The Environmental Issues of Shale Gas Development
Current Situation and Countermeasures

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Introduction

In the United States since the mid-2000s[2], the development of shale gas has been rapidly expanding, and while the production ratio of shale gas in 2007[3] occupied a mere 8% of the total domestic gas production, it reached 30% in 2011. Furthermore, it is forecast to reach 50% in 2040[4]. Meanwhile, the flipside of such rapid shale gas development is that various impacts on the environment are being pointed out.

This report, based principally on information being disclosed by the major stakeholders in shale gas development, namely, the government, industries, research institutions and environmental organizations, is aimed at 1) outlining the development process of shale gas and its impact on the environment, 2) introducing the mechanisms that induce major effects on the environment and 3) observing the environmental risks inherent in shale gas development.

1. The Shale Gas Development Process and its Impact on the Environment

Understanding the impact on the environment due to shale gas development first requires an understanding of its development process. The process goes through exploration, drilling, production, refining and transportation, which is generally similar to the conventional gas development process.

Shale gas, however, is generally extracted at a depth of 1,000 to 5,000 meters, from the shale stratum with extremely low permeability; therefore, employment of the conventional gas drilling method is very difficult. Generally, the production of conventional gas is conducted through the vertical drilling method, while the production of shale gas is done basically through the horizontal drilling method. In shale gas drilling, after part of the vertical drilling is done, it is further drilled horizontally, injecting the fracturing fluid composed of pressurized water, sand and chemical substances to create gas access routes through the rocks by utilizing the essential method called hydraulic fracturing. This process, because of the high technological level required and cost incurred, was considered difficult for commercial production. However, after the technological advances for hydraulic fracturing that enabled the creation and preservation of an artificial crack formation and those for a micro-seismic fracture-status monitoring system with reduced cost, commercial production became possible from around the mid-2000s. This provided a rapid expansion in its production.

The drilling of shale gas wells is conducted under the following specific procedures.

a. Vertical Drilling

The drilling of the production wells is carried out by rotating the pipes connected by drill bit. The drill moves through the underground, shaving off hard rocks by making use of the pipe rotation and its weight.

b. Horizontal Drilling

Next, the rig is gradually directed horizontally while drilling is continued. The horizontal drilling sometimes extends to as long as 2,000 meters[5].

c. Well Casing

During the drilling process, insertion of casing pipes and injection of cement are conducted simultaneously to lock in the entirety of drilled holes with several layers. This is done to prevent the liquid flowing through the holes from leaking. Particularly, at the shallow layers of less than 600 meters, as stringent precautions are required from the standpoint of preventing water contamination, several layers (Conductor Casing and Surface Casing) are installed.

d. Perforating Gun

At the tip of the well, the perforating gun (pipe set with explosives) is inserted and electrically ignited to penetrate the cement and build cracks in the shale layers.

e. Hydraulic Fracturing

Following the fracturing of the shale layers with the perforating gun, the high pressure fracturing mixtures composed of water, sand and chemicals are pumped in to fracture the rocks further and to expand the fractured areas. This method is hydraulic fracturing and it is utilized about ten times on average per well (The distance of one stage is approximately 100 meters)[6]. Proppant such as sand powder serves to prevent the fractures from shutting when the well is depressurized. The average composition ratio of the fracturing mixture is 99.2% water and 0.79% chemicals such as friction depressants[7]. The volume of water utilized in one hydraulic fracturing is a maximum of about 2 to 3 million gallons[8].

