	51.2	51.2	51.2	51.2
Number of years supply	**1.2**	**2.1**	**1.6**	**3.9**	**10.5**	**17.6**	**23.4**
Target 3: 50% of imports for the period 2021-2050 (bcm)	820.3	820.3	820.3	820.3	820.3	820.3	820.3
30-year annual requirement (bcm)	27.3	27.3	27.3	27.3	27.3	27.3	27.3
Number of years supply	**2.2**	**4.0**	**2.9**	**7.3**	**19.7**	**32.9**	**43.9**
Target 4: 100% of imports for the period 2021-2050 (bcm)	1,640.5	1,640.5	1,640.5	1,640.5	1,640.5	1,640.5	1,640.5
30-year annual requirement (bcm)	54.7	54.7	54.7	54.7	54.7	54.7	54.7
Number of years supply	**1.1**	**2.0**	**1.5**	**3.7**	**9.9**	**16.5**	**21.9**

[blue] Indicates a target for import substitution with shale gas could not be achieved. (Blue cells: Target 1 – 2.3, 4.3, 3.1, 7.8; Target 2 – 1.2, 2.1, 1.6, 3.9, 10.5; Target 3 – 2.2, 4.0, 2.9, 7.3, 19.7; Target 4 – all.)

[green] Indicates a target for import substitution with shale gas could be achieved. (Green cells: Target 1 – 21.1, 35.2, 46.9; Target 2 – 17.6, 23.4; Target 3 – 32.9, 43.9.)

*A resource can defined as technically recoverable if it can be extracted using current exploration and production technology without consideration of economic and planning issues.

REFERENCES

1. G P Hammond and A O'Grady, Applied Energy, 185, p.1909, 2017.

2. Future Energy Scenarios Data Workbook Version 2, Table 5.15: Revised Gas Supply Pattern in Consumer Evolution (no shale gas sensitivity), National Grid, July 2018.

Fracking road tanker by Spencer Platt/ Getty Ima

4 ESTIMATES OF NUMBERS OF UNCONVENTIONAL (HYDRAULICALLY FRACTURED) WELLS REQUIRED TO REPLACE UK GAS IMPORTS

Cuadrilla's consultants Anderson Thompson have forecast a "most likely" Estimated Ultimate Recovery (EUR) of 6.5 billion cubic feet of gas for a 2.5 km Bowland-Hodder horizontal shale gas well[1]. An EUR is defined as the amount of gas that is technically recoverable from a well over its lifetime, commonly assumed to be 30 years. 6.5 billion can be compared with an average of 6.2 billion and a median of 5.0 billion for 4,936 wells in the Pennsylvania Marcellus that commenced production during the 7-year period 2008 to 2014 and for which production data are available up to June 2017[2].

An estimated EUR can be obtained by "decline curve analysis". Daily production rates (based on the average for a month's production) are plotted as a function of time and a best curve fit (typically exponential or hyperbolic) is found and extrapolated to obtain the intercept with the y axis (the initial daily flow rate) and the value of y at x equals 30 years. The area under the curve gives the EUR. An example of a decline curve is shown in Figure 4.1. It is the average curve for 5,119 wells based on monthly reports submitted to the Pennsylvania Department of Environmental Protection from 2010 to 2013. It can be calculated from this curve that 97% of the EUR is recovered in 7 years[3].

Table 4 is based on the Anderson Thompson EUR estimate of 6.5 billion cubic feet, shown as 0.18406 billion cubic metres. It indicates the number of wells required for each of the four target substitutions set out in Table 4 based on National Grid's Consumer Evolution Scenario. It also shows that approximately one well would have to be drilled, on average, every two days of the 15 or 30 year period if the target import replacement is 50% and one every day if the target is 100%.

Table 4 ESTIMATED WELL NUMBERS FROM EUR VALUE

TIME PERIOD	TARGET % of IMPORTS	GAS REQUIRED billion cubic metres	EUR VALUE billion cubic metres	NUMBER of WELLS REQUIRED	NUMBER of PADS REQUIRED (assuming 6 wells per pad)	AVERAGE NUMBER OF NEW WELLS PER WEEKDAY*
15 Years 2021-2035	50	383.9	0.18406	2,086	348	0.53
	100	767.9	0.18406	4,172	695	1.07
30 Years 2021-2050	50	820.3	0.18406	4,456	743	0.57
	100	1,640.5	0.18406	8,913	1,485	1.14

* i.e. not including Saturday or Sunday

Fracking road tanker by Spencer Platt/ Getty Images (https://www.ge

REFERENCES

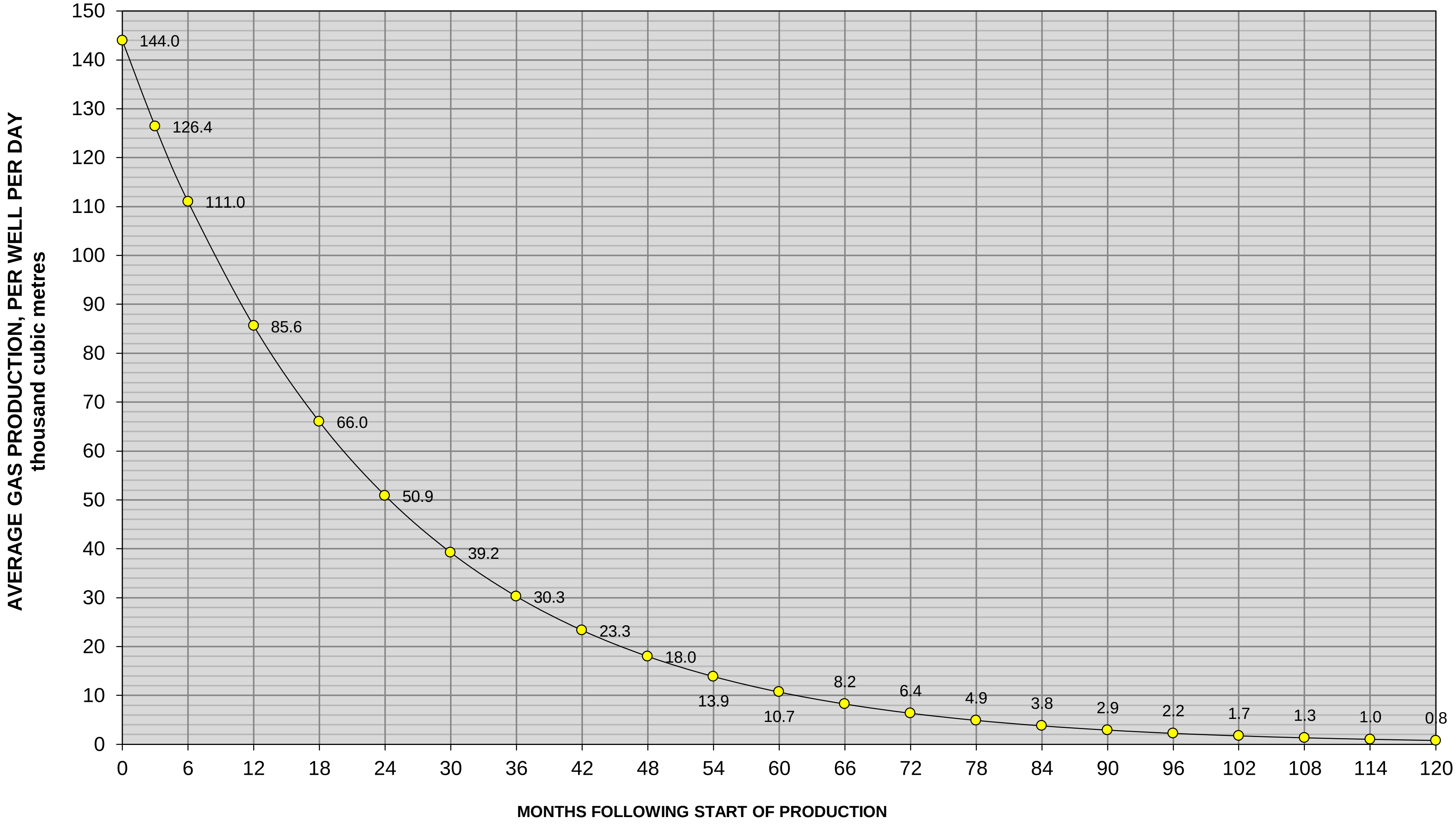
1. Cuadrilla: What is Fracking?, Gas-Model -120x78.png, 18 December 2017.
http://cuadrillaresources.com/about-fracking/what-is-fracking/

2. Estimated Ultimate Recovery (EUR) Study of 5,000 Marcellus Shale Wells, G S Swindell, February 2018.
www.gswindell.com/marcellus_eur_study.pdf

3. Devin Moeller and David Murphy, Biophysical Economics and Resource Quality, 1:5, Springer, 2016.

Figure 4.1 EXPONENTIAL DECLINE CURVE OF THE AVERAGE WELL

FOR PENNSYLVANIA WELLS ACTIVE FROM 1 JANUARY 2010 TO 30 JUNE 2014



The area under the curve at 30 years represents the well's EUR and has been calculated to be 0.10113 bcm.
Analysis of the curve indicates 97.3% of the EUR would be recovered at 84 months of production.
(Ref.3, page 11)

Curve equation: $y = 143.97e^{-0.26x}$

5 HISTORICAL RECORD AND STATUS OF UNCONVENTIONAL (HYDRAULICALLY FRACTURED) GAS WELLS IN PENNSYLVANIA

Table 5.1 STATUS AT 31/12/2018 OF PERMITTED WELLS

Well Status	Spud Date[4] Recorded	Spud Date Not Recorded	All Permitted Wells
Active	10,258	1,130	11,388
Operator Reported Not Drilled	1	5,931	5,932
Proposed But Never Materialized	0	2,263	2,263
Plugged	862	13	875
Regulatory Inactive	575	0	575
Abandoned	3	0	3
TOTAL	**11,699**	**9,337**	**21,036**

NOTES

1. A permit is required from the State before a well can be drilled and any gas is produced.
2. Following permission, the operator is required to submit a monthly report providing information on the status of the well, the amount of gas extracted and the types, amounts and methods of disposal of waste produced.
3. A well's configuration: vertical, horizontal or deviated, refers to the angle between the well bore and the surface: 90^0, 180^0 or any angle between these two, respectfully.
4. A spud date is the date when drilling of a well is commenced.
5. An active well is one with a permit but which has not necessarily been drilled or producing gas.
6. (Regulatory) inactive status is requested by a well operator for a well that is capable of producing gas but which is required to stop producing temporarily. This status is valid for an initial 5 years.
7. A plugged well is one that has been sealed and is no longer capable of producing gas.
8. An abandoned well is one that has not producd gas within 12 months of being drilled and must be plugged.

Table 5.2 DATA FOR WELLS WITH A RECORDED SPUD DATE

SPUD YEAR	WELL CONFIGURATION[3]				CURRENT STATUS OF WELLS WITH A RECORDED SPUD					
	Horizontal	Vertical	Deviated	TOTAL	Active[5]	Inactive[6]	Plugged[7]	Abandoned[8]	Not drilled	TOTAL
unknown	2	1	0	3	0	0	3	0	0	3
1974	0	1	0	1	0	0	1	0	0	1
1979	0	1	0	1	1	0	0	0	0	1
1982	0	1	0	1	1	0	0	0	0	1
1983	0	1	0	1	1	0	0	0	0	1
1984	0	2	0	2	1	0	1	0	0	2
1987	0	1	0	1	1	0	0	0	0	1
1995	0	1	0	1	0	1	0	0	0	1
1999	0	5	0	5	5	0	0	0	0	5
2002	0	1	0	1	1	0	0	0	0	1
2003	0	4	0	4	1	2	1	0	0	4
2004	0	2	0	2	2	0	0	0	0	2
2005	0	9	0	Fracking road tanker	2	0	7	0	0	9
2006	4	33	0	37	9	4	24	0	0	37
2007	18	95	0	113	56	8	49	0	0	113
2008	117	214	1	332	260	29	43	0	0	332
2009	613	208	0	821	708	38	73	2	0	821
2010	1,403	195	0	1,598	1,247	166	185	0	0	1,598
2011	1,836	122	0	1,958	1,597	120	240	0	1	1,958
2012	1,302	43	5	1,350	1,181	65	104	0	0	1,350
2013	1,182	29	0	1,211	1,153	30	28	0	0	1,211
2014	1,347	22	0	1,369	1,294	31	43	1	0	1,369
2015	783	1	0	784	705	32	47	0	0	784
2016	503	0	0	503	474	24	5	0	0	503
2017	810	0	0	810	789	21	0	0	0	810
2018	781	0	0	781	769	4	8	0	0	781
TOTALS	**10,701**	**992**	**6**	**11,690**	**10,258**	**575**	**862**	**3**	**1**	**11,699**

NOTE

1. Gas production from an unconventional well in Pennslvania was first reported in 2004.
2. Data for Table 5.3 below are taken from Table 6.

Table 5.3 GAS PRODUCTION 2004 - 2018

YEAR	Number of Wells Producing Gas	Total Annual Gas Production (10^6 cubic metres)	Average Gas Production per Well per Day (10^3 cubic metres)
2004	5	2	1.14
2005	11	3	0.71
2006	27	21	2.15
2007	88	54	1.69
2008	211	277	3.58
2009	948	4,983	14.39
2010	1,633	10,395	17.44
2011	1,953	30,181	42.35
2012	3,235	57,862	48.88
2013	4,591	87,865	52.43
2014	5,738	115,261	55.04
2015	6,275	130,284	56.89
2016	7,145	144,306	55.18
2017	7,794	151,887	53.39
2018	8,553	173,380	55.54
		AVERAGE 2014-2018	**55.21**

SOURCE: Bureau of Compliance & Data Administration, Office of Oil & Gas Management, Department of Environmental Protection, Pennsylvania, USA.

6 SUMMARY OF PENNSYLVANIA UNCONVENTIONAL GAS PRODUCTION AND CONCOMITANT WASTE GENERATION 2004 - 2018[1]

Table 6 ANNUAL GAS PRODUCTION AND WASTE GENERATION

	ITEM	UNIT	2004	2005	2006	2007	2008	2009	2010	2011
	Days in year	number	366	365	365	365	366	365	365	365
GAS PRODUCTION	Gas production reports submitted	number	5	11	27	88	211	949	1,633	3,905
GAS PRODUCTION	Producing wells	number	5	11	27	88	211	949	1,633	1,953
GAS PRODUCTION	Producing days	number	1,769	1,767	5,477	22,542	54,886	241,034	278,001	567,883
GAS PRODUCTION	Maximum producing days	number	1,830	4,015	9,855	32,120	77,226	346,197	376,499	712,663
GAS PRODUCTION	Capacity Factor	ratio	0.97	0.44	0.56	0.70	0.71	0.70	0.74	0.80
GAS PRODUCTION	Gas produced per year	10^6 cubic metres	2.08	2.84	21.19	54.16	276.68	4,982.95	10,394.80	30,180.94
GAS PRODUCTION	Gas produced per day	10^3 cubic metres	6	8	58	148	756	13,652	28,479	82,688
GAS PRODUCTION	Gas produced per well per year	10^6 cubic metres	0.42	0.26	0.78	0.62	1.31	5.25	6.37	15.46
GAS PRODUCTION	Gas produced per well per day	10^3 cubic metres	1.14	0.71	2.15	1.69	3.58	14.39	17.44	42.35
GAS PRODUCTION	Gas produced per well per day	10^6 cubic feet	0.04	0.02	0.08	0.06	0.13	0.51	0.62	1.50
WASTE GENERATION	Waste Reports submitted	number	6	8	19	1	1,263	3,777	6,260	15,418
WASTE GENERATION	Waste per 10^6 cubic metres of gas	metric tonnes	220.6	111.5	89.2	0.2	1,739.2	485.9	171.5	151.6
WASTE GENERATION	Waste per year	metric tonnes	459	316	1,889	11.45	481,184	2,421,192	1,782,928	4,575,905
WASTE GENERATION	Waste per well per year	metric tonnes	92	29	70	0.1	2,280	2,551	1,092	2,344
WASTE GENERATION	Waste per well per day	metric tonnes	0.3	0.1	0.2	0.0004	6.2	7.0	3.0	6.4
WASTE GENERATION	18 tonne HGV pay loads per well per year	number	5	2	4	0	127	142	61	130
WASTE GENERATION	18 tonne HGV pay loads per well per day	number	0.02	0.01	0.01	0.00003	0.49	0.54	0.23	0.50

	ITEM	UNIT	2012	2013	2014	2015	2016	2017	2018	15-YEAR TOTAL	5 -YEAR AVERAGE 2014 -2018
	Days in year	number	366	365	365	365	366	365	365		
GAS PRODUCTION	Gas production reports submitted	number	6,469	9,182	11,475	75,297	85,739	93,534	98,892	387,417	
GAS PRODUCTION	Producing wells	number	3,235	4,591	5,731	6,275	7,145	7,794	8,553	48,199	
GAS PRODUCTION	Producing days	number	1,006,057	Fracking ro	1,846,616	2,147,597	2,487,892	2,722,571	2,985,295	#VALUE!	
GAS PRODUCTION	Maximum producing days	number	1,183,827	1,675,715	2,091,633	2,290,284	2,615,040	2,844,810	3,121,875	17,383,588	
GAS PRODUCTION	Capacity Factor	ratio	0.85	#VALUE!	0.88	0.94	0.95	0.96	0.96	#VALUE!	0.94
GAS PRODUCTION	Gas produced per year	10^6 cubic metres	57,861.85	87,864.54	115,259.14	130,283.84	144,306.04	151,887.03	173,380.08	906,758	143,023.23
GAS PRODUCTION	Gas produced per day	10^3 cubic metres	158,092	240,725	315,778	356,942	394,279	416,129	475,014		391,628
GAS PRODUCTION	Gas produced per well per year	10^6 cubic metres	17.89	19.14	20.11	20.76	20.20	19.49	20.27		20.17
GAS PRODUCTION	Gas produced per well per day	10^3 cubic metres	48.88	52.43	55.10	56.89	55.18	53.39	55.54		55.22
GAS PRODUCTION	Gas produced per well per day	10^6 cubic feet	1.73	1.85	1.95	2.01	1.95	1.89	1.96		1.95
WASTE GENERATION	Waste Reports submitted	number	24,557	29,239	35,339	41,013	62,711	190,477	269,619	679,707	
WASTE GENERATION	Waste per 10^6 cubic metres of gas	metric tonnes	132.5	88.5	83.7	69.3	64.7	72.7	75.0		73.067
WASTE GENERATION	Waste per year	metric tonnes	7,665,699	7,776,252	9,645,733	9,023,511	9,338,092	11,037,646	13,005,106	76,755,924	10,410,018
WASTE GENERATION	Waste per well per year	metric tonnes	2,370	1,694	1,683	1,438	1,307	1,416	1,521		1,473
WASTE GENERATION	Waste per well per day	metric tonnes	6.5	4.6	4.6	3.9	3.6	3.9	4.2		4.03
WASTE GENERATION	18 tonne HGV pay loads per well per year	number	132	94	94	80	73	79	84		82
WASTE GENERATION	18 tonne HGV pay loads per well per day	number	0.50	0.36	0.36	0.31	0.28	0.30	0.32		0.31

NOTE 847 production and 2,668 waste reports for the 365 days 1 July 2009 to 30 June 2010 were assigned to 2009 and 2010 in the ratios 184/365 and 181/365, respectively.

REFERENCE

1. Production and Waste Reports, Office of Oil & Gas Management, Department of Environmental Protection, Harrisburg, Pennslvania PA17101

7 ESTIMATES OF BOWLAND-HODDER WASTE GENERATION AND HEAVY GOODS VEHICLE JOURNEYS REQUIRED FOR WASTE REMOVAL FROM WELL SITES

These estimates are based on gas production and waste generation for unconventional wells in Pennsylvania for the 5-year period 2014 - 2018 (ref.5). It should be noted that the traffic generated by the waste removal journeys shown in Table 7.3 is additional to traffic generated by the transportation of plant, equipment and materials required for drilling and fracturing and by traffic generated as a result of well site monitoring, maintenance and repair ovwer the lifetime of a well.

Also, it should be noted that well site storage space is limited and most if not all waste generated at a site will need to be removed at some stage during the lifetime of a well.

Table 7.1 ESTIMATED SHALE GAS PRODUCTION & WASTE GENERATION DATA FOR THE BOWLAND-HODDER

TARGET NUMBER	GAS IMPORTS REDUCTION %	PRODUCTION PERIOD years	WELLS REQUIRED number	GAS PRODUCTION REQUIRED (ref.10) billion cubic metres	GAS PRODUCTION REQUIRED (ref.10) tonnes (NOTE 1)	WASTE GENERATED (NOTE 2) tonnes per billion cubic metres	WASTE GENERATED (NOTE 2) tonnes	WASTE GENERATED (NOTE 2) tonnes per 100 tonnes gas
1	50	15	2,086	383.93	269,901,784	73,067	28,052,694.69	10.3937
2	100	15	4,172	767.86	539,803,569	73,067	56,105,389.38	10.3937
3	50	30	4,456	820.26	576,641,324	73,067	59,934,183.32	10.3937
4	100	30	8,913	1,640.52	1,153,282,649	73,067	119,868,366.64	10.3937

Table 7.2 WASTE GENERATED tonnes

TARGET NUMBER	NUMBER OF WELLS	Daily*	Weekly	Monthly	Annually	Full Period
1	2,086	5,120	35,965	155,848.3038	1,870,180	28,052,695
2	4,172	10,241	71,930	311,697	3,740,359	56,105,389
3	4,456	5,470	38,419	166,484	1,997,806	59,934,183
4	8,913	10,939	76,839	332,968	3,995,612	119,868,367

Table 7.3 NUMBERS OF HGV JOURNEYS REQUIRED FOR WASTE REMOVAL (NOTE 3)

TARGET NUMBER	WELLS	Hourly (NOTE 4)	Weekday 0730-1830	Saturday 0730-1200	Weekly	Monthly	Annually	Full Period
1	2,086	34	369	151	1,998	8,658	103,899	1,558,483
2	4,172	67	739	302	3,996	17,316	207,798	3,116,966
3	4,456	36	395	161	2,134	9,249	110,989	3,329,677
4	8,913	72	789	323	4,269	18,498	221,978	6,659,354

*To take leap years into account, the number of days in the year has been assumed to be 365.25.

Fracking road tanker by Spencer Platt/ Getty Im

NOTES

1. Cuadrilla has reported (ref.6) that the gas it has been recovering from the Bowland-Hodder shale at Preston New Road "has a very high methane content". The density of pure methane is 0.671 kg m^{-3} at STP (15°C and 100 kPa) (refs.7,8). A typical high methane content natural gas with the following composition has a density of 0.703 kg m^{-3} at STP (refs.7,8) : methane (CH_4) 96.5%, ethane (C_2H_6) 1.8%, propane (C_3H_8) 0.45%, other hydrocarbons 0.35%, carbon dioxide 0.6% and nitrogen 0.3%.

2. For the 5-year period 2014 - 2018, 73,067 metric tonnes of waste were generated for every billion cubic metres produced of gas produced. This equates to 10.39 tonnes of waste generated per 100 tonnes of gas produced, with an assumed natural gas density of 703,000 tonnes per billion cubic metres.

3. Journey numbers are based on a 32 tonne 4-axle HGV with a payload of 18 tonnes or 4,000 imperial gallons of water.

4. Hourly numbers are based on a 59.5 hour week: Monday to Friday 0730 to 1830 and Saturday 0730 to 1200 (ref.9).

REFERENCES

5. Office of Oil & Gas Management, Department of Environmental Protection, Harrisburg, Pennsylvania, PA 17101.

6. Cuadrilla Press Release, 6 February 2019.

7. Society of Petroleum Engineers and ISO definition of STP (Standard Temperature and Pressure).

8. Methane and natural gas mass densities: https://www.unitrove.com/engineering/tools/gas/natural-gas-density

9. Cuadrilla Bowland Limited, Transport Management Plan, 24 February 2017.

10. Future Energy Scenarios Data Workbook, Version 2, Chapter 5: Energy Supply, National Grid, July 2018.

8. PENNSYLVANIA RESIDUAL WASTE CODES (RWCs) AND METHODS OF DISPOSAL

RWC	WASTE CODE NAME	DESCRIPTION
802	Produced Fluid	Flow-back, brine and any other formation fluids recovered from the wellbore. Flow-back is defined as sand and fracturing/stimulation fluids that are recovered from the wellbore following injection under presure and that return to the surface following pressure release. Formation fluids occur naturally and are released by the fracturing process. Along with gas, they travel through the wellbore to the surface where separation takes place.
803	Drilling Fluid Waste	Drilling mud and other drilling fluids.
804	Wastewater Treatment Sludge	Sludge or sediment generated during processing or storage of wastewater and soil contaminated with 804.
805	Unused Fracturing Fluid Waste	Fracturing stimulation fluid (water and additives) and fracturing sand that have not been injected into a well bore.
806	Synthetic Liner Materials	Intended to encompass all synthetic liner materials used on a well site.
807	Sediment from Production Storage	Sediment from storage of a marketable oil or gas product.
808	Servicing Fluid	Oil and water-based mud and foam and well cellar cleanout waste, removed when drilling is complete. Also waste from production well maintenance and well work overs *.
809	Spent Lubricant	Well drilling and plug drilling lubricants.
810	Drill Cuttings	Rock cuttings and related mineral residues generated during the drilling of an oil or gas well.
811	Soil Contaminated by Spills	Soil contaminated by spills of Residual Waste Codes 802, 803, 805 & 807-810. Soils contaminated by 804 and 812 are coded 804 and 812, respectively.
812	Filter Socks	Filters, filter socks and other media used to filter wastewater. Also soil contaminated by spills of RWC 812.
899	Other Oil and Gas Wastes	All oil and gas wastes that are not already covered by existing Residual Waste Codes.

* A well work over can be carried out if routine maintenance does not maintain a satisfactory gas production rate and the cost is justified.

NOTES

1. The Pennslyvania Department of Environmental Protection (PADEP) is the official body that regulates Pennsylvania's oil and gas industries.
2. Unconventional gas production and its associated wastes were first reported to and published by PADEP in 2004.
4. A number of changes have been made to the coding system over the years.
3. The twelve Residual Waste Codes listed above are current and came into force on 1 January 2017.
4. In 2004 there were just three : Brine, Drilling and Fracking Fluid (later referred to as Fracing Fluid and currently Fracturing Fluid Waste).
5. In addition to the increase in Waste Types there have been other significant changes:
   i. In 2009-2010 Brine was renamed Produced Fluid and Drilling was divided into Drilling Fluid Waste and Drill Cuttings.
   ii Fracturing Fluid Waste was Code 804 from 2004 to 2015. In 2016 its Code was changed to 805 and Wastewater Treatment Sludge became 804.
   iii In 2017 Fracturing Fluid Waste was incorporated into Produc Fracking road tanker by Spencer Platt/ Getty Images (https://www.gettyimages.co.uk/)

METHODS FOR WASTE DISPOSAL

CODE**	DESCRIPTION
101	Reuse other than road spreading
102	Residual waste processing facility
103	Reuse at well pad
104	Landfill
105	Centralised treatment plant for recycle
106	Injection disposal well
107	Surface impoundment
108	Public sewage treatment plant
109	Identify method in Comment column of report
110	Central waste treatment facility, NPDES discharge**
111	Reuse at a well pad outside Pennsylvania

CODE	DESCRIPTION
112	Storage pending disposal or reuse
113	Residual waste transfer facility
114	Other
115	On site encapsulation
116	Land application
117	Reuse at a conventional well site in Pennsylvania
118	Treated on site, NPDES discharge ***
119	Road spreading
120	On site pit
121	Beneficial reuse permitted by rule

** Code assigned by Dorset CPRE

*** an NPDES discharge indicates a disharge carried out with a National Pollutant Discharge Elimination System permit.

NOTE ON UNITS OF MEASUREMENT

Pennsylvania well operators are required to report a quantity of waste in either US Barrels (a liquid measure) or US tons (2,000 lbs). For this report all waste is reported in metric tonnes. The following conversion factors have been used ****:

For Produced Fluid and Used and Unused Fracturing Fluid Waste a density of 1.2 tonnes per cubic metre is assumed and 1 US Barrel = 0.190785 metric tonnes.

For all other liquids the density of water is assumed and 1 US Barrel = 0.158987 metric tonnes.

1 US ton = 0.907185 metric tonnes.

**** On advice from Paul Howard, Mineral Resources Program Specialist, Bureau of Oil & Gas Planning and Program Management, Office of Oil & Gas Management, Department of Environmental Protection, Harrisburg, Pennslvania PA17101

9 HISTORICAL RECORD OF WASTE GENERATED BY HYDRAULICALLY FRACTURED (UNCONVENTIONAL) GAS WELLS IN PENNSYLVANIA

Table 9

	YEAR	2004		2005		2006		2007		2008		2009		2010		2011	
	NUMBER OF PRODUCING WELLS	5		11		27		88		211		948		1,633		1,953	
	GAS PRODUCED (million cubic metres)	2.1		2.8		21.2		54.2		277		4,990		10,420		30,181	
Waste Code	Waste Description	No. of Reports	Quantity metric tonnes	No. of Reports	Quantity metric tonnes	No. of Reports	Quantity metric tonnes	No. of Reports	Quantity metric tonnes	No. of Reports	Quantity metric tonnes	No. of Reports	Quantity metric tonnes	No. of Reports	Quantity metric tonnes	No. of Reports	Quantity metric tonnes
802	Produced Fluid	1	88	6	137	17	729	1	11	777	228,084	2,081	1,270,500	2,988	626,667.23	7,101	1,809,032
	Fracturing Fluid Waste	1	40	1	40	2	1,160			272	212,399.90	932	754,134	941	686,014	2,820	1,576,579.12
803	Drilling Fluid Waste	4	331	1	139					214	40,701	743	383,113	1,337	270,161	2,348	402,867
804	Waste Water Treatment Sludge																
805	Unused Fracturing Fluid Waste																
806	Synthetic Liner Materials																
807	Sediment from Production Storage											7	3,336	129	1,704	298	845
808	Servicing Fluids													1	1		
809	Spent Lubricant Waste											1	3	1	21	10	859
810	Drill Cuttings											13	10,106	862	198,360	2,841	785,723
811	Soil Contaminated by Oil & Gas Related Spills																
812	Filter Socks																
899	Other Oil & Gas Wastes																
	TOTAL WASTE	**6**	**459**	**8**	**316**	**19**	**1,889**	**1**	**11**	**1,263**	**481,184**	**3,777**	**2,421,192**	**6,260**	**1,782,928**	**15,418**	**4,575,905**
	WASTE PER WELL PER YEAR		**92**		**29**		**70**		**0**		**2,280**		**2,553**		**1,092**		**2,343**
	WASTE per WELL per million cubic metres GAS		**221**		**111**		**89**		**0**		**1,739**		**485**		**171**		**152**

Table 9 (continued)

	YEAR	2012		2013		2014		2015		2016		2017		2018		**2004 - 2018**		
	NUMBER OF PRODCING WELLS	3,235		4,591		5,738		6,275		7,145		7,794		8,553				
	GAS PRODUCED (million cubic metres)	57,862		87,865		115,261		130,284		144,306		151,887		173,380				
Waste Code	Waste Description	No. of Reports	Quantity metric tonnes	No. of Reports	Quantity metric tonnes	No. of Reports	Quantity metric tonnes	No. of Reports	Quantity metric tonnes	No. of Reports	Quantity metric tonnes	No. of Reports	Quantity metric tonnes	No. of Reports	Quantity metric tonnes	No. of Reports	Quantity metric tonnes	%
802	Produced Fluid	15,118	3,243,041	21,006	Fracking road ta	24,914	5,540,796.27	32,190	6,376,033	46,175	7,316,951	147,889	9,649,562	202,810	11,369,232	503,075	#VALUE!	#####
	Fracturing Fluid Waste	4,013	2,764,182.61	3,975	1,832,980	4,994	2,437,611.51	4,769	1,513,489	2,897	1,229,539.17					25,617	13,008,172	
803	Drilling Fluid Waste	2,075	336,961	1,804	247,866	2,146	285,142.66	1,520	180,554	1,105	105,647	2,996	161,279	4,522	237,528	20,815	2,652,291	3.5
804	Waste Water Treatment Sludge									621	11,764	1,353	15,650	2,126	21,709	4,100	49,124	0.1
805	Unused Fracturing Fluid Waste											429	9,735	274	2,791	703	12,526	0.0
806	Synthetic Liner Materials									1,674	39,999	3,494	14,974	3,810	18,030	8,978	73,004	0.1
807	Sediment from Production Storage	614	566	12	338	13	132.61	169	1,644	16	189	4	19	3	14	1,265	8,786	0.0
808	Servicing Fluids	42	1,672	38	4,073	35	2,644.73	154	7,302	727	19,124	273	4,007	1,211	32,817	2,481	71,641	0.1
809	Spent Lubricant Waste	52	822	13	7	10	16.99	1	35	14	62	9	69	19	31	130	1,926	0.0
810	Drill Cuttings	2,643	1,318,456	2,391	1,174,158	3,170	1,378,956.73	2,099	938,765	1,203	466,075	5,246	883,982	3,157	875,637	23,625	8,030,219	10.5
811	Soil Contaminated by Oil & Gas Related Spills									626	5,891	1,216	11,406	1,270	32,538	3,112	49,836	0.1
812	Filter Socks									239	46	394	186	299	1,232	932	1,464	0.0
899	Other Oil & Gas Wastes					57	431.60	111	5,688	7,414	142,803	27,174	286,775	50,118	413,546	84,874	849,244	1.1
	TOTAL WASTE	**24,557**	**7,665,699**	**29,239**	**3,259,423**	**35,339**	**9,645,733**	**41,013**	**9,023,511**	**62,711**	**9,338,092**	**190,477**	**11,037,646**	**269,619**	**13,005,106**	**679,707**	**#VALUE!**	**#####**
	WASTE PER WELL PER YEAR		**2,370**		**710**		**1,681**		**1,438**		**1,307**		**1,416**		**1,521**			
	WASTE PER MILLION CUBIC METRES OF GAS PRODUCED		**132**		**37**		**84**		**69**		**65**		**73**		**75**			

10. HISTORICAL RECORD OF DISPOSAL OF WASTE GENERATED BY HYDRAULICALLY FRACTURED (UNCONVENTIONAL) GAS WELLS IN PENNSYLVANIA

	YEAR	2004		2005		2006		2007		2008		2009		2010		2011	
	NUMBER OF PRODUCING WELLS	5		11		27		88		211		948		1,633		1,953	
Disposal Code	Waste Disposal Method	No. of Reports	Quantity metric tonnes	No. of Reports	Quantity metric tonnes	No. of Reports	Quantity metric tonnes	No. of Reports	Quantity metric tonnes	No. of Reports	Quantity metric tonnes	No. of Reports	Quantity metric tonnes	No. of Reports	Quantity metric tonnes	No. of Reports	Quantity metric tonnes
101	Reuse other than road spreading									149	7,848	479	151,331.91	582	340,828	4,069	2,113,745
102	Residual waste processing facility	5	371	6	295	14	1,701			392	147,075	1,124	1,206,335.19				
103	Reuse at well pad																
104	Landfill											7	3,057.46	737	152,266	3,653	789,408
105	Centralised treatment plant for recycle											915	329,078.43	3,855	1,006,994	4,933	1,149,768
106	Injection disposal well									4	1,122	43	6,390.73	454	68,699	2,447	425,929
107	Surface impoundment																
108	Public sewage treatment plant					1	139			534	251,643	460	314,351.86	110	48,770	137	8,627
109	Identify method in "Comment"											286	126,598.16	455	144,554	4	2,108
110	Central waste treatment facility NPDES discharge															7	1,769
111	Reuse at a well pad outside Pennsylvania																
112	Storage pending disposal or reuse											9	7,333.64	40	9,387	90	65,917
113	Residual waste transfer facility																
114	Other			2	21.0	3	40			182	73,463	446	274,378.48			26	9,130
115	On site encapsulation											6	2,282.03	22	10,733	52	9,503
116	Land application																
117	Reuse at a conventional well site in Pennsylvania																
118	Treated on site, NPDES discharge													1	624		
119	Road Spreading	1	88			1	9	1	11	2	32	3	53.65	3	74		
120	On site pit																
121	Beneficial reuse permitted by rule																
	TOTAL WASTE DISPOSED	**6**	**459**	**8**	**316**	**19**	**1,889**	**1**	**11**	**1,263**	**481,184**	**3,777**	**2,421,192**	**6,260**	**1,782,928**	**15,418**	**4,575,905**

	YEAR	2012		2013		2014		2015		2016		2017		2018		2004 - 2018		
	NUMBER OF PRODUCING WELLS	3,235		4,591		5,738		6,275		7,145		7,794		8,553				
Disposal Code	Waste Disposal Method	No. of Reports	Quantity metric tonnes	No. of Reports	latt/ Getty Image metric tonnes	No. of Reports	Quantity metric tonnes	No. of Reports	Quantity metric tonnes	No. of Reports	Quantity metric tonnes	No. of Reports	Quantity metric tonnes	No. of Reports	Quantity metric tonnes	No. of Reports	Quantity metric tonnes	%
101	Reuse other than road spreading	7,307	3,853,589	8,698	4,564,136	10,492	5,251,490	13,333	5,214,453.81	20,547	5,258,441	21	589			65,677	26,756,453	34.9
102	Residual waste processing facility	516	109,255	6,095	911,434	10,029	2,183,592	13,361	1,864,398.27	22,614	1,849,037	58,191	3,434,192	65,547	3,288,774	177,894	14,996,462	19.5
103	Reuse at well pad											96,401	5,060,144	157,090	6,881,091	253,491	11,941,235	15.6
104	Landfill	4,275	1,324,070	2,807	1,092,318	4,582	1,349,567	3,532	940,494.5387	4,100	480,901	9,946	896,186	9,851	921,485	43,490	7,949,753	10.4
105	Centralised treatment plant for recycle	4,898	766,706	2,545	389,521	139	9,900	1,393	273,222.94	6,772	1,262,059	393	21,799	324	5,427	26,167	5,214,475	6.8
106	Injection disposal well	7,087	1,350,375	8,152	632,580	8,946	712,757	8,334	581,206.88	6,918	416,227	10,495	572,113	11,549	603,461	64,429	5,370,861	7.0
107	Surface impoundment											9,668	868,684	17,454	1,039,732	27,122	1,908,415	2.5
108	Public sewage treatment plant	2	2,137									1	15	5	79	1,250	625,762	0.8
109	Identify method in "Comment"															745	273,260	0.4
110	Central waste treatment facility NPDES discharge	131	191,399	364	116,909	391	92,597	297	89,386.7965	163	16,620	341	9,524	182	1,507	1,876	519,713	0.7
111	Reuse at a well pad outside Pennsylvania											2,201	131,916	5,671	244,873	7,872	376,789	0.5
112	Storage pending disposal or reuse	154	61,976	180	28,014	430	24,618	160	14,564.14	415	38,680	465	28,314	339	13,438	2,282	292,240	0.4
113	Residual waste transfer facility	145	4,111	385	39,674	325	20,671	603	45,783.51	1,182	16,126	2,227	13,095	1,563	5,106	6,430	144,566	0.2
114	Other															659	357,032	0.5
115	On site encapsulation	22	1,995	12	1,647	4	507					4	84			122	26,750	0.03
116	Land application											7	93			7	93	0.0001
117	Reuse at a conventional well site in Pennsylvania											100	717	12	43	112	760	0.001
118	Treated on site, NPDES discharge	17	6													18	630	0.001
119	Road Spreading	3	81	1	20	1	34									16	405	0.001
120	On site pit											15	174	1	80	16	254	0.0003
121	Beneficial reuse permitted by rule											1	7	31	8	32	15	0.00002
	TOTAL WASTE DISPOSED	**24,557**	**7,665,699**	**29,239**	**7,776,252**	**35,339**	**9,645,733**	**41,013**	**9,023,511**	**62,711**	**9,338,092**	**190,477**	**11,037,646**	**269,619**	**13,005,106**	**679,707**	**76,755,924**	**100.0**

Table 11.1a 2004 WASTE TYPE REPORTS FOR 5 UNCONVENTIONAL WELLS				
Waste Code	Waste Description	No. of Reports	Quantity metric tonnes	%
802	Produced Fluid	1	88	19.2
	Fracturing Fluid Waste	1	40	8.8
803	Drilling Fluid Waste (Drilling)	4	331	72.0
804	Waste Water Treatment Sludge			
805	Unused Fracturing Fluid Waste			
806	Synthetic Liner Materials			
807	Sediment from Production Storage			
808	Servicing Fluids			
809	Spent Lubricant Waste			
810	Drill Cuttings			
811	Soil Contaminated by Oil & Gas Related Spills			
812	Filter Socks			
899	Other Oil & Gas Wastes			
	2004 TOTAL	**6**	**459**	**100.0**

Table 11.2a 2005 WASTE TYPE REPORTS FOR 11 UNCONVENTIONAL WELLS				
Waste Code	Waste Description	No. of Reports	Quantity metric tonnes	%
802	Produced Fluid	6	137	43.2
	Fracturing Fluid Waste	1	40	12.8
803	Drilling Fluid Waste (Drilling)	1	139	44.0
804	Waste Water Treatment Sludge			
805	Unused Fracturing Fluid Waste			
806	Synthetic Liner Materials			
807	Sediment from Production Storage			
808	Servicing Fluids			
809	Spent Lubricant Waste			
810	Drill Cuttings			
811	Soil Contaminated by Oil & Gas Related Spills			
812	Filter Socks			
899	Other Oil & Gas Wastes			
	2005 TOTAL	**8**	**316**	**100.0**

Table 11.1b 2004 WASTE DISPOSAL REPORTS FOR 5 UNCONVENTIONAL WELLS				
Disposal Code	Disposal Method	No. of Reports	Quantity metric tonnes	%
101	Reuse other than road spreading			
102	Residual waste processing facility	5	371	80.8
103	Reuse at well pad			
104	Landfill			
105	Centralised treatment plant for recycle			
106	Injection disposal well			
107	Surface impoundment			
108	Public sewage treatment plant			
109	Identify method in "Comment"			
110	Central waste treatment facility NPDES discharge			
111	Reuse at a well pad outside Pennsylvania	d tanker by Spencer Platt/ Getty Image		
112	Storage pending disposal or reuse			
113	Residual waste transfer facility			
114	Other			
115	On site encapsulation			
116	Land application			
117	Reuse at a conventional well site in Pennsylvania			
118	Treated on site, NPDES discharge			
119	Road Spreading	1	88	19.2
120	On site pit			
121	Beneficial reuse permitted by rule			
	2004 TOTAL	**6**	**459**	**100.0**

Table 11.2b 2005 WASTE DISPOSAL REPORTS FOR 11 UNCONVENTIONAL WELLS				
Disposal Code	Disposal Method	No. of Reports	Quantity metric tonnes	%
101	Reuse other than road spreading			
102	Residual waste processing facility	6	295	93.4
103	Reuse at well pad			
104	Landfill			
105	Centralised treatment plant for recycle			
106	Injection disposal well			
107	Surface impoundment			
108	Public sewage treatment plant			
109	Identify method in "Comment"			
110	Central waste treatment facility NPDES discharge			
111	Reuse at a well pad outside Pennsylvania			
112	Storage pending disposal or reuse			
113	Residual waste transfer facility			
114	Other	2	21	6.6
115	On site encapsulation			
116	Land application			
117	Reuse at a conventional well site in Pennsylvania			
118	Treated on site, NPDES discharge			
119	Road spreading			
120	On site pit			
121	Beneficial reuse permitted by rule			
	TOTAL 2005	**8**	**316**	**100.0**

Table 11.3a 2006 WASTE TYPE REPORTS FOR 27 UNCONVENTIONAL WELLS				
Waste Code	Waste Description	No. of Reports	Quantity metric tonnes	%
802	Produced Fluid	17	729	38.6
	Fracturing Fluid Waste	2	1,160	61.4
803	Drilling Fluid Waste (Drilling)			
804	Waste Water Treatment Sludge			
805	Unused Fracturing Fluid Waste			
806	Synthetic Liner Materials			
807	Sediment from Production Storage			
808	Servicing Fluids			
809	Spent Lubricant Waste			
810	Drill Cuttings			
811	Soil Contaminated by Oil & Gas Related Spills			
812	Filter Socks			
899	Other Oil & Gas Wastes			
	2006 TOTAL	**19**	**1,889**	**100.0**

Table 11.4a 2007 WASTE TYPE REPORTS FOR 88 UNCONVENTIONAL WELLS				
Waste Code	Waste Description	No. of Reports	Quantity metric tonnes	%
802	Produced Fluid	1	11	100.0
	Fracturing Fluid Waste			
803	Drilling Fluid Waste			
804	Waste Water Treatment Sludge			
805	Unused Fracturing Fluid Waste			
806	Synthetic Liner Materials			
807	Sediment from Production Storage			
808	Servicing Fluids			
809	Spent Lubricant Waste			
810	Drill Cuttings			
811	Soil Contaminated by Oil & Gas Related Spills			
812	Filter Socks			
899	Other Oil & Gas Wastes			
	2007 TOTAL	**1**	**11**	**100.0**

Table 11.3b 2006 WASTE DISPOSAL REPORTS FOR 27 UNCONVENTIONAL WELLS				
Disposal Code	Disposal Method	No. of Reports	Quantity metric tonnes	%
101	Reuse other than road spreading			
102	Residual waste processing facility	14	1,701	90.0
103	Reuse at well pad			
104	Landfill			
105	Centralised treatment plant for recycle			
106	Injection disposal well			
107	Surface impoundment			
108	Public sewage treatment plant	1	139	7.4
109	Identify method in "Comment"			
110	Central waste treatment facility NPDES discharge			
111	Reuse at a well pad outside Pennsylvania			
112	Storage pending disposal or reuse			
113	Residual waste transfer facility			
114	Other	3	40	2.1
115	On site encapsulation			
116	Land application			
117	Reuse at a conventional well site in Pennsylvania			
118	Treated on site, NPDES discharge			
119	Road Spreading	1	9	0.5
120	On site pit			
121	Beneficial reuse permitted by rule			
	2006 TOTAL	**19**	**1,889**	**100.0**

Table 11.4b 2007 WASTE DISPOSAL REPORTS FOR 88 UNCONVENTIONAL WELLS				
Disposal Code	Disposal Method	No. of Reports	Quantity metric tonnes	%
101	Reuse other than road spreading			
102	Residual waste processing facility			
103	Reuse at well pad			
104	Landfill			
105	Centralised treatment plant for recycle			
106	Injection disposal well			
107	Surface impoundment			
108	Public sewage treatment plant			
109	Identify method in "Comment"			
110	Central waste treatment facility NPDES discharge			
111	Reuse at a well pad outside Pennsylvania			
112	Storage pending disposal or reuse			
113	Residual waste transfer facility			
114	Other			
115	On site encapsulation			
116	Land application			
117	Reuse at a conventional well site in Pennsylvania			
118	Treated on site, NPDES discharge			
119	Road Spreading	1	11	100.0
120	On site pit			
121	Beneficial reuse permitted by rule			
	TOTAL 2007	**1**	**11**	**100.0**

Table 11.5a 2008 WASTE TYPE REPORTS FOR 211 UNCONVENTIONAL WELLS				
Waste Code	Waste Description	No. of Reports	Quantity metric tonnes	%
802	Produced Fluid	777	228,084	47.4
	Fracturing Fluid Waste	272	212,399.90	44.1
803	Drilling Fluid Waste (Drilling)	214	40,701	8.5
804	Waste Water Treatment Sludge			
805	Unused Fracturing Fluid Waste			
806	Synthetic Liner Materials			
807	Sediment from Production Storage			
808	Servicing Fluids			
809	Spent Lubricant Waste			
810	Drill Cuttings			
811	Soil Contaminated by Oil & Gas Related Spills			
812	Filter Socks			
899	Other Oil & Gas Wastes			
	2008 TOTAL	**1,263**	**481,184**	**100.0**

Table 11.6a 2009 WASTE TYPE REPORTS FOR 948 UNCONVENTIONAL WELLS				
Waste Code	Waste Description	No. of Reports	Quantity metric tonnes	%
802	Produced Fluid	2,081	1,270,500	52.5
	Fracking Fluid Waste	932	754,134	31.1
803	Drilling Fluid Waste (Drilling)	743	383,113	15.8
804	Waste Water Treatment Sludge			
805	Unused Fracturing Fluid Waste			
806	Synthetic Liner Materials			
807	Sediment from Production Storage	7	3,336	0.1
808	Servicing Fluids			
809	Spent Lubricant Waste	1	3	0.0001
810	Drill Cuttings	13	10,106	0.4
811	Soil Contaminated by Oil & Gas Related Spills			
812	Filter Socks			
899	Other Oil & Gas Wastes			
	2009 TOTAL	**3,777**	**2,421,192**	**100.0**

Table 11.5b 2008 WASTE DISPOSAL REPORTS FOR 211 UNCONVENTIONAL WELLS				
Disposal Code	Disposal Method	No. of Reports	Quantity metric tonnes	%
101	Reuse other than road spreading	149	7,848	1.6
102	Residual waste processing facility	392	147,075	30.6
103	Reuse at well pad			
104	Landfill			
105	Centralised treatment plant for recycle			
106	Injection disposal well	4	1,122	0.2
107	Surface impoundment			
108	Public sewage treatment plant	534	251,643	52.3
109	Identify method in "Comment"			
110	Central waste treatment facility NPDES discharge			
111	Reuse at a well pad outside Pennsylvania			
112	Storage pending disposal or reuse			
113	Residual waste transfer facility			
114	Other	182	73,463	15.3
115	On site encapsulation			
116	Land application			
117	Reuse at a conventional well site in Pennsylvania			
118	Treated on site, NPDES discharge			
119	Road Spreading	2	32	0.01
120	On site pit			
121	Beneficial reuse permitted by rule			
	TOTAL 2008	**1,263**	**481,184**	**100.0**

Table 11.6b 2009 WASTE DISPOSAL REPORTS FOR 948 UNCONVENTIONAL WELLS				
Disposal Code	Disposal Method	No. of Reports	Quantity metric tonnes	%
101	Reuse other than road spreading	479	151,331.91	6.3
102	Residual waste processing facility	1,124	1,206,335.19	49.8
103	Reuse at well pad			
104	Landfill	7	3,057.46	0.1
105	Centralised treatment plant for recycling	915	329,078.43	13.6
106	Injection disposal well	43	6,390.73	0.3
107	Surface impoundment			
108	Public sewage treatment plant	460	314,351.86	13.0
109	Identify method in "Comment"	286	126,598.16	5.2
110	Central waste treatment facility NPDES discharge			
111	Reuse at a well pad outside Pennsylvania			
112	Storage pending disposal or reuse	9	7,333.64	0.3
113	Residual waste transfer facility			
114	Other	446	274,378.48	11.3
115	On site encapsulation	6	2,282.03	0.1
116	Land application			
117	Reuse at a conventional well site in Pennsylvania			
118	Treated on site, NPDES discharge			
119	Road spreading	3	53.65	0.002
120	On site pit			
121	Beneficial reuse permitted by rule			
	TOTAL 2009	**3,777**	**2,421,192**	**100.0**

Table 11.7a 2010 WASTE TYPE REPORTS FOR 1,633 UNCONVENTIONAL WELLS				
Waste Code	Waste Description	No. of Reports	Quantity metric tonnes	%
802	Produced Fluid	2,988	626,667.23	35.1
	Fracking Fluid Waste	941	686,014	38.5
803	Drilling Fluid Waste	1,337	270,161	15.2
804	Waste Water Treatment Sludge			
805	Unused Fracturing Fluid Waste			
806	Synthetic Liner Materials			
807	Sediment from Production Storage	129	1,704	0.1
808	Servicing Fluids	1	1	0.0001
809	Spent Lubricant Waste	1	21	0.001
810	Drill Cuttings	862	198,360	11.1
811	Soil Contaminated by Oil & Gas Related Spills			
812	Filter Socks			
899	Other Oil & Gas Wastes			
	2010 TOTAL	**6,260**	**1,782,928**	**100.0**

Table 11.8a 2011 WASTE TYPE REPORTS FOR 1,953 UNCONVENTIONAL WELLS				
Waste Code	Waste Description	No. of Reports	Quantity metric tonnes	%
802	Produced Fluid	7,101	1,809,032	39.5
	Fracturing Fluid Waste	2,820	1,576,579.12	34.5
803	Drilling Fluid Waste	2,348	402,867	8.8
804	Waste Water Treatment Sludge			
805	Unused Fracturing Fluid Waste			
806	Synthetic Liner Materials			
807	Sediment from Production Storage	298	845	0.02
808	Servicing Fluids			
809	Spent Lubricant Waste	10	859	0.02
810	Drill Cuttings	2,841	785,723	17.2
811	Soil Contaminated by Oil & Gas Related Spills			
812	Filter Socks			
899	Other Oil & Gas Wastes			
	2011 TOTAL	**15,418**	**4,575,905**	**100.0**

Table 11.7b 2010 WASTE DISPOSAL REPORTS FOR 1,633 UNCONVENTIONAL WELLS				
Disposal Code	Disposal Method	No. of Reports	Quantity metric tonnes	%
101	Reuse other than road spreading	582	340,828	19.1
102	Residual waste processing facility			
103	Reuse at well pad			
104	Landfill	737	152,266	8.5
105	Centralised treatment plant for recycle	3,855	1,006,994	56.5
106	Injection disposal well	454	68,699	3.9
107	Surface impoundment			
108	Public sewage treatment plant	110	48,770	2.7
109	Identify method in "Comment"	455	144,554	8.1
110	Central waste treatment facility NPDES discharge			
111	Reuse at a well pad outside Pennsylvania			
112	Storage pending disposal or reuse	40	9,387	0.5
113	Residual waste transfer facility			
114	Other			
115	On site encapsulation	22	10,733	0.6
116	Land application			
117	Reuse at a conventional well site in Pennsylvania			
118	Treated on site, NPDES discharge	1	624	0.03
119	Road spreading	3	74	0.004
120	On site pit			
121	Beneficial reuse permitted by rule			
	TOTAL 2010	**6,260**	**1,782,928**	**100.0**

Table 11.8b 2011 WASTE DISPOSAL REPORTS FOR 1,953 UNCONVENTIONAL WELLS				
Disposal Code	Disposal Method	No. of Reports	Quantity metric tonnes	%
101	Reuse other than road spreading	4,069	2,113,745	46.2
102	Residual waste processing facility			
103	Reuse at well pad			
104	Landfill	3,653	789,408	17.3
105	Centralised treatment plant for recycle	4,933	1,149,768	25.1
106	Injection disposal well	2,447	425,929	9.3
107	Surface impoundment			
108	Public sewage treatment plant	137	8,627	0.2
109	Identify method in "Comment"	4	2,108	0.05
110	Central waste treatment facility NPDES discharge	7	1,769	0.04
111	Reuse at a well pad outside Pennsylvania			
112	Storage pending disposal or reuse	90	65,917	1.4
113	Residual waste transfer facility			
114	Other	26	9,130	0.2
115	On site encapsulation	52	9,503	0.2
116	Land application			
117	Reuse at a conventional well site in Pennsylvania			
118	Treated on site, NPDES discharge			
119	Road spreading			
120	On site pit			
121	Beneficial reuse permitted by rule			
	TOTAL 2011	**15,418**	**4,575,905**	**100.0**

Table 11.9a 2012 WASTE TYPE REPORTS FOR 3,235 UNCONVENTIONAL WELLS				
Waste Code	Waste Description	No. of Reports	Quantity metric tonnes	%
802	Produced Fluid	15,118	3,243,041	42.3
	Fracturing Fluid Waste	4,013	2,764,182.61	36.1
803	Drilling Fluid Waste	2,075	336,961	4.4
804	Waste Water Treatment Sludge			
805	Unused Fracturing Fluid Waste			
806	Synthetic Liner Materials			
807	Sediment from Production Storage	614	566	0.01
808	Servicing Fluids	42	1,672	0.02
809	Spent Lubricant Waste	52	822	0.01
810	Drill Cuttings	2,643	1,318,456	17.20
811	Soil Contaminated by Oil & Gas Related Spills			
812	Filter Socks			
899	Other Oil & Gas Wastes			
	2012 TOTAL	**24,557**	**7,665,699**	**100.0**

Table 11.10a 2013 WASTE TYPE REPORTS FOR 4,591 UNCONVENTIONAL WELLS				
Waste Code	Waste Description	No. of Reports	Quantity metric tonnes	%
802	Produced Fluid	21,006	4,516,829	58.1
	Fracturing Fluid Waste	3,975	1,832,980	23.6
803	Drilling Fluid Waste	1,804	247,866	3.2
804	Waste Water Treatment Sludge			
805	Unused Fracturing Fluid Waste			
806	Synthetic Liner Materials			
807	Sediment from Production Storage	12	338	0.004
808	Servicing Fluids	38	4,073	0.05
809	Spent Lubricant Waste	13	7	0.0001
810	Drill Cuttings	2,391	1,174,158	15.1
811	Soil Contaminated by Oil & Gas Related Spills			
812	Filter Socks			
899	Other Oil & Gas Wastes			
	2013 TOTAL	**29,239**	**7,776,252**	**100.0**

Table 11.9b 2012 WASTE DISPOSAL REPORTS FOR 3,235 UNCONVENTIONAL WELLS				
Disposal Code	Disposal Method	No. of Reports	Quantity metric tonnes	%
101	Reuse other than road spreading	7,307	3,853,589	50.3
102	Residual waste processing facility	516	109,255	1.4
103	Reuse at well pad			
104	Landfill	4,275	1,324,070	17.3
105	Centralised treatment plant for recycle	4,898	766,706	10.0
106	Injection disposal well	7,087	1,350,375	17.6
107	Surface impoundment			
108	Public sewage treatment plant	2	2,137	0.03
109	Identify method in "Comment"			
110	Central waste treatment facility NPDES discharge	131	191,399	2.5
111	Reuse at a well pad outside Pennsylvania			
112	Storage pending disposal or reuse	154	61,976	0.8
113	Residual waste transfer facility	145	4,111	0.1
114	Other			
115	On site encapsulation	22	1,995	0.03
116	Land application			
117	Reuse at a conventional well site in Pennsylvania			
118	Treated on site, NPDES discharge	17	6	0.0001
119	Road spreading	3	81	0.001
120	On site pit			
121	Beneficial reuse permitted by rule			
	TOTAL 2012	**24,557**	**7,665,699**	**100.0**

Table 11.10b 2013 WASTE DISPOSAL REPORTS FOR 4,591 UNCONVENTIONAL WELLS				
Disposal Code	Disposal Method	No. of Reports	Quantity metric tonnes	%
101	Reuse other than road spreading	8,698	4,564,136	58.7
102	Residual waste processing facility	6,095	911,434	11.7
103	Reuse at well pad			
104	Landfill	2,807	1,092,318	14.0
105	Centralised treatment plant for recycle	2,545	389,521	5.0
106	Injection disposal well	8,152	632,580	8.1
107	Surface impoundment			
108	Public sewage treatment plant			
109	Identify method in "Comment"			
110	Central waste treatment facility NPDES discharge	364	116,909	1.5
111	Reuse at a well pad outside Pennsylvania			
112	Storage pending disposal or reuse	180	28,014	0.4
113	Residual waste transfer facility	385	39,674	0.5
114	Other			
115	On site encapsulation	12	1,647	0.02
116	Land application			
117	Reuse at a conventional well site in Pennsylvania			
118	Treated on site, NPDES discharge			
119	Road spreading	1	20	0.0003
120	On site pit			
121	Beneficial reuse permitted by rule			
	TOTAL 2013	**29,239**	**7,776,252**	**100.0**

Table 11.11a 2014 WASTE TYPE REPORTS FOR 5,731 UNCONVENTIONAL WELLS				
Waste	Waste Description	No. of	Quantity	
Code		Reports	metric tonnes	%
802	Produced Fluid	24,914	5,540,796.27	57.4
	Fracturing Fluid Waste	4,994	2,437,611.51	25.3
803	Drilling Fluid Waste	2,146	285,142.66	3.0
804	Waste Water Treatment Sludge			
805	Unused Fracturing Fluid Waste			
806	Synthetic Liner Materials			
807	Sediment from Production Storage	13	132.61	0.001
808	Servicing Fluids	35	2,644.73	0.03
809	Spent Lubricant Waste	10	16.99	0.0002
810	Drill Cuttings	3,170	1,378,956.73	14.3
811	Soil Contaminated by Oil & Gas Related Spills			
812	Filter Socks			
899	Other Oil & Gas Wastes	57	431.60	0.004
	2014 TOTAL	**35,339**	**9,645,733**	**100.0**

Table 11.12a 2015 WASTE TYPE REPORTS FOR 6,275 UNCONVENTIONAL WELLS				
Waste	Waste Description	No. of	Quantity	
Code		Reports	metric tonnes	%
802	Produced Fluid	32,190	6,376,033	70.7
	Fracturing Fluid Waste	4,769	1,513,489	16.8
803	Drilling Fluid Waste (in Barrels)	1,520	180,554	2.0
804	Waste Water Treatment Sludge			
805	Unused Fracturing Fluid Waste			
806	Synthetic Liner Materials			
807	Sediment from Production Storage	169	1,644	0.02
808	Servicing Fluids	154	7,302	0.1
809	Spent Lubricant Waste	1	34.76	0.0004
810	Drill Cuttings	2,099	938,765	10.4
811	Soil Contaminated by Oil & Gas Related Spills			
812	Filter Socks			
899	Other Oil & Gas Wastes	111	5,688	0.1
	TOTAL 2015	**41,013**	**9,023,511**	**100.0**

Table 11.11b 2014 WASTE DISPOSAL REPORTS FOR 5,731 UNCONVENTIONAL WELLS				
Disposal	Disposal Method	No. of	Quantity	
Code		Reports	metric tonnes	%
101	Reuse other than road spreading	10,492	5,251,490	54.4
102	Residual waste processing facility	10,029	2,183,592	22.6
103	Reuse at well pad			
104	Landfill	4,582	1,349,567	14.0
105	Centralised treatment plant for recycle	139	9,900	0.1
106	Injection disposal well	8,946	712,757	7.4
107	Surface impoundment			
108	Public sewage treatment plant			
109	Identify method in "Comment"			
110	Central waste treatment facility NPDES discharge	391	92,597	1.0
111	Reuse at a well pad outside Pennsylvania			
112	Storage pending disposal or reuse	430	24,618	0.3
113	Residual waste transfer facility	325	20,671	0.2
114	Other			
115	On site encapsulation	4	507	0.005
116	Land application			
117	Reuse at a conventional well site in Pennsylvania			
118	Treated on site, NPDES discharge			
119	Road spreading	1	34	0.0004
120	On site pit			
121	Beneficial reuse permitted by rule			
	TOTAL 2014	**35,339**	**9,645,733**	**100.0**

Table 11.12b 2015 WASTE DISPOSAL REPORTS FOR 6,275 UNCONVENTIONAL WELLS				
Disposal	Disposal Method	No. of	Quantity	
Code		Reports	metric tonnes	%
101	Reuse other than road spreading	13,333	5,214,453.81	57.8
102	Residual waste processing facility	13,361	1,864,398.27	20.7
103	Reuse at well pad			
104	Landfill	3,532	940,494.5387	10.4
105	Centralised treatment plant for recycle	1,393	273,222.94	3.0
106	Injection disposal well	8,334	581,206.88	6.4
107	Surface impoundment			
108	Public sewage treatment plant			
109	Identify method in "Comment"			
110	Central waste treatment facilility NPDES discharge	297	89,386.7965	1.0
111	Reuse at a well pad outside Pennsylvania			
112	Storage pending disposal or reuse	160	14,564.14	0.2
113	Residual waste transfer facility	603	45,783.51	0.5
114	Other			
115	On site encapsulation			
116	Land application			
117	Reuse at a conventional well site in Pennsylvania			
118	Treated on site, NPDES discharge			
119	Road spreading			
120	On site pit			
121	Beneficial reuse permitted by rule			
	TOTAL 2015	**41,013**	**9,023,511**	**100.0**

Table 11.13a 2016 WASTE TYPE REPORTS FOR 7,145 UNCONVENTIONAL WELLS				
Waste Code	Waste Description	No. of Reports	Quantity metric tonnes	%
802	Produced Fluid	46,175	7,316,951	78.4
	Fracturing Fluid Waste	2,897	1,229,539.17	13.2
803	Drilling Fluid Waste	1,105	105,647	1.1
804	Waste Water Treatment Sludge	621	11,764	0.1
805	Unused Fracturing Fluid Waste			
806	Synthetic Liner Materials	1,674	39,999	0.4
807	Sediment from Production Storage	16	189	0.002
808	Servicing Fluids	727	19,124	0.2
809	Spent Lubricant Waste	14	62	0.001
810	Drill Cuttings	1,203	466,075	5
811	Soil Contaminated by Oil & Gas Related Spills	626	5,891	0.1
812	Filter Socks	239	46	0.0005
899	Other Oil & Gas Wastes	7,414	142,803	1.5
	2016 TOTAL	**62,711**	**9,338,092**	**100.0**

Table 11.13b 2016 WASTE DISPOSAL REPORTS FOR 7,145 UNCONVENTIONAL WELLS				
Disposal Code	Disposal Method	No. of Reports	Quantity metric tonnes	%
101	Reuse other than road spreading	20,547	5,258,441	56.3
102	Residual waste processing facility	22,614	1,849,037	19.8
103	Reuse at well pad			
104	Landfill	4,100	480,901	5.1
105	Centralised treatment plant for recycle	6,772	1,262,059	13.5
106	Injection disposal well	6,918	416,227	4.5
107	Surface impoundment			
108	Public sewage treatment plant			
109	Identify method in "Comment"			
110	Central waste treatment facility NPDES discharge	163	16,620	0.2
111	Reuse at a well pad outside Pennsylvania			
112	Storage pending disposal or reuse	415	38,680	0.4
113	Residual waste transfer facility	1,182	16,126	0.2
114	Other			
115	On site encapsulation			
116	Land application			
117	Reuse at a conventional well site in Pennsylvania			
118	Treated on site, NPDES discharge			
119	Road spreading			
120	On site pit			
121	Beneficial reuse permitted by rule			
	TOTAL 2016	**62,711**	**9,338,092**	**100.0**

Table 11.14a 2017 WASTE TYPE REPORTS FOR 7,794 UNCONVENTIONAL WELLS				
Waste Code	Waste Description	No. of Reports	Quantity metric tonnes	%
802	Produced Fluid	147,889	9,649,562	87.4
	Fracturing Fluid (included with Produced Fluid)			
803	Drilling Fluid Waste	2,996	161,279	1.5
804	Waste Water Treatment Sludge	1,353	15,650	0.1
805	Unused Fracturing Fluid Waste	429	9,735	0.1
806	Synthetic Liner Materials	3,494	14,974	0.1
807	Sediment from Production Storage	4	19	0.0002
808	Servicing Fluids	273	4,007	0.04
809	Spent Lubricant Waste	9	69	0.0006
810	Drill Cuttings	5,246	883,982	8
811	Soil Contaminated by Oil & Gas Related Spills	1,216	11,406	0.1
812	Filter Socks	394	186	0.002
899	Other Oil & Gas Wastes	27,174	286,775	2.6
	TOTAL 2017	**190,477**	**11,037,646**	**100.0**

Table 11.14b 2017 WASTE DISPOSAL REPORTS FOR 7,794 UNCONVENTIONAL WELLS				
Disposal Code	Disposal Method	No. of Reports	Quantity metric tonnes	%
101	Reuse other than road spreading	21	589	0.01
102	Residual waste processing facility	58,191	3,434,192	31.1
103	Reuse at well pad	96,401	5,060,144	45.8
104	Landfill	9,946	896,186	8.1
105	Centralised treatment plant for recycle	393	21,799	0.2
106	Injection disposal well	10,495	572,113	5.2
107	Surface impoundment	9,668	868,684	7.9
108	Public sewage treatment plant	1	15	0.0001
109	Identify method in "Comment"			
110	Central waste treatment facility NPDES discharge	341	9,524	0.1
111	Reuse at a well pad outside Pennsylvania	2,201	131,916	1.2
112	Storage pending disposal or reuse	465	28,314	0.3
113	Residual waste transfer facility	2,227	13,095	0.1
114	Other			
115	On site encapsulation	4	84	0.001
116	Land application	7	93	0.001
117	Reuse at a conventional well site in Pennsylvania	100	717	0.01
118	Treated on site, NPDES discharge			
119	Road spreading			
120	On site pit	15	174	0.002
121	Beneficial reuse permitted by rule	1	7	0.0001
	TOTAL 2017	**190,477**	**11,037,646**	**100.0**

Table 11.15a 2018 WASTE TYPE REPORTS FOR 8,553 UNCONVENTIONAL WELLS				
Waste Code	Waste Description	No. of Reports	Quantity metric tonnes	%
802	Produced Fluid	202,810	11,369,232	87.4
	Fracturing Fluid (included with Produced Fluid)			
803	Drilling Fluid Waste	4,522	237,528	1.8
804	Waste Water Treatment Sludge	2,126	21,709	0.17
805	Unused Fracturing Fluid Waste	274	2,791	0.02
806	Synthetic Liner Materials	3,810	18,030	0.14
807	Sediment from Production Storage	3	14	0.0001
808	Servicing Fluids	1,211	32,817	0.3
809	Spent Lubricant Waste	19	31	0.0002
810	Drill Cuttings	3,157	875,637	6.7
811	Soil Contaminated by Oil & Gas Related Spills	1,270	32,538	0.3
812	Filter Socks	299	1,232	0.01
899	Other Oil & Gas Wastes	50,118	413,546	3.2
	TOTAL 2018	**269,619**	**13,005,106**	**100.0**

Table 11.16a 2004 - 2018 WASTE TYPE REPORTS FOR UNCONVENTIONAL WELLS				
Waste Code	Waste Description	No. of Reports	Quantity metric tonnes	%
802	Produced Fluid	503,075	51,947,692	67.7
	Fracturing Fluid Waste	25,617	13,008,172	16.9
803	Drilling Fluid Waste	20,815	2,652,291	3.5
804	Waste Water Treatment Sludge	4,100	49,124	0.1
805	Unused Fracturing Fluid Waste	703	12,526	0.0
806	Synthetic Liner Materials	8,978	73,004	0.1
807	Sediment from Production Storage	1,265	8,786	0.0
808	Servicing Fluids	2,481	71,641	0.1
809	Spent Lubricant Waste	130	1,926	0.0
810	Drill Cuttings	23,625	8,030,219	10.5
811	Soil Contaminated by Oil & Gas Related Spills	3,112	49,836	0.1
812	Filter Socks	932	1,464	0.0
899	Other Oil & Gas Wastes	84,874	849,244	1.1
	TOTAL 2004 - 2018	**679,707**	**76,755,924**	**100.0**

Table 11.15b 2018 WASTE DISPOSAL REPORTS FOR 8,553 UNCONVENTIONAL WELLS				
Disposal Code	Disposal Method	No. of Reports	Quantity metric tonnes	%
101	Reuse other than road spreading			
102	Residual waste processing facility	65,547	3,288,774	25.3
103	Reuse at well pad	157,090	6,881,091	52.9
104	Landfill	9,851	921,485	7.1
105	Centralised treatment plant for recycle	324	5,427	0.04
106	Injection disposal well	11,549	603,461	4.6
107	Surface impoundment	17,454	1,039,732	8.0
108	Public sewage treatment plant	5	79	0.001
109	Identify method in "Comment"			
110	Central waste treatment facility NPDES discharge	182	1,507	0.01
111	Reuse at a well pad outside Pennsylvania	5,671	244,873	1.9
112	Storage pending disposal or reuse	339	13,438	0.1
113	Residual waste transfer facility	1,563	5,106	0.04
114	Other			
115	On site encapsulation			
116	Land application			
117	Reuse at a conventional well site in Pennsylvania	12	43	0.0001
118	Treated on site, NPDES discharge			
119	Road spreading			
120	On site pit	1	80	0.001
121	Beneficial reuse permitted by rule	31	8	0.0001
	TOTAL 2018	**269,619**	**13,005,106**	**100.0**

Table 11.16b 2004 - 2018 WASTE DISPOSAL REPORTS FOR UNCONVENTIONAL WELLS				
Disposal Code	Disposal Method	No. of Reports	Quantity metric tonnes	%
101	Reuse other than road spreading	65,677	26,756,453	34.9
102	Residual waste processing facility	177,894	14,996,462	19.5
103	Reuse at well pad	253,491	11,941,235	15.6
104	Landfill	43,490	7,949,753	10.4
105	Centralised treatment plant for recycle	26,167	5,214,475	6.8
106	Injection disposal well	64,429	5,370,861	7.0
107	Surface impoundment	27,122	1,908,415	2.5
108	Public sewage treatment plant	1,250	625,762	0.8
109	Identify method in "Comment"	745	273,260	0.4
110	Central waste treatment facility NPDES discharge	1,876	519,713	0.7
111	Reuse at a well pad outside Pennsylvania	7,872	376,789	0.5
112	Storage pending disposal or reuse	2,282	292,240	0.4
113	Residual waste transfer facility	6,430	144,566	0.2
114	Other	659	357,032	0.5
115	On site encapsulation	122	26,750	0.03
116	Land application	7	93	0.000
117	Reuse at a conventional well site in Pennsylvania	112	760	0.001
118	Treated on site, NPDES discharge	18	630	0.001
119	Road spreading	16	405	0.001
120	On site pit	16	254	0.0003
121	Beneficial reuse permitted by rule	32	15	0.00002
	TOTAL 2004 - 2018	**679,707**	**76,755,924**	**100.0**

12. ESTIMATES OF WATER REQUIREMENTS FOR HYDRAULIC FRACTURING IN THE BOWLAND-HODDER AND THE NUMBERS OF TANKER JOURNEYS REQUIRED FOR DELIVERY TO THE WELL SITES

The hydraulic fracturing of shale requires a fluid with three constituents: water, proppant and additives. A typical composition by volume is proppant (up to 10%), additives (up to 2%) and the balance water[1]. The purpose of a proppant is to keep open the cracks created in the shale by the high pressure injection of fracturing fluid. Additives are chemicals added to the fracturing fluid in small amounts for a wide range of purposes.

The following assumptions have been made to arrive at estimates for water requirements for Bowland-Hodder shale gas extraction:

1. Water is needed to hydraulically fracture 2,086 to 8,913 wells, as set out in Table 5.1.
2. The lateral length of each well is 2,500 metres.
3. The water requirement for a lateral length of 1 metre is 21.74 cubic metres. This figure[2] is the average for 5,769+ Marcellus wells with an average lateral length of 1,203 metres.
4. The water requirement for each well is 2,500 x 21.74 = 54,350 cubic metres or 54,350 tonnes.

Table 14.1 is based on the above assumptions and indicates the water requirements for the four targets for gas import substitution set out in Table 4. It also indicates the number of journeys needed to deliver the required water using 32 tonne 4-axle rigid road tankers with a payload of 18 tonnes (4,000 imperial gallons).

Table 12 NUMBERS OFJOURNEYS REQUIRED FOR DELIVERY OF WATER FOR HYRAULIC FRACTURING BASED ON A WATER REQUIREMENT OF 54,350 TONNES PER WELL

TARGET PERIOD	LENGTH OF TARGET PERIOD	GAS IMPORT REDUCTION TARGET		WELLS REQUIRED	WATER REQUIRED FOR FRACTURING	HGV JOURNEYS REQUIRED FOR DELIVERY OF WATER*						
	years	%	billion cubic metres	number	tonnes	Hourly**	Weekday 0730-1830	Saturday 0730-1200	Weekly	Monthly	Annually	Full Period
2021-2035	15	50	383.9	2,086	113,368,328	136	1,493	611	8,075	34,990	419,883	6,298,240
2021-2035	15	100	767.9	4,172	226,736,656	271	2,986	1,221	16,149	69,980	839,765	12,596,481
2021-2050	30	50	820.3	4,456	242,209,821	145	1,595	652	8,626	37,378	448,537	13,456,101
2021-2050	30	100	1,640.5	8,913	484,419,641	290	3,189	1,305	17,251	74,756	897,073	26,912,202

*Journey numbers are based on a 32 tonne 4-axle HGV with a payload of 18 tonnes or 4,000 imperial gallons.

** Hourly numbers are based on a 59.5 hour week: Monday to Friday 0730 to 183(Fracking road tanker by Spencer Platt/ Getty Images (https://www.gettyimages.co.uk/)
REFERENCE Cuadrilla Bowland Limited, Transport Management Plan, 24 February 2017.

REFERENCES

1. M4Shalegas-D11.1-Composition of operational fluids in hydraulic fracturing-nov.2015.pdf
2. A J Kondash, et al., The Intensification of the water footprint of hydraulic fracturing, Science Advances, **4,** eaar5982, 15 August 2018.

13. ESTIMATES OF PROPPANT REQUIREMENTS FOR HYDRAULIC FRACTURING IN THE BOWLAND-HODDER AND THE NUMBERS OF HGV Journeys REQUIRED FOR DELIVERY TO THE WELL SITES

A proppant plays a vital role in determing the rate at which gas leaves fractured shale and enters the well bore. As small particles dispersed throughout the fracturing fluid, it enters the cracks created by high pressure injection of the fluid. The injection pressure must exceed the natural compressive stress that exists below the surface and put the shale into tension so that flaws in the shale will create a network of cracks through which trapped gas can escape. Following crack formation, the applied pressure is removed and the proppant holds the cracks open as the natural compressive force of the surrounding shale returns.

With a 95% share, silica proppant dominates the commercial market. Resin coated silica (2%) and alumina based ceramics (3%) make up the balance. Silica (SiO_2) is washed and sieved quartz sand. Its performance is generally satisfactory except in the deepest laterals where its crush resistance is inadequate. Resin coated silica has higher crush resistance because the resin spreads the load. This provides better performance at higher depths. Ceramic proppants offer the best performance but are the most expensive. Starting with the aluminium ore bauxite, complex processing procedures are used to produce uniform-sized, smooth spheres of up to 100% alumina (Al_2O_3) in the form of corundum - with a hardness second to that of diamond amongst natural minerals.

For the purposes of this report quartz sand has been used to illustrate the amounts of proppant required to meet import reduction targets. The fracturing fluid has been chosen to contain unspecified types and amounts of additives and a water/proppant mixture containing 90% water and 10% proppant by volume. Weights of quartz sand proppant have been calculated using a density of 2.650 tonnes per cubic metre.

Table 13 NUMBERS OF JOURNEYS REQUIRED FOR DELIVERY OF SAND FOR HYRAULIC FRACTURING BASED ON A 9:1 WATER/SAND MIXTURE BY VOLUME

TARGET PERIOD	LENGTH OF TARGET PERIOD years	GAS IMPORT REDUCTION TARGET %	GAS IMPORT REDUCTION TARGET billion cubic metres	WELLS REQUIRED number	SAND for FRACTURING tonnes	HGV JOURNEYS REQUIRED FOR DELIVERY OF SAND PROPPANT* Hourly**	Weekday 0730-1830	Saturday 0730-1200	Weekly	Monthly	Annually	Full Period
2021-2035	15	50	383.9	2,086	33,380,674	40	440	180	2,378	10,303	123,632	1,854,482
2021-2035	15	100	767.9	4,172	66,761,349	80	879	360	4,755	20,605	247,264	3,708,964
2021-2050	30	50	820.3	4,456	71,317,336	43	470	192	2,540	11,006	132,069	3,962,074
2021-2050	30	100	1,640.5	8,913	142,634,672	85	939	384	5,080	22,012	264,138	7,924,148

*Journey numbers are based on a 32 tonne 4-axle rigid HGV with a payload of 18 tonnes

** Hourly numbers are based on a 59.5 hour week: Monday to Friday 0730 to 183(Fracking road tanker by Spencer Platt/ Getty Images (https://www.gettyimages.co.uk/)

REFERENCE Cuadrilla Bowland Limited, Transport Management Plan, 24 February 2017.

SOURCE

1. A Comprehensive review on proppant technologies, Feng Liang, et al., Petroleum, Volume 2, Issue 1, pp.26-39, March 2016.

14. CONSIDERATION OF HGV JOURNEYS WITHOUT THE APPLICATION OF TRANSPORTATION LOGISTICS

Tables 7.3,12 &13 provide estimates of the numbers of HGV journeys[1] required to remove waste from well sites and to deliver water and proppant to well sites. Each journey to remove waste has the potential to require an empty vehicle to drive to the site to carry out that task and each journey to deliver water or proppant has the potential to generate an empty return journry. If both these potentials were fully realised it would give rise to significant costs to both the gas industry and the natural environment. However, the application of transportation logistics could reduce the number of HGV journeys withouta payload by 32% and the total number of journeys by 16%. This could be achieved if, following delivery of water or proppant to a well site, the empty vehicle were to be directed to remove waste from, for example, the same well site or another close by. More details are provided in Table 15.

Table 14 sets out numbers of journeys without the application of transportation logistics and assumes parity between journeys with and without payloads.

Table 14 JOURNEYS TO AND FROM WELL SITES - No Transportation Logistics Applied
(ssumes parity between HGV journeys with and without payloads)

		WATER DELIVERY		PROPPANT DELIVERY		WASTE REMOVAL		ALL
		WITH PAYLOAD	WITHOUT PAYLOAD	WITH PAYLOAD	WITHOUT PAYLOAD	WITH PAYLOAD	WITHOUT PAYLOAD	JOURNEYS
TARGET 1	Hourly[2]	136	136	40	40	34	34	418
2021 - 2035	Weekday	1,493	1,493	440	440	369	369	4,603
(15 years)	Saturday	611	611	180	180	151	151	1,883
50% of Imports	Weekly	8,075	8,075	2,378	2,378	1,998	1,998	24,901
(383.9 bcm)	Monthly	34,990	34,990	10,303	10,303	8,658	8,658	107,902
Number of wells:	Annually	419,883	419,883	123,632	123,632	103,899	103,899	1,294,827
2,086	Full Period	6,298,240	6,298,240	1,854,482	1,854,482	1,558,483	1,558,483	19,422,411
TARGET 2	Hourly[2]	271	271	80	80	67	67	837
2021 - 2035:	Weekday	2,986	2,986	879	879	739	739	9,207
(15 years)	Saturday	1,221	1,221	360	360	302	302	3,766
100% of Imports	Weekly	16,149	16,149	4,755	4,755	3,996	3,996	49,801
(767.9 bcm)	Monthly	69,980	69,980	20,605	20,605	17,316	17,316	215,805
Number of wells:	Annually	839,765	839,765	247,264	247,264	207,798	207,798	2,589,655
4,172	Full Period	12,596,481	12,596,481	3,708,964	Fracking road	3,116,966	3,116,966	35,135,858
TARGET 3	Hourly[2]	145	145	43	43	36	36	447
2021 - 2050	Weekday	1,595	1,595	470	470	395	395	4,918
(30 years)	Saturday	652	652	192	192	161	161	2,012
50% of Imports	Weekly	8,626	8,626	2,540	2,540	2,134	2,134	26,600
(820.3 bcm)	Monthly	37,378	37,378	11,006	11,006	9,249	9,249	115,266
Number of wells:	Annually	448,537	448,537	132,069	132,069	110,989	110,989	1,383,190
4,456	Full Period	13,456,101	13,456,101	3,962,074	3,962,074	3,329,677	3,329,677	41,495,704
Target 4	Hourly[2]	290	290	85	85	72	72	894
2021 - 2050	Weekday	3,189	3,189	939	939	789	789	9,835
(30 years)	Saturday	1,305	1,305	384	384	323	323	4,024
100% of Imports	Weekly	17,251	17,251	5,080	5,080	4,269	4,269	53,200
(1,640.5 bcm)	Monthly	74,756	74,756	22,012	22,012	18,498	18,498	230,532
Number of wells:	Annually	897,073	897,073	264,138	264,138	221,978	221,978	2,766,380
8,913	Full Period	26,912,202	26,912,202	7,924,148	7,924,148	6,659,354	6,659,354	82,991,409

NOTES

1. Journey numbers are based on a 32 tonne 4-axle rigid HGV with a payload of 18 tonnes or 4,000 imperial gallons of water.
2. Hourly numbers are based on a 59.5 hour week: Monday to Friday 0730 to 1830 and Saturday 0730 to 1200. REFERENCE Cuadrilla Bowland Limited, Transport Management Plan, 24 February 2017.

15. CONSIDERATION OF HGV JOURNEYS WITH THE APPLICATION OF TRANSPORTATION LOGISTICS

Table 15 sets out the numbers of journeys that result from arranging for all journeys that remove waste to be carried out by vehicles that are empty following delivery of water. This eliminates the need to send an empty HGV to the well site for this purpose and concomitantly provides a payload for an otherwise empty vehicle. The majority of waste is fluid and road tankers that deliver water would appear to be appropriate for this task. Although not illustrated in the Table, clearly vehicles that deliver proppant would be the more appropriate for removal of solid waste.

Table 15 HGV JOURNEYS TO AND FROM WELL SITES - Transportation Logistics Applied

(assumes removal of waste by vehicles following delivery of water)

		WATER DELIVERY		PROPPANT DELIVERY		WASTE REMOVAL		ALL JOURNEYS		NON-PAYLOAD JOURNEYS	
		WITH PAYLOAD	WITHOUT PAYLOAD	WITH PAYLOAD	WITHOUT PAYLOAD	WITH PAYLOAD	WITHOUT PAYLOAD	NUMBER	cf. Table 14 % CHANGE	NUMBER	cf. Table 14 % CHANGE
TARGET 1	Hourly[2]	136	102	40	40	34	0	351	-16.0	142	-32.1
2021 - 2035	Weekday	1,493	1,123	440	440	369	0	3,865	-16.0	1,563	-32.1
15 years	Saturday	611	460	180	180	151	0	1,581	-16.0	639	-32.1
50% of Imports	Weekly	8,075	6,077	2,378	2,378	1,998	0	20,904	-16.0	8,454	-32.1
383.9 bcm	Monthly	34,990	26,332	10,303	10,303	8,658	0	90,586	-16.0	36,635	-32.1
Number of wells	Annually	419,883	315,984	123,632	123,632	103,899	0	1,087,030	-16.0	439,616	-32.1
2,086	Full Period	6,298,240	4,739,757	1,854,482	1,854,482	1,558,483	0	16,305,445	-16.0	6,594,239	-32.1
TARGET 2	Hourly[2]	271	204	80	80	67	0	703	-16.0	284	-32.1
2021 - 2035	Weekday	2,986	2,247	879	879	739	0	7,729	-16.0	3,126	-32.1
15 years	Saturday	1,221	919	360	360	302	0	3,162	-16.0	1,279	-32.1
100% of Imports	Weekly	16,149	12,153	4,755	4,755	3,996	0	41,809	-16.0	16,908	-32.1
767.9 bcm	Monthly	69,980	52,664	20,605	20,605	17,316	0	181,172	-16.0	73,269	-32.1
Number of wells	Annually	839,765	631,968	247,264	247,264	207,798	0	2,174,059	-16.0	879,232	-32.1
4,172	Full Period	12,596,481	9,479,515	3,708,964	3,708,964	3,116,966	0	32,610,889	-16.0	13,188,479	-32.1
TARGET 3	Hourly[2]	145	109	43	43	36	0	375	-16.0	152	-32.1
2021 - 2050	Weekday	1,595	1,200	470	470	395	0	4,128	-16.0	1,670	-32.1
30 years	Saturday	652	491	192	Fracking road	161	0	1,497	-16.0	#VALUE!	-32.1
50% of Imports	Weekly	8,626	6,491	2,540	2,540	2,134	0	22,331	-16.0	9,031	-32.1
820.3 bcm	Monthly	37,378	28,129	11,006	11,006	9,249	0	96,768	-16.0	39,135	-32.1
Number of wells	Annually	448,537	337,547	132,069	132,069	110,989	0	1,161,212	-16.0	469,617	-32.1
4,456	Full Period	13,456,101	10,126,424	3,962,074	3,962,074	3,329,677	0	34,836,351	-16.0	14,088,499	-32.1
TARGET 4	Hourly[2]	290	218	85	85	72	0	751	-16.0	304	-32.1
2021 - 2050	Weekday	3,189	2,400	939	939	789	0	8,257	-16.0	3,339	-32.1
30 years	Saturday	1,305	982	384	384	323	0	3,378	-16.0	1,366	-32.1
100% of Imports	Weekly	17,251	12,983	5,080	5,080	4,269	0	44,662	-16.0	18,062	-32.1
1,640.5 bcm	Monthly	74,756	56,258	22,012	22,012	18,498	0	193,535	-16.0	78,269	-32.1
Number of wells	Annually	897,073	675,095	264,138	264,138	221,978	0	2,322,423	-16.0	939,233	-32.1
8,913	Full Period	26,912,202	20,252,849	7,924,148	7,924,148	6,659,354	0	69,672,701	-16.0	28,176,997	-32.1

NOTES

1. Journey numbers are based on a 32 tonne 4-axle rigid HGV with a payload of 18 tonnes or 4,000 imperial gallons of water.
2. Hourly numbers are based on a 59.5 hour week: Weekdays Monday to Friday 0730 to 1830 and Saturday 0730 to 1200.
   REFERENCE Cuadrilla Bowland Limited, Transport Management Plan, 24 February 2017.

16. CONSIDERATION OF TRAFFIC and GHG EMISSIONS GENERATED BY THE HGV JOURNEYS IDENTIFIED IN Table 15.

Table 16 sets out estimates of vehicular traffic and greenhouse gas (GHG) emissions that result from the HGV journeys identified in Table 15. Vehicular traffic is defined here as the product of the number of vehicles making a journey and the average journey length. For the purposes of this report a nominal 40.0 km has been chosen as the average journey length. GHG emissions are based on rates published by Government and are for a >17 tonne rigid diesel HGV: 0.76605 kg km^{-1} for 0% laden and 0.12125 kg $tonne^{-1}$ km^{-1} 100% laden.

It should be noted that only traffic and emissions for journeys generated by water and proppant delivery and waste removal are considered here. Not taken into account are additional journeys required (1) for the transportation of plant and equipment for drilling and fracturing between 2,086 and 8,913 wells, (2) for purposes of well and well site monitoring, maintenance and repair over a 15 or 30 year target period and (3) for the decommissioning of wells and well sites.

		JOURNEYS WITHOUT A PAYLOAD				JOURNEYS WITH AN 18 tonne PAYLOAD				JOURNEYS WITH & WITHOUT AN 18 tonne PAYLOAD			
	AVERAGE JOURNEY LENGTH 40 km	JOURNEYS[1] number	TOTAL TRAFFIC (for a 40 km trip) vehicle km	GHG CONVERSION FACTOR kg $veh.^{-1}$ km^{-1}	TOTAL GHG EMISSIONS tonnes	JOURNEYS[1] number	TOTAL TRAFFIC (for a 40 km trip) vehicle km	GHG CONVERSION FACTOR kg $tonne^{-1}$ km^{-1}	TOTAL GHG EMISSIONS tonnes	JOURNEYS[1] number	TOTAL TRAFFIC vehicle km	EFECTIVE GHG CONVERSION FACTOR kg km^{-1}	TOTAL GHG EMISSIONS tonnes
TARGET 1	Hourly[2]	142	5,683	0.76605	4	209	8,370	0.12125	18	351	14,053	1.60966	23
2021 - 2035	Weekday	1,563	62,518	0.76605	48	2,302	92,069	0.12125	201	3,865	154,587	1.60966	249
15 years	Saturday	639	25,576	0.76605	20	942	37,665	0.12125	82	1,581	63,240	1.60966	102
50% of Imports	Weekly	8,454	338,166	0.76605	259	12,450	498,011	0.12125	1,087	20,904	836,177	1.60966	1,346
383.9 bcm	Monthly	36,635	1,465,387	0.76605	1,123	53,951	2,158,046	0.12125	4,710	90,586	3,623,432	1.60966	5,832
Number of wells	Annually	439,616	17,584,638	0.76605	13,471	647,414	25,896,548	0.12125	56,519	1,087,030	43,481,186	1.60966	69,990
2,086	Full Period	6,594,239	263,769,572	0.76605	202,061	9,711,205	388,448,215	0.12125	847,788	16,305,445	652,217,788	1.60966	1,049,849
TARGET 2	Hourly[2]	284	11,367	0.76605	9	418	16,740	0.12125	37	703	28,107	1.60966	45
2021 - 2035	Weekday	3,126	125,036	0.76605	96	4,603	184,138	0.12125	402	7,729	309,175	1.60966	498
15 years	Saturday	1,279	51,151	0.76605	39	1,883	75,329	0.12125	164	3,162	126,481	1.60966	204
100% of Imports	Weekly	16,908	676,332	0.76605	518	24,901	996,021	0.12125	2,174	41,809	1,672,353	1.60966	2,692
767.9 bcm	Monthly	73,269	2,930,773	0.76605	2,245	107,902	4,316,091	0.12125	9,420	181,172	7,246,864	1.60966	11,665
Number of wells	Annually	879,232	35,169,276	0.76605	26,941	1,294,827	51,793,095	0.12125	113,038	2,174,059	86,962,372	1.60966	139,980
4,172	Full Period	13,188,479	527,539,144	0.76605	404,121	19,422,411	776,896,431	0.12125	1,695,576	32,610,889	1,304,435,575	1.60966	2,099,698
TARGET 3	Hourly[2]	152	6,071	0.76605	5	224	8,941	0.12125	20	375	15,012	1.60966	24
2021 - 2050	Weekday	1,670	66,785	0.76605	51	2,459	98,352	0.12125	215	4,128	165,137	1.60966	266
30 years	Saturday	683	27,321	0.76605	21	1,006	40,235	0.12125	88	1,689	67,556	1.60966	109
50% of Imports	Weekly	9,031	361,244	0.76605	277	13,300	531,996	0.12125	1,161	22,331	893,240	1.60966	1,438
820.3 bcm	Monthly	39,135	1,565,389	0.76605	1,199	57,633	2,305,317	0.12125	5,031	96,768	3,870,706	1.60966	6,231
Number of wells	Annually	469,617	18,784,665	0.76605	14,390	691,595	27,663,803	0.12125	60,376	1,161,212	46,448,468	1.60966	74,766
4,456	Full Period	14,088,499	563,539,941	0.76605	431,700	20,747,852	829,914,089	0.12125	1,811,287	34,836,351	1,393,454,029	1.60966	2,242,987
TARGET 4	Hourly[2]	304	12,143	0.76605	9	447	17,882	0.12125	39	751	30,025	1.60966	48
2021 - 2050	Weekday	3,339	133,569	0.76605	102	4,918	196,704	0.12125	429	8,257	330,274	1.60966	532
30 years	Saturday	1,366	54,642	0.76605	42	2,012	80,470	0.12125	176	3,378	135,112	1.60966	217
100% of Imports	Weekly	18,062	722,487	0.76605	553	26,600	1,063,992	0.12125	2,322	44,662	1,786,480	1.60966	2,876
1,640.5 bcm	Monthly	78,269	3,130,777	0.76605	2,398	115,266	4,610,634	0.12125	10,063	193,535	7,741,411	1.60966	12,461
Number of wells	Annually	939,233	37,569,329	0.76605	28,780	1,383,190	55,327,606	0.12125	120,752	2,322,423	92,896,935	1.60966	149,532
8,913	Full Period	28,176,997	1,127,079,881	0.76605	863,400	41,495,704	1,659,828,177	0.12125	3,622,575	69,672,701	2,786,908,058	1.60966	4,485,975

NOTES

1. Journey numbers are based on a 32 tonne 4-axle rigid HGV with a payload of 18 tonnes or 4,000 imperial gallons of water.
2. Hourly numbers are based on a 59.5 hour week: Weekdays Monday to Friday 0730 to 1830 and Saturday 0730 to 1200.
   REFERENCE: Cuadrilla Bowland Limited, Transport Management Plan, 24 February 2017.

17. GREENHOUSE GAS EMISSIONS ATTIBUTABLE TO THE TRANSPORTATION OF IMPORTED LIQUID NATURAL GAS

With the decline in North Sea gas production, the UK became a net importer of gas in 2004. Between 2004 and 2018 the UK imported 595.5 billion cubic metres (bcm) of gas including 133.9 bcm (22.5%) as LNG. Norway supplied 369.2 bcm (61.5%) of all imports and Qatar 108.0 bcm (80.6%) of all LNG. For the purpose of illustration, it has been assumed in Table 17 below that all 133.9 bcm (103.0 million tonnes) of LNG imported by the UK in the period 2004 - 2018 was supplied by Qatar and delivered to its South Hook LNG terminal at Milford Haven, Pembrokeshire. It has also been assumed that transportation is by 112,500 tonne LNG capacity diesel ocean tanker. The journey distance is 1,640 nautical miles (11,371 km). Based on the appropriate greenhouse gas conversion factor of 0.00934 kg $tonne^{-1}$ km^{-1}, transportation of 103.0 million tonnes of LNG from Qatar to Milford Haven would generate a total of 10.9 million tonnes of CO_2 (equivalent) GHG emissions at an average annual rate of 729,503 tonnes or 106.2 kg per tonne of LNG transported over a distance of 11,371 km.

The historical record of the UK's LNG imports for the 15-year period 2004 - 2018 and estimates of GHG emissions generated by their transportation by ocean tanker can be compared with those for LNG in the National Grid's Consumer Evolution Energy Supply Scenario for the 15-year period 2021-2035 and the 30-year period 2021 - 2050. These are shown in the second and third rows of Table 17. LNG imports for 2021-2035 and 2021-2050 are 87.7 and 211.8 million tonnes, respectively. Transportation from Qatar would generate GHG emissions equivalent to 9.3 and 22.5 million tonnes of CO_2, respectively, at average annual rates of 621,129 and 749,808 tonnes, respectively.

Table 17 GREENHOUSE GAS EMISSIONS ATTRIBUTABLE TO THE USE OF OCEAN TANKERS FOR THE IMPORTATION OF LIQUID NATURAL GAS

Period	Years	Total Gas Demand	ALL GAS IMPORTS (Gas by undersea pipeline and LNG by ocean tanker, both expressed as gas)		LNG IMPORTED		TRANSPORTATION BY OCEAN TANKER									
					Volume (when regasified)	Weight	% of Total Gas Imports	% of Total Gas Demand	Tanker LNG Capacity Volume (liquid)	Tanker LNG Capacity Weight	Journey Distance	Delivery Journeys Required	Conversion Factor	Emissions for Total Period	Annual Average	per Tonne of LNG Transported
		10^9m^3	10^9m^3	% of Demand	10^9m^3	million tonnes			m^3	tonnes	km	number	kg $tonne^{-1}km^{-1}$	tonnes	tonnes	kg
2004 - 2018	15	1,306.5	595.5	45.6	133.9	103.0	22.5	10.3	250,000	112,500	11,371	916	0.00934	10,942,541	729,503	106.21
2021 - 2035	15	1,135.3	767.9	67.6	114.0	87.7	14.9	10.0	250,000	112,500	11,371	780	0.00934	9,316,942	621,129	106.21
2021 - 2050	30	2,163.9	1,640.5	75.8	275.3	211.8	16.8	12.7	250,000	112,500	11,371	1,883	0.00934	22,494,228	749,808	106.21

In the light of the increasing urgency to reduce the UK's greenhouse gas emissions, the UK Government should endeavour to reduce LNG imports in favour of increased pipeline imports from Norway and the Continent. Although not quantified in this report, it is generally accepted that greenhouse gas emissions generated by offshore pipeline transportation, in particular, are significantly less than those generated by transportation of LNG by diesel-engined ocean tanker.

DATA SOURCES

Fracking road tanker by Spencer Platt/ Getty Images (https://www.gettyimages.co.uk/)

1. Natural Gas Supply & Consumption, Table 4.1, Energy Trends, BEIS, 19 December 2019.
   NOTE: This reference does not show UK gas demand for the years 2000 to 2007 in units of 10^6m^3.
   For these years, data reported in GWh are converted to 10^6m^3 by a factor of 11 GWh per 10^6m^3.
2. Natural Gas Imports and Exports, Table 4.3, Energy Trends, BEIS 19 December 2019.
3. Future Energy Scenarios Data Workbook, Version 2, Chapter 4: Energy Demand, National Grid, July 2018:
   3.1 Figure GD1 Annual Gas Demand (including interconnector exports and shrinkage).
4. Future Energy Scenarios Data Workbook, Version 2, Chapter 5: Energy Supply, National Grid, July 2018:
   4.1 Figure 5.15 Revised Gas Supply Pattern in Consumer Evolution (no shale gas sensitivity).
5. South Hook LNG Terminal Company Limited, Liquefied Natural Gas, the Supply Chain, Transportation:
   https://www.southhooklng.com/liquefied-natural-gas/the-supply-chain/transportations/
6. 2019 Government Greenhouse Gas Conversion Factors for Company Reporting (Condensed or Full Set), BEIS, 9 August 2019:
   https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2019