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Elements to clarify the shale gas debate

Committee on Energy Prospective

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General framework for studies originating from the Committee on Energy Prospective (CPE) and background to the present report

Energy has become a major problem at a stage where global demand is increasing at a rapid pace resulting in the accumulation of greenhouse gases in the atmosphere and the depletion of natural resources. Although the topic is and has been extensively debated, unavoidable constraints regarding production, transportation and exploitation have been often neglected while the scientific challenges that should be addressed and the major technological breakthroughs that need to be implemented are in general under-estimated or overlooked in this debate. It is natural and in accordance with its mission that the Académie des Sciences take up this complex issue and ask its advisory committee on energy, the Comité de Prospective en Énergie (CPE), to examine this issue and address problems with a systematic and reasoned approach that will distinguish it from prevailing simplistic views. In its report on scientific research facing the energy challenge ("La recherche scientifique face aux défis de l'énergie") published at the end of 2012, the committee had identified areas worthy of further consideration. In the domain of fossil energy sources, it had specifically recommended to reconsider the question of shale gases. In the present opinion, the issues arising from the exploration and potential exploitation of this resource are addressed using information presented during a conference-debate organized at the academy on February 26, 2013. The analysis benefited from the contributions of our British and American colleagues who attended the debate (Robert Mair, Chair of the joint working group of Royal Society and Royal Academy of Engineering of the United Kingdom and Robert Siegfried, President of the Research Partnership to Secure Energy for America, RPSEA). It also relies on a set of documents already published by other organizations such as the International Energy Agency (IEA) and the "Alliance Nationale de Coordination de la Recherche pour l'Énergie" (ANCRE). The first version of this report was drafted by the Committee on Energy Prospective and forwarded to all the Académie members in July 2013. A revised version that takes into account comments received at that stage was then presented to the Select Committee on October 1st. The resulting version was then submitted for debate during a plenary assembly on October 29 and after some additional revisions for a final vote on November 15 2013.

The Académie des Sciences is fully aware of the need to reduce energy consumption, in particular fossil fuel consumption, and considers that this will require improvements in efficiency of all uses of energy. The issue of shale gases is worthwhile examining in the current context of transition to other sources of energy for the following reasons: (1) To ensure the security of fossil energy supply which still represents 80% of primary energy, (2) To reduce energy dependency and its costs (over 60 billion euros per year), (3) To improve competitiveness of the economy and (4) To enable a wider insertion of renewable energies by providing a dispatchable energy source that can compensate for their intermittency and avoid the use of coal. This report will first describe the various contextual elements and then the recommendations that have been formulated to help reduce the current uncertainties. These recommendations are synthesized below.

Summary of Recommendations

The first four recommendations concern research and exploration. The five that follow concern the exploitation of shale gases which could be potentially undertaken provided that necessary conditions, in particular for reducing environmental risks, are fulfilled.

1. Launch a research effort involving academic laboratories and major organizations should to study all the scientific issues arising from the exploration and exploitation of shale gases.
2. Prepare exploration be making use of existing or archived geological, geophysical and geochemical data and involve geologists in the evaluation of reserves.
3. Develop studies and experiments aimed at evaluating and reducing the environmental impact of any potential exploitation should be conducted.
4. Create an independent and multidisciplinary scientific authority to monitor actions taken to evaluate resources and their methods of exploitation.
5. Address issues of water management, a major problem in the exploitation of shale gases.
6. Implement environmental monitoring implemented before, during and after exploitation.
7. Launch developments to improve processes of hydraulic fracturing and methods to replace it.
8. Initiate a research program to develop appropriate regulations to address the long-term problems linked to tightness of exploitation drilling.
9. Full-scale tests should be carried out under conditions that conform to current French regulations, which ban hydraulic fracturing, in former coal-mining areas that have already undergone fracturing in order to better assess resources and maximize production performance.