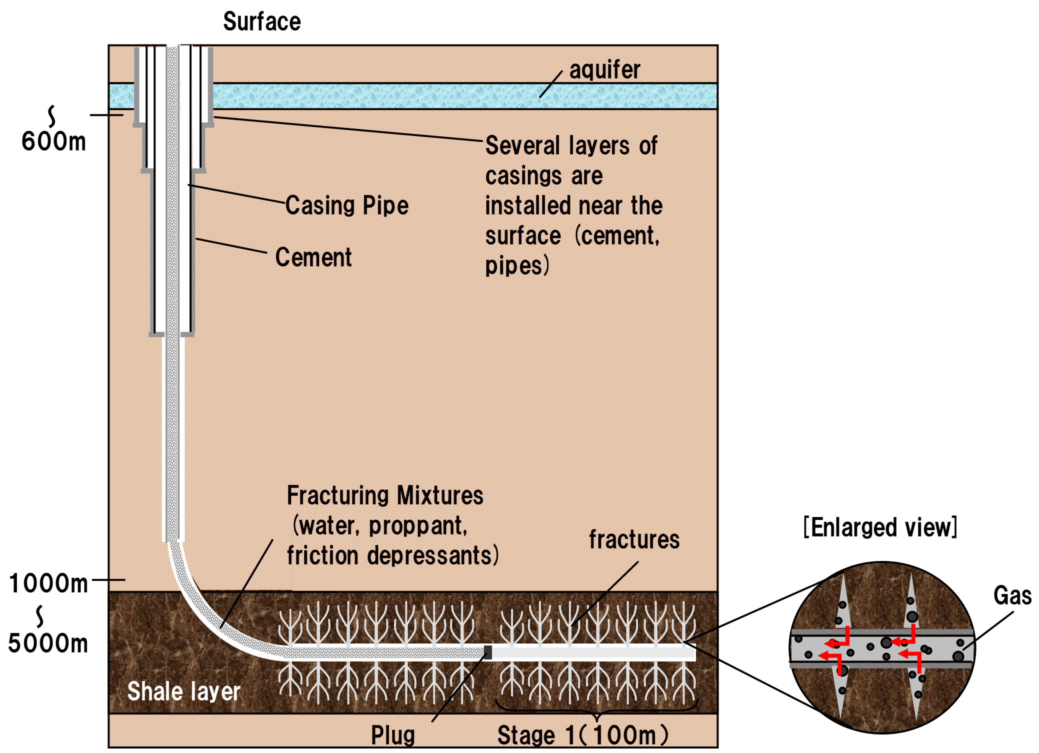
f. Drill-Out

Drill-out is the process to clear out the remains of the cement and the plugs utilized to maintain the pressure in the well at the time of hydraulic fracturing. Simultaneously with the drill–out, the pressurized gas and fracturing mixtures accumulated underground will flow out to the surface.

g. Flow-Back

Of the fracturing mixtures utilized for hydraulic fracturing, 30% to 70% are returned back to the surface (this is called "flow-back water")[9]. In the event that collecting equipment (details explained in section 2.2) is installed, gas, oil, and water will be segregated from the flow-back water. The collected gas and oil is sent to the marketing pipeline and the volatile organic compounds (VOC) are treated through combustion, etc. The flow-back water will be recycled after being processed at water treatment installations or either injected into the ground or discharged into rivers. The proppant, on the other hand, will be left underground to prevent the fractures from shutting down.

Figure 1 The General Image Of Shale Gas Drilling



(Source) The Institute of Energy Economics, Japan

1.2 Impact on Environment

Development of shale gas, excluding the drilling process, basically progresses under the same development stage as the conventional gas development process; therefore, the impact on the environment inherent in shale gas means that its impact occurs during the drilling stage[10]. As such, the drilling process proper to shale gas and the environmental risks assumed to accompany its stages are listed in Table l. Among various supposed impacts on the environment, according to the current research[11], roughly the following three main factors are attributable to the environmental risks. First is the permeation of the fracturing mixtures utilized in hydraulic fracturing at the time of drilling into the underground and surface water deposits. Second is the methane gas and volatile organic compounds which are generated from the drilling site and spread into the atmosphere. Third is the high pressure injection of fracturing mixtures and waste water into the ground which trigger small-scale earthquakes.

Table 1　Shale Gas Drilling and Alarming Environmental Risks

Shale Gas Drilling Process	Major Impact on Environment
Vertical Drilling Horizontal Drilling	○ Noise, vibration, smell ○ Deforestation as a result of road and site construction (Impact on ecosystem) ○ Deterioration of the landscape (This, however, is not inherent in shale gas development as similar conditions occur at conventional oil and gas development sites)
Well Casing	○ Water contamination (Commingling of gas and water from the fracturing mixtures utilized for hydraulic fracturing into underground water reservoir due to incomplete casing)
Perforating Gun Hydraulic Fracturing	○ Water contamination (Due to occurrence of unpredictable large fractures causing the chemicals and gas to flow into the underground water reservoir) ○ Soil contamination (Leakage of flow-back water from the storage pool) ○ Water supply (Water utilized for hydraulic fracturing suppressing water supply for farming) ○ Trigger earthquakes (The high pressure water for hydraulic fracturing triggering small-scale earthquakes) ○ Damage to roads and traffic congestion (Busy traffic by water supply trucks)
Drill-out Flow-back	○ Air pollution (Leakage of poisonous and methane gases from the drill-out/flow-back processes) ○ Water and soil contamination (The leakage of flow-back water into the soil caused by defective flow-back water pool construction) (Unprocessed flow-back water discharged into river) ○ Trigger earthquakes (Injection of waste water into underground triggers small-scale earthquakes)

(Source) The Institute of Energy Economics, Japan

2. Impact on Environment in Shale Gas Development

2.1 Water Pollution and Water Resources

It has been pointed out that with respect to water pollution, the problem is the contamination of underground and surface waters caused by inadequate treatment of the waste water from the hydraulic fracturing, while with respect to water resources, it is the regional depletion of water because of the abundant water supply needed for the hydraulic fracturing.

Specific phenomenon and the current situation of each process will be summarized below with respect to a) Hydraulic Fracturing, b) Waste Water Treatment and c) Water Resources.

a. Hydraulic Fracturing

With respect to the hydraulic fracture process, friction depressants/chemicals (anti-corrosive, anti-scaling and anti-septic chemicals) are commingled with water and injected into the soil. The risks being pointed out are that these chemicals will flow into the underground water vein during the course of injection if there are larger cracks formed compared to the original plan.

In pointing out such risks, it is necessary to pay attention to the differences in depth between the underground water vein and of the hydraulic fracturing. For instance, in Marcellus located in the northeastern part of the United States, the depth of the water vein is 1,000 feet (about 300 meters) while that of the hydraulic fracturing, even at the shallowest, is 4,700 feet (about 1,400 meters). This means, it has been observed in general that, notwithstanding the shale gas layers of Marcellus, there are usually substantial differences in depth between them[12]. Furthermore, the technology is already established to create the cracks by controlling the water pressure through the application of micro-seismic techniques that can observe the magnitude of crack formation. This is done after measuring the seismic wave generated at the time of crack formation. As regulatory measures, many states in the United States, for the development of oil and gas fields, obligate developers to secure certain distances between the site and residential areas, and when applying for a permit, to conduct water analysis[13], to disclose the chemical substances used for the hydraulic fracturing[14], and so forth.

Another risk pointed out involves the leakage of chemical substances and methane gas into the underground water vein caused by cracks in the casings of defective and inferior casing pipes. This problem, however, currently is regulated in detail for casing structures, execution methods, depths, administration, etc., and developers are penalized should there be any breach of these regulations[15]. Also, in addition to strict enforcement of these regulations, the American Petroleum Institute (API) provides precise operating manuals and technical guidance to developers[16].

Given such circumstances as above, the probability of pressurized water leaking into the water vein is most unlikely if the existing technologies are executed with adequate measurements in the hydraulic fracturing process.

b. Waste Water Treatment

In the United States, the collected waste water from the conventional oil and gas developments, as well as from the industrial sectors, are commonly treated by injecting them into the soil[17]. With regard to shale gas, the same method is generally adopted where the waste water from the hydraulic fracturing is injected into the soil. However, it has been pointed out that there is a possibility the waste water will flow into the underground water vein.

As much of the underground water veins are popularly consumed as drinking water in the United States, in 1974, the Safe Drinking Water Act (SDWA) was enacted to safeguard the quality of drinking water, prohibiting the injection of waste water into the soil as it would pollute the drinking water.

Furthermore, in accordance with the SDWA and Clean Water Act[19], the law enacted in 1948 to control water pollution, the US Environment Protection Agency (EPA) regulates underground water injection in accordance with the Underground Injection Control (UIC) standards[20]. These regulations mandate developers to report on items such as the specifications of casing and cement, regular monitoring, and pre-testing of the equipment, and, in the event of its termination, to submit a termination schedule.

If, on the other hand, there is no injection made, the waste water will be treated accordingly and either recycled or discharged into rivers. However, in doing this, such methods are under strict surveillance by the NPDES (National Pollutant Discharge Elimination System) program[21] under the EPA based on the Clean Water Act. The EPA necessitates developers to obtain approval for discharging waste water, and further, in collaboration with the regulatory apparatus of each state, monitors the suitability of the respective discharge plans of developers, and penalizes them if there is any act of breach of regulations.

Based on such circumstances, there already exists a control system by federal law. Therefore, the risks inherent in waste water injection are expected to be minimal if the developers observe the law as set forth.

c. Water Resource

In applying hydraulic fracturing, a substantial amount of water is consumed, hence it has been pointed out that retaining the water supply for drinking and farming industries, etc. becomes difficult. On the other hand, a research team at Massachusetts Institute of Technology (MIT) reports that the water consumed by shale gas development is less than 1% of the total water consumed in the region (Table 2). Moreover, the team reported that when an amount of energy generated equivalent to the calorific value of 1 Btu (British thermal unit) was evaluated in terms of the water consumed in energy development processes, against 1 gallon for shale gas, bio-ethanol, a derivative of corn, consumed as much as a few thousand gallons[22].

Table 2 Comparative Water Usage in Major Shale Plays

Play	Barnett (TX)	Fayetteville (AR)	Haynesville (LA/TX)	Marcellus (NY/PA/WV)
Public Supply	82.7%	2.3%	45.9%	12.0%
Industrial /Mining	3.7%	33.3%	13.5%	71.7%
Irrigation	6.3%	62.9%	8.5%	0.1%
Livestock	2.3%	0.3%	4.0%	<0.1%
Shale Gas	0.4%	0.1%	0.8%	<0.1%
other	4.6%	1.1%	27.3%	16.2%

Source: MIT (2011), The Future of Natural Gas

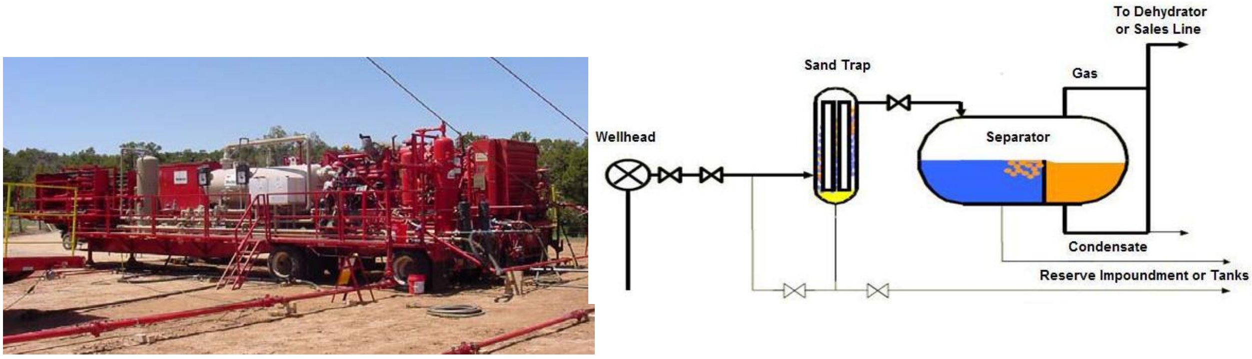
2.2 Air Pollution

It has been pointed out that during the course of collecting the flow-back water along the hydraulic fracturing process, a diffusion of volatile organic compounds occurs which pollutes the air and that the spreading of methane gas into the atmosphere promotes global warming. For instance, the research team led by Professor Robert Howarth of Cornell University, indicated that should there be a substantial leakage of methane gas, especially in shale gas drilling and the hydraulic fracturing process, the amount of gas causing the global warming effect would be greater than that of coal in the life cycle assessment from drilling to final consumption[23]. On the other hand, the professor's thesis is under criticism for using erratic data such as utilizing the global warming potential (GWP) which indicates an excessive green house effect by methane gas[24]. Furthermore, the majority of recently announced papers arrive at the life cycle greenhouse gas emissions from shale gas being smaller than those of oil and coal[25].

Meanwhile, on the regulatory side, the EPA had been examining the Clean Air Act, a federal law, and as a result, in April of 2012, it formulated standards for air pollution prevention and obligated developers to introduce devices for the practice called Reduced Emission Completions (RECs) which collect VOC generated during the collection of flow-back water[26]. Any developer who does not conform to the regulations is penalized by this law[27]. It has been reported that already many developers have installed the REC devices because they can pay off the installment costs through marketing the collected gas[28]. Based on such reasons, the indication by Howarth et al (2011), "All gases generated during the course of the hydraulic fracturing will spread into the atmosphere," is judged not to reflect the current situation of shale gas development[29].

Also, the Greenhouse Gas Reporting Program in petroleum and natural gas system was enacted starting in 2011[30]. In February 2013, large-scale GHG emission data including natural gas was disclosed for the first time. As such, it is predicted that these disclosures will serve as incentives to put efforts toward emission reductions.

Figure 2 The Outline of RECs (Reduced Emission Completions)



- A reduction of toxic substances by 95% is possible.
- After the sands are removed from the sand container, the toxic liquids are removed from the gas container and methane is collected. The collected methane will be sent out to products pipelines (or used as a flare gas).
- In the United States, up to 2.18 hundred million cubic feet in 2009 from 2 hundred million cubic feet in 2000 of methane had been collected. According to the EPA's Reduced Emissions Completions for Hydraulic Fractured Natural Gas Wells estimation, the additional revenue will amount to about 15 billion dollars.

(Source) US Environmental Protection Agency

2.3 Occurrence of Micro-seismic Earthquake

It has been pointed out that in shale gas development, the hydraulic fracturing triggers micro-seismic earthquakes in the vicinities, and currently a number of researches and studies are being conducted in the United States, Canada and England[31]. The mechanism of the hydraulic fracturing triggering earthquakes is that it occurs from the shear slip of existing faults as a result of a large volume of pressurized water being pumped into the ground.

The National Research Council of the United States had been examining the records of artificially triggered earthquakes and disclosed its reports in July 2007. It has categorized the causes of earthquakes assumed to have been artificially triggered based on the past occurrences into "Oil and Natural Gas Exploitation," "Secondary Recovery," "Injection of Waste Water into Underground," "Geothermal Heat," and "Hydraulic Fracturing." As a result, it has been verified that the causes of earthquakes from hydraulic fracturing are very few with lesser risks compared to other causes as mentioned above[32]. Furthermore, inthe United Kingdom, hydraulic fracturing had been prohibited but, in December 2012, the Department of Energy & Climate Change lifted the ban with the conditions that evaluation must be performed beforehand for the presence of faults and for the seismic risks involved and that close monitoring must be conducted so as to be able to control the risks of earthquakes occurring during the hydraulic fracturing[33,34].

3. Observations

"Hydraulic fracturing," a process essential for shale gas drilling, was developed in the 1940s, and it has a track record of being utilized at oil development sites more than 2.5 million times over 60 years[35]. On the other hand, there are renewed concerns about the hydraulic fracturing process in relation to environmental problems. The reasons for such concerns are attributable to the rapid expansion of shale gas development. Because of the handling difficulties that accompany shale gas compared to conventional gas drilling, obstacles arise in putting it into practical use. Nonetheless, due to the major leap in drilling technology along with the cost reduction, the situation changed, and, particularly in the past 10 years, it has expanded rapidly led by small and medium-sized enterprises. The flipside to this rapid expansion is that the accompanying regulations and measures to control the impact on the environment were unable to catch up. As such, it has become a concern particularly for the people living in the vicinities. Currently, evaluations and discussions continue aimed at tackling the environmental effects that shale gas drilling might bring about.

Given such circumstances, the International Energy Agency in June 2012, compiled and disclosed the basic principles and conditions under the report titled "GOLDEN RULES FOR A GOLDEN AGE OF GAS～World Energy Outlook Special Report on Unconventional Gas" to promote unconventional gas development. In this report, it points out, as a result of large-scale unconventional gas development, the current status of regional community, land utilization, and water resources will change as they are interrelated and it will bring about serious effects regarding pollution of the atmosphere, surface and underground waters. Furthermore, it refers to the expansion of unconventional gas utilization including shale gas and points out that this holds the key to the coming golden age of natural gas, and concludes that the implementation of measures against impacts on the environment are absolutely necessary for sustainable gas development.

Nevertheless, with respect to such environmental risks, the report evaluates, "The technologies and know-how are already sufficiently in place to continue the development from the standpoint of preserving the environment." This report suggests that the practices and operations carried out by adequately making use of the existing technologies and knowledge hold important keys. It also assembles a code of conduct, [Golden Rules] concerning each stage of shale gas development and production, such as selection of drilling sites, considering minimizing the effects on ecosystems, prevention of gas and chemicals from leaking out into the underground water veins through adequate designing and construction of drilling wells, introduction of superior technologies to prevent the leakage of methane when finished drilling, and close communications with the local residents and stakeholders, thereby obtaining understanding from the local residents through quick and adequate responses. The level of cost increases for general shale gas development is in the order of about 7% even if the code of conduct is fully implemented, and, in the case of a multilateral well project, the cost ratio is estimated to fall further[36].

Actually, in the United States where shale gas development is most advanced, these few years have seen the preparations of regulations by the government. In addition, various movements at various levels to minimize the effects on the environment are being activated such as industrial groups handing out operation guidelines and manuals[37] and collaboration between shale gas developers and environmental protection groups (NGOs) to study the performance standards necessary for sustainable shale gas production[38]. Hence, in the future, it is expected that these pioneering and concrete activities will be able to be used as references so that measures to tackle environmental issues will be smoothly implemented at the locations where shale gas development is anticipated.

Currently, shale gas development and its impact on the environment are still under debate and more time will be required before they are fully clarified; however, at this point in time, it is fair enough to evaluate that the effects on the environment like water contamination, methane leakage and triggering of earthquakes can sufficiently be prevented by introducing adequate technologies and operations[39,40].

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References

・International Energy Agency (2012), Golden Rules for a Golden Age of Gas
http://www.worldenergyoutlook.org/media/weowebsite/2012/goldenrules/WEO2012_GoldenRulesReport.pdf

・Broderick et al. (2011), Shale gas: an updated assessment of environmental and climate change impacts, Tyndall Center
http://www.tyndall.ac.uk/sites/default/files/broderick_et_al_2011_shale_gas_update_high_quality.pdf

・Broomfield et al. (2012), Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe, AEA
http://ec.europa.eu/environment/integration/energy/pdf/fracking%20study.pdf#search='support+to+the+identification+of+potential+risk+for+the+environment+and+human+health'

・Groat et al. (2012), Fact-Based Regulation for Environmental Protection in Shale Gas Development, The Energy Institute, Flawn Academic Center, The University of Texas
http://www.velaw.com/UploadedFiles/VEsite/Resources/ei_shale_gas_reg_summary1202[1].pdf

・Hyland et al. (2013), Realizing the Potential of U.S. Unconventional Natural Gas, CISIS
http://csis.org/files/publication/130409_Ladislaw_RealizingPotentialUnconGas_Web.pdf

・Krupnick et al. (2013), Pathways to Dialogue: What the Experts Say about the Environmental Risks of Shale Gas Development, Resources for the Future
http://www.rff.org/Documents/RFF-Rpt-PathwaystoDialogue_FullReport.pdf

・MIT Energy Initiative (2011),The Future of Natural Gas
http://mitei.mit.edu/publications/reports-studies/future-natural-gas

・K. Ihara, "Shale Gas Sodatsusen," Nikkon Kogyou Shimbun, 2011

Remarks and Footnotes

〔1〕 My special thanks to Mr. Koichi Sasaki, Ms. Gan Peck Yean and Ms. Ayako Sugino for their great help in writing this report. Without their support, the report would not have been completed.

〔2〕 The United States is the biggest producer of shale gas overtaking Russia. In 2012, the U.S. occupied 20% of world natural gas production.
BP Statistical Review
2012http://www.bp.com/en/global/corporate/about-bp/statistical-review-of-worl
d-energy-2013/downloads.html

〔3〕 Based on http://www.eia.gov/dnav/ng/ng_prod_sum_dcu_NUS_m.htm

〔4〕 USDOE (2013), Annual Energy Outlook 2013
http://www.eia.gov/forecasts/aeo/pdf/0383(2013).pdf

〔5〕 http://www.total.com/en/special-reports/shale-gas/appropriate-production-techniques/horizontal-drilling-hydraulic-fracturing-201957.html

〔6〕 http://www.dec.ny.gov/docs/materials_minerals_pdf/rdsgeisch50911.pdf

〔7〕 http://fracfocus.org/water-protection/drilling-usage

〔8〕 http://www.netl.doe.gov/technologies/oil-gas/publications/EPreports/Shale_Gas_Primer_2009.pdf

〔9〕 http://www.netl.doe.gov/technologies/oil-gas/publications/EPreports/Shale_Gas_Primer_2009.pdf

〔10〕 Excluding the drilling process, it has been mentioned that deforestation from road construction, noise during the predevelopment process, and gas leakage and explosions caused by operational errors occur during the production process. These incidents do not exemplify characteristics of shale gas, as these incidents also occur in conventional oil and gas development.

〔11〕 IEA (2012), AEA (2012), Broderick et al. (2011), Hyland et al. (2013), Krupnick et al. (2013), etc.

〔12〕 MIT (2011), The Future of Natural Gas
http://mitei.mit.edu/system/files/NaturalGas_Report.pdf

〔13〕 For example, in the State of Pennsylvania, where Marcellus Shale is located, the existing wells must be kept a distance of 200 feet (60m) from buildings under "The Pennsylvania Oil and Gas Act Section 205; Well Location Restrictions (58 P.S. § 601.205). Others include "The Pennsylvania Code Title 25 Environmental Protection Chapter 78, Oil and Gas Well Subchapter D. Well Drilling, Operation And Plugging" where it sets up detailed rules of management and procedures.

〔14〕 The States of New York (RSGEIS 8.2.11), Colorado (2 CCR 404-1 Rule 205) and Texas (HB

3328) obligate disclosure of the chemical substances to the regulating authorities.

〔15〕 In the States of Pennsylvania, New York, and Texas, for instance, the construction management standards are stipulated respectively under CODE 25 PAADC 78 (aforementioned), SGEIS on the Oil, Gas and Solution Mining Regulatory Program Chapter 7 Mitigation Measures and Texas Administrative Code Title 16 Economic Regulation Part 1 Railroad Commission of Texas Chapter 3 Oil And Gas Division Rule # 3.13 Casing, Cementing Drilling, and Completion Requirements, respectively.

〔16〕 http://www.api.org/~/media/Files/Policy/Exploration/Hydraulic_Fracturing_InfoSheet.pdf

〔17〕 In 1965, the Solid Waste Disposal Act, along with, in 1976, the Resource Conservation and Recovery Act was approved and became the basic law for underground injection. The items subject to this law are mainly domestic waste, municipal waste, industrial solid waste and hazardous waste containing toxic substances, and it stipulates in detail their minimization (reducing waste), collection, and disposal.

〔18〕 http://water.epa.gov/lawsregs/rulesregs/sdwa/index.cfm

〔19〕 http://cfpub.epa.gov/npdes/cwa.cfm?program_id=45

〔20〕 http://water.epa.gov/type/groundwater/uic/index.cfm

〔21〕 http://www.epa.gov/compliance/monitoring/programs/cwa/npdes.html

〔22〕 MIT (2011), The Future of Natural Gas
http://mitei.mit.edu/publications/reports-studies/future-natural-gas

〔23〕 Howarth et al. (2011), "Methane and the Greenhouse-Gas Footprint of Natural Gas from Shale Formations"
http://thehill.com/images/stories/blogs/energy/howarth.pdf

〔24〕 Cathles et al. (2011), A commentary on "The greenhouse-gas footprint of natural gas in shale formations" by R.W. Howarth, R. Santoro, and Anthony Ingraffea
http://www.geo.cornell.edu/eas/PeoplePlaces/Faculty/cathles/Natural%20Gas/2012%20Cathles%20et%20al%20Commentary%20on%20Howarth.pdf
Marcellus Shale Coalition (2011), Marcellus Shale Coalition: Five Things to Know about the Cornell Shale Study (Courtesy of Energy In Depth)
http://marcelluscoalition.org/2011/04/five-things-to-know-about-the-cornell-shale-study-courtesy-of-energy-in-depth/
HIS CERA (2011), Mismeasuring Methane: Estimating Greenhouse Gas Emissions from Upstream Natural Gas Development

〔25〕 Jiang et al. (2011), Life cycle greenhouse gas emissions of Marcellus shale gas
http://iopscience.iop.org/1748-9326/6/3/034014/pdf/1748-9326_6_3_034014.pdf
Skone et al, (2011), Life Cycle Greenhouse Gas Inventory of Natural Gas Extraction, Delivery and Electricity Production

http://www.netl.doe.gov/energy-analyses/pubs/NG-GHG-LCI.pdf

Stephenson et al. (2011), Modeling the Relative GHG Emissions of Conventional and Shale Gas Production

http://pubs.acs.org/doi/abs/10.1021/es2024115

Burnham et al. (2011), Life-Cycle Greenhouse Gas Emissions of Shale and Conventional Natural Gas

http://pubs.acs.org/doi/abs/10.1021/es201942m

AEA Technology plc (2012), Climate Impact of Potential Shale Gas Production in the EU

http://ec.europa.eu/clima/policies/eccp/docs/120815_final_report_en.pdf

〔26〕 While the gas collected from August 2012 up to the end of 2014 is approved for flaring as a provisional measure, starting from January 1, 2015, the installation of REC equipment becomes compulsory.

〔27〕 Oil and Natural Gas Sector: New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants Reviews

http://www.epa.gov/airquality/oilandgas/pdfs/20120417finalrule.pdf

〔28〕 O'Sullivan et al. (2012), Shale gas production: potential versus actual greenhouse gas emissions, MIT

http://iopscience.iop.org/1748-9326/7/4/044030/pdf/1748-9326_7_4_044030.pdf

〔29〕 A report was released as a result of evaluation being conducted by about 400 researchers at the Massachusetts Institute of Technology based on the GHG data for horizontal well drilling. The report states that it is not correct to conclude that the volume of gas generated from the finishing stage of the shale gas drilling is larger than that of the conventional method, hence, the costs incurred for GHG will pay off sufficiently and that the hydraulic fracturing process induces a rise in the cost per unit of GHG of the gas industries as a whole.

http://www.epa.gov/ghgreporting/ghgdata/reported/petroleum.html

〔30〕 Pater et al. (2011), Geomechanical Study of Bowland Shale Seismicity

http://www.cuadrillaresources.com/wp-content/uploads/2012/02/Geomechanical-Study-of-Bowland-Shale-Seismicity_02-11-11.pdf

〔31〕 BC Oil and Gas Commission (2012), Investigation of Observed Seismicity in the Horn River Basin

www.bcogc.ca/node/8046/download

〔32〕 National Research Council (2012), Induced Seismicity Potential in Energy Technologies http://www.nap.edu/catalog.php?record_id=13355#toc

〔33〕 Preese Hall Shale Gas Fracturing Review & Recommendations For Induced Seismic Mitigation

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/15745/5075-p

reese-hall-shale-gas-fracturing-review.pdf

〔34〕 Written Ministerial Statement by Edward Davey: Exploration for shale gas
https://www.gov.uk/government/news/written-ministerial-statement-by-edward-davey-exploration-for-shale-gas

〔35〕 Ihara (2011)

〔36〕 Method which increases the production efficiency by conducting the horizontal drilling in multiple directions per well thereby broadening the contact area of the shale layers.

〔37〕 API, "Guidance/Best Practices on Hydraulic Fracturing (HF)"
http://www.api.org/policy/exploration/hydraulicfracturing/upload/hydraulic_fracturing_infosheet.pdf
Petroleum Technology Alliance Canada and Science and Community Environmental Knowledge Fund, "The Modern Practices of Hydraulic Fracturing: A Focus on Canadian Resources"
http://www.capp.ca/getdoc.aspx?DocId=210903&DT=NTV

〔38〕 For example, the Center for Sustainable Shale Development is collaborating with Shell and Chevron from the industrial sector, the Environmental Defense Fund and the Clean Air Task Force from the environmental group, the Pennsylvania Environmental Council from the administration, and a research body from Carnegie Mellon University to formulate the performance standards. https://www.sustainableshale.org/

〔39〕 The energy and climate change commission from the English Parliament in its 5th Term Environmental Report concluded that "Sufficient safety can be maintained through adequate management. Monitoring by the government (Ministry of Energy and Climate Changes) is also an absolute necessity."
http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenergy/795/79502.htm

〔40〕 The viewpoint of the United States evaluation commissions in "Induced Seismic Potential in Energy Technologies" (2012) is that the risk posed in hydraulic fracturing is small as a result of classifying the causes of earthquakes assumed to have been artificially triggered into "Exploitation of Oil and Gas," "Secondary Recovery," "Injection of Waste Water into Underground," "Geothermal Heat," and "Hydraulic Fracturing."
http://i2.cdn.turner.com/cnn/2012/images/06/15/induced.seismicity.prepublication.pdf