Introduction

Shale gases have been the centre of heated debates for a few years. The opinions range from an outright ban on their exploitation to the notion that they might in an unexpected and almost miraculous way restore growth to our country and create jobs. In view of the importance of the questions raised by this topic, the Comité de Prospective en Énergie de l'Académie des Sciences (CPE) wished to provide elements to help clarify the debate and to formulate recommendations with the aim in particular of reducing current uncertainties.

In its previous report on scientific research facing the energy challenge [7], the CPE noted that some decisions about shale gas were taken hastily without serious examination. It concluded that this new resource should not be overlooked, the future of our energy being too uncertain not to at least carry out an assessment of its potential. The CPE pursued its investigation on the basis of facts presented during a conference discussion[1] organized at the Académie des Sciences in February 2013 ([1] to [5]) and on the basis of a set of documents cited in the References ([6] and [8-16]), in particular a report drafted jointly by the Royal Society and the Royal Academy of Engineering of the United Kingdom.

After analyzing the context to the shale gas debate, the CPE formulates nine recommendations that are scientific in nature. The main message is that the issue of exploration and potential exploitation of shale gases are worthy of examination and that progress should be made in this area and research developed, but that nothing should be undertaken without numerous verifications and prior experimentation subjected to strict regulation in order to control the potential risks for the environment and for human health. In line with this, the present report insists that research is required to address the numerous issues raised by the exploration and potential exploitation of shale gases and that it should to be initiated or further developed.

1. Context

The CPE wishes to stress that it remains within its field of competence which is that of scientific assessment. Certain contextual aspects, in particular of economic or legal character, such as those related to the mining laws and regulations are mentioned for information only. Further analyses of these aspects are being carried out by the Académie des Technologies (French Academy of Technology) and various think tanks. The topic of non-conventional hydrocarbons is also being examined by the French parliamentary office for scientific and technological options assessment (Office parlementaire d'évaluation des choix scientifiques et technologiques, OPECST) as part of a study on alternative techniques to hydraulic fracturing [12].

1. At a time when our neighbouring countries engage in shale gas exploration and exploitation, the debate on the subject seems to be terminated in France and one may wonder whether it was of any use to put this question on the table. The Académie des Sciences believes it is worthwhile. Examining scientific problems and working in an international framework falls within its mission. It is noted that analyses and debates are being carried out by the world's major academies. The Royal Society and Royal Academy of Engineering of the United Kingdom have recently published a joint report on this issue [6]. The debate has also developed within the American academies, for example by the Board on Environmental Change and Society [15]. It seemed appropriate to pursue this topic, and to carry it out in a balanced and reasoned fashion.

2. The discussion under way on the politics of "energy transition" also calls for further reflection. On the one hand, the large-scale development of intermittent dilute non-dispatchable energy sources such as wind and solar energy without appropriate means of storage requires that concentrated backup alternative energies be readily available. Currently, combustion power plants are the only sources of such energy. Intermittency cannot be mitigated by load balancing based on aggregation as shown

[1] The panel debates of the Académie des Sciences bring together specialists to examine current scientific issues. The aim is to exchange different viewpoints so that all those interested in a particular issue (general public, media and policy-makers) may be informed on the basis of the best scientific and technological evidence available at the time and presentations by experts in the field.

in recent studies ([7]) even if its effects can be attenuated by "cutting-off" certain users or by a suitable management of hydropower equipment. Hence, the development of renewable energies is accompanied by a need for fossil energy. If one chooses this for the future, at least over the medium term, it would be better to rely on gas combustion that emits reduced levels of CO_2, nitrogen oxides, sulphur compounds and soot particles rather than coal or lignite with a lower impact on health and the environment. If in addition one decides to commit to a significant reduction of nuclear energy in the production of electricity, which would reduce among others France's relative advantage in terms of CO_2 emission, it would be better to substitute nuclear energy with fossil energy based on gas rather than coal for the same reasons.

3. Before considering exploiting potential gas deposits, one needs to be able to explore them. If exploration confirms the estimates put forward about our reserves – and these remain to be demonstrated– their exploitation may lead to a reduction in France's energy dependence since our country imports more than 95% of its fossil energy and more than 98% of its natural gas. Imported fossil fuel contributes heavily to the French trade balance, which in 2012 alone was over 14 billion euros for natural gas[2]. The exploitation of shale gas and oil could help reduce France's trade imbalance and guarantee gains in competitiveness for industry. Also, the energy produced would be consumed locally, which would be globally favourable because that would eliminate the problems linked to transportation of gas over long distances. Concerning the environment, it is interesting to note that one of the collateral effects of shale gas exploitation in the United States has been the exportation and introduction of cheap coal on the European market at prices lower than that of gas. This has led to the shutdown and replacement of high-yield combined cycle gas turbine (CCGT) plants with coal plants that emit higher levels CO_2 (see the impairment of GDF-Suez's assets a few months ago). This further points to the importance of having a gas source at a competitive price.

One cannot ignore the industrial revival of the United States, in particular that of industries that depend on energy and resources such as the chemical industry. The price of gas, which is three to four times cheaper than in Europe (essentially because of exploitation of shale gases), confers a strong competitive advantage to the United States relative to Europe. Economic gains have already been observed on the other side of the Atlantic ocean, resulting in a considerable decrease in energy costs and a greater availability of chemical raw materials. More and more industries that could establish operations in Europe and create jobs choose the United States because of the low cost of energy from gas. In the current crisis situation, the positive economical consequences for France of developing shale gas and oils are too important to reject out of hand without taking a closer look at this potential resource. In any event, its potential development should be carried out while retaining the virtuous goal of overall reduction of energy consumption per capita. In view of the immediate economic interests, the benefits of an interim solution built on the long-term need for a mix of energy sources, an expected improvement in extraction techniques and the inevitable increase in the cost of liquid and liquefied hydrocarbons also deserve to be considered.

[2] The exploitation of nuclear energy results in savings amounting to 20 billion euros in fossil fuels that would otherwise have to be imported in addition.

4. However we should not commit to the exploitation of shale gases without a thorough study of the potential risks to the environment associated with this type of production. Many of the risks are not new and have already been addressed in the exploitation of other types of resources (drillings linked to the conventional exploitation of oil, gas, geothermal sources...). Hydraulic fracturing itself has been widely used in the past. It is employed each year worldwide in several thousand conventional oil and gas drillings and although the type of rocks concerned are not shale there has been a large amount of feedback. It is important to consider each risk in a completely transparent manner and to determine whether novel technologies, appropriate operating procedures and adequate regulation would be compatible with concerns for the protection of the environment and lifestyles. At this stage, one should remember that the exploitation of the Lacq gas field although not similar to a shale gas deposit, raised some serious technological problems (the field was discovered in the South-West of France in 1951 which was operational in the 1960s and was closed down on October 14, 2013). Despite these difficulties, exploitation was carried out under conditions that respected both the environment and the local water quality in spite of the high proportion of acid gases (hydrogen sulphide).

5. As is the case for many complex topics, the expected benefits and risks should be presented in a non-partisan way on the basis of scientific data and an assessment of whether the risks can be potentially controlled must be made. It would be important to define conditions acceptable to the local communities and to the environment which would allow exploration and enable any potential exploitation. To this end, it is essential to develop research and formulate a set of regulations and practices to reduce the impact of exploitation on ecosystems.

6. Even if on the long-term electrical needs can be covered by nuclear energy and by certain renewable energies (hydraulic, wind, solar, high enthalpy geothermal energy,...), there will still remain a pressing need for liquid and gaseous fuels (such as oil, natural gas as well as synthetic fuels derived from biomass, plant waste, algae and hydrogen from water electrolysis). These liquid and gaseous fuels, which are essential for many uses, will retain their importance over a long period of time. When choosing between the sources of fossil fuel energy currently available, it is important to keep in mind that natural gas combustion, while producing greenhouse gases, is two to three times cleaner in terms of gaseous emissions than that of coal (increased Carnot efficiency and half the CO_2 emitted per unit of energy). Natural gas is also a raw material of major importance in chemistry.

7. There is a major difference in the regulations concerning subsurface exploitation between the United States and Europe. In the latter, because underground resources belong to the nation, there is a better control of exploitation procedures. The current revision of the mining code could even strengthen the rules regarding the protection of the environment for all forms of exploitation of subsurface resources while allowing local communities and landowners to draw higher profits from any potential exploitation of the underground.

2. Analysis and Recommendations

1. The Comité de Prospective en Énergie recognizes that there is currently no public research program in France on shale gases although it notes that proposals have been gathered in the report "Programme de recherche sur l'exploitation des hydrocarbures de roches-mères" of the Alliance pour l'Energie (ANCRE) [8] and that the 2013 call for proposals of the Energy program of the CNRS focuses on the theme "Resources, society and environment". The Committee stresses the importance of these initiatives and **recommends that a sustained research effort be launched in this area** (involving both academic laboratories and technological research institutes) aimed at: (1) Acquiring good knowledge about the resource and assessing the accessibility of the reserves, (2) Better evaluating the environmental impact of any potential exploitation, (3) Improving and regulating current exploitation techniques and procedures to minimize this impact, (4) Developing alternative technologies to exploitation by hydraulic fracturing, (5) Demonstrating whether environmental impacts can be controlled and (6) Undertaking experimentation at various scales under well-controlled situations and setting up a pilot research site where an independent analysis of the processes involved can be undertaken. The Committee is of the opinion that if exploration follows specific and carefully monitored guidelines, it will have no significant environmental impact.

2. The conditions for hydrocarbon generation and migration in sedimentary basins are well known. Based on the nature of the sediments and their organic matter content, the sedimentological and tectonic storage history and subsequent thermal evolution of hydrocarbons, one knows how to evaluate the quantities of liquid and gaseous hydrocarbons that were generated and the amount still trapped within the rocks, much of it having usually been lost. With regard to the preparation for exploration, the Committee **sets as a priority the use of geological, geophysical and geochemical knowledge** already acquired (or lying dormant in archives) from drillings and fracturing as well as the collection of new data from field observations, laboratory experiments and numerical simulation models. It stresses that it is important to combine all this information in order to evaluate on a scientific basis the potential resources in shale gas and oil of our country. It is urgent to involve all the geoscientists (geologists, geophysicists, geochemists, hydrogeologists,...) from the academic world and public (CNRS, BRGM, IFPEN) or private institutions and to urge them to work jointly to assess national reserves.

3. While noting that hydraulic fracturing has existed for a long time and has been widely used[3], the Committee **highlights the importance of carrying out studies aimed at evaluating and reducing the environmental impact of this technique**. To this end, modelling of fracturing mechanisms should be improved taking into account both the hybrid (mineral and organic) composition and the heterogeneity of bedrocks, the optimization of hydraulic fracturing agents. This should also allow to identify alternative products that are compatible with the highest environmental standards. In this respect, it might be possible to use "intelligent" materials that are quick-setting and display improved gas transfer properties. The Committee stresses

[3] Since the industrial introduction of deep hydraulic fracturing in 1947, 2.5 million operations have been implemented worldwide.

the need to carry out experimentation at all levels, ranging from sample to site, in order to produce models validated on a full-scale. It also recognizes that such studies and experiments should closely involve the public in formulating the issues to be examined, in analyzing in a transparent manner the solutions put forward and in monitoring the outcomes of this analysis. This work should result in the development of regulations and specifications adapted to an environmentally responsible exploitation.

4. Because the issue is so highly controversial at the national level, the Committee suggests that an independent multidisciplinary scientific authority be created to objectively monitor any action taken to evaluate shale gas resources and exploitation methods.

If the above actions should confirm the interest to move on to exploitation, the following recommendations could be implemented.

5. The Committee considers that **water management constitutes a major issue in shale gas exploitation.** It must take into account availability, recycling and prevention of aquifer and surface contamination by the water used for drilling, fracturing and flowback from fractured wells (water returned to the surface after fracturing). The first drillings conducted in the USA did not always comply with the standards necessary for the proper protection of the environment and led to significant pollution, something that must be absolutely avoided in a country as densely populated as France. It seems, although this still needs to be evaluated, that current techniques and experience from the oil industry can help define drilling and exploitation procedures that are environmentally friendly and safe over the long term. Aquifers that are drilled through must be protected by multiple casings and wells must be perfectly sealed. Water flowing out of wells can leach out heavy metals or radioactive elements naturally present within the rocks and must therefore be treated before release into the environment [1, 2]. This is neither new nor specific to shale gases; however, the quantities of water required by the latter are on a much greater scale.

6. The presence of methane and other contaminants in groundwater must be monitored as well as any leakage of methane and other gases into the atmosphere. The Committee highlights the **importance of monitoring before, during and after exploration/exploitation operations**. Monitoring potential methane leaks allows better assessment of the greenhouse footprint of shale gas extraction [3, 4, 14]. Before any exploration, an environmental survey should be carried out to establish a baseline describing the local initial situation (fresh water quality, initial amount of methane in near surface aquifers). This will make it easier to monitor the impact of exploitation and restoration of the area once exploration and exploitation operations are terminated and avert blaming shale gas extraction for pollution that was initially present [1, 2].

7. On the issue of alternatives to hydraulic fracturing, the Committee notes that methods using electrocracking, thermal fracturing and propane or supercritical CO_2 injection have been proposed and are already being used on a small scale. However, the Committee observes that to date **these methods do not yet constitute an alternative to hydraulic fracturing that can be used in practice**. It is noted that

while research on these and new methods should proceed, efforts should also be made to improve hydraulic fracturing techniques (reducing the amount of water used, monitoring, identification of additives that are the most compatible with the environment, among others).

8. The Committee considers that the **issue of long-term sealing of shale gas exploitation drillings**, even when they are plugged, deserves careful examination. Ageing of cement and pipe corrosion are unavoidable on the long term, but their effects are not yet known and could result in the loss of leak-tightness of sealed wells after a rise in pressure. Perennial sealing is possible by reaming and extracting casings over a sufficient depth, cementing and finally placing a seal-proof cap made from natural materials (compacted clay). However, there may be an alternative to these expensive operations. It is clear that this topic should be addressed if need be with appropriate regulations ([13]).

9. Gases from hydrocarbon and coal source rocks have existed naturally for millions of years and have not dropped unexpectedly from the sky in the 21st century. They have been known to geologists for at least 40 years and to coal miners for much longer. Until now a proper exploitation method has been lacking. The law forbids hydraulic fracturing but does not forbid vertical drilling or horizontal drilling from existing wells. Presumably, methane reserves are abundant in former coal basins as evidenced by the large amount of fossil organic matter and the number of accidents that have occurred throughout their exploitation history. That is why it would be interesting to carry out one or more trials in such a geologic context. The Committee suggests as a first course of action towards the exploitation of shale gases that **full-scale tests be conducted under conditions that comply with the current regulation**. Vertical wells should be tested without any hydraulic fracturing in areas within former coal basins that have already been fractured and have a high amount of organic matter likely to generate large quantities of gas. Such vertical drills could be optionally followed by various types of horizontal drillings in order to maximize the flow of methane, measure its evolution over time and study the density of drillings required to recover industrially significant amounts of methane. The Committee notes that the distinction between coal gas and shale gas is of limited importance because the same geological processes are involved and because the nature and mechanical resistance of the subsurface layers is highly variable.

ANNEX

This annex covers four aspects. Section 1 summarizes current knowledge on shale gases (see reference [9] for a more detailed review of shale gases and non-conventional hydrocarbons in general and reference [17] for documents accessible to a wide audience). Section 2 gathers the main substance of the recommendations presented by the British Royal Society and the Royal Academy of Engineering [6]. Section 3 addresses the environmental risks associated with the extraction of bedrock gases and reviews the methods that could be used to control these risks. Finally, Section 4 provides an overall assessment of the extraction and use of shale gases in terms of greenhouse gas emission.

1. Shale gases and oils in a few words

Shale gas is a **natural gas** formed by methane and other hydrocarbons, most often buried at a great depth (1,500 to 3,000 m) within compact and impermeable rocks [1]. The presence of shale gases is not a new discovery as some may think. The scientific knowledge acquired over more than 30 years on the genesis of liquid and gaseous hydrocarbons can be used to evaluate these resources. Reserves are considerable, well distributed around the world and sufficient to provide 120 to 150 years of natural gas consumption at current levels.

Figure – European regions with potentially exploitable shale and coal gas reserves (Source: International Energy Agency 2012 [16], presented by B. Courme [2]).

In Europe, shale gas reserves are estimated to be between 3,000 and 12,000 billion m^3 (75 to 300 years of current French consumption among which France's resources would amount to 5,100 billion m^3). Figure 1 is a map of European regions with potentially exploitable shale and coal gas reserves.

Although these numbers are currently being debated, the conditions for hydrocarbon formation and migration in these sedimentary basins are well known. From the nature and content of organic matter in the sediments, the history of their burial and resulting thermal evolution, we know how to determine the quantities of liquid and gaseous hydrocarbons that have been generated and those that have remained in place. The geological, geophysical and geochemical knowledge already available can be used to assess our country's potential resources in bedrock oil and gas on a scientific basis. This would help refine current estimates. The uncertainty is high in the absence of such information. For example, the numbers given for Poland correspond to 30 to 440 years of its current consumption and could enable the country to regain some independence from Russian gas imports. However, these estimates could not be refined any further. Exxon, which had started exploration, stopped it in the absence of any regulatory clarity concerning the exploitation of shale gases and the uncertainties surrounding commercial extraction from relatively impermeable rocks.

The exploitation of shale gases is based on the combination of two technologies: hydraulic fracturing, which was invented in 1949 and used in over one million wells in many oilfield applications, and horizontal drilling which was introduced more recently. It is this combination that enabled its large-scale deployment in the United States.

The development of shale gas has radically changed the supply situation in the United States. This resource, which is considered as being relatively inexpensive, has enabled the US to regain an energy supply independence and to induce the revival of job-creating manufacturing activities while ensuring a reduction of carbon emissions. There is however an impact on the communities located in the areas where this resource is being exploited. Most of these areas are inhabited and the local people are not familiar with oil and gas exploitation activities. Development of shale gas has been questioned by residents, environmental groups and regulatory authorities. Their concerns constitute the basis for an active dialogue on matters relating to shale gas development in the United States [4]. Although major errors due to negligence were committed in the beginning, the American experience has shown that shale gases can be developed in a responsible way when the entities concerned commit to using appropriate methods and develop open and transparent communication with all the stakeholders involved [4].

2. British recommendations

Studies carried out within the framework of the Royal Society and Royal Academy of Engineering of the United Kingdom [3,6] by a committee chaired by Robert Mair give some practical directions. The main points are summarized below as a list of observations formulated expressly for the British context but they could as well be applied to France:

- Hydraulic fracturing can be developed efficiently in the United Kingdom provided that the best operational practices are implemented and are tightly controlled by regulation.

- Strong regulation and efficient monitoring systems must be implemented and best practices strictly observed in case the government gives the go ahead for new explorations.

- Seismicity induced by hydraulic fracturing is expected to be lower than that naturally occurring in the United Kingdom or linked to mining activities – both of which are already very low when judged according to world standards. Robust and efficient monitoring must however be implemented.

- The risk of aquifer contamination from fracturing is very low provided that gas extraction is done several hundreds of meters below water tables.

We can build on this experience and analyses to develop specifications, appropriate regulations and best practices. The recommendations are the following:

- Give primary responsibility for regulating shale gas extraction to a single regulatory authority.

- Strengthen the role and means of regulatory agencies by giving them additional resources according to their needs.

- Require the assessment of environmental risks for any operation concerning shale gases and ensure that these are submitted to regulatory authorities for analysis.

- Establish a map of the initial environmental state and ensure that any potential contamination is monitored before and during exploration activities and throughout exploitation.

- Ensure strict monitoring of groundwater methane, seismicity and methane leakage before, during and after hydraulic fracturing.

- Strengthen the well inspection system to guarantee that well designs not only take into account concerns for health and safety but also allow for the environmental impact.

- Carry out appropriate integrity tests of the wells based on a standardized framework.

- Establish integrated monitoring procedures to ensure that water is used in a sustainable manner and to minimize waste.

3. Analysis of environmental risks associated with extraction of bedrock gases

The potential impact of shale gas extraction is a subject of concern for the public and communities. Worries are mainly centred on potential water contamination due to methane and chemicals used in hydraulic fracturing, air pollution induced by hydrocarbon leakage during exploitation, disturbances to the communities caused by the works associated with shale gas exploitation and production as well as negative cumulative impacts on communities and ecosystems. The criticisms about shale gas extraction concern mainly their environmental consequences [1,2].

Aquifer pollution by methane
The most important issue is that of possible aquifer pollution by methane and products used in hydraulic fracturing. At this stage, it should be stated that the presence of methane could also be due to a variety of causes not all linked to leakages during shale gas exploitation. It can originate from **biogenic methane** generated by microorganism respiration within the most superficial strata or from **geogenic methane** naturally flowing in fault zones exposed to high pressures. Usually, these sources of methane are already known or can be evaluated before any exploitation. It is possible to distinguish between these sources of methane using their isotopic signatures. Methane dissolved in water can pose a risk of explosion when it is released into a confined space. In solution in low amounts it does not present any toxicological risk. However, aromatic compounds that potentially accompany methane should be monitored. A value of 10 mg/L of methane is considered a threshold for concern by the American health authorities.

Leaks induced by exploitation activities can also be a source of methane seepage into aquifers. Several migration pathways have been identified. They can follow naturally existing or induced fractures, they can be due to defective cementation between casings and soil, the ageing of the casings, cement or a leak between production wells and any neighbouring wells or a leak associated to flowback from fracture fluid.

The risk of direct contamination from hydraulic fracturing is unlikely and can be controlled by respecting a safe vertical distance to the aquifers. In most exploitations, this distance is at least several hundred meters and can be even greater than a kilometre. The depth of the fractures identified by microseismic mapping indicates the position of fractures relative to aquifers and, in general, it has been observed that this distance is quite large. Hence, it would be easy to meet this requirement and to avoid this type of risk. The risk of coming into contact with a deep aquifer due to the existing fracture network is considered to be very low if the vertical distance between the areas of hydrofracturing and the aquifers is sufficient.

Casing integrity

Another possible path of contamination is associated with defects that compromise casing integrity. Leakage into aquifers due to a defective casing can also happen with conventional deposits. This risk is well known and controlled by the oil and gas industry. It can be lowered by a strict compliance to regulation. The probability of failure is low when construction, exploitation and then shutdown of wells are done according to best practices. There are examples not to follow [14] and the role of regulation is to make sure that these are avoided.

Management of fracturing fluids

Contamination can also result from spillage or defects of the surface structures in which the fracturing fluids are stored. This same risk exists in many industrial sectors and can be diminished by a strict adherence to best practices.

The environmental impact of the products injected in order to carry out hydraulic fracturing must also be considered. The possible contamination by these products and the fate of borehole water are subjects of concern. Additives are used to increase fracturing and productivity efficiency. They belong to three categories: (1) Biocides which lower bacterial proliferation in wells, (2) Products which help penetration of the sand injected to keep fractures open and (3) Compounds that enhance well productivity. There is a real need for transparency on these additives and for an assessment of the risks associated with their use. Studies to identify additives that are compatible with current environmental standards should also be undertaken. To answer all questions, the greatest transparency about the additives used in this process must be ensured and dangerous products replaced with less toxic equivalents (according to the REACH regulation adopted by the European Union Council in 2006). A site was created by the United States in which all suppliers must now clearly indicate the exact composition of the products injected, which was previously kept secret for industrial competition reasons. Ensuring borehole treatment is now part of the operators' specifications. Related wastewater treatment processes and systems must of course be defined before any exploration or exploitation.

Air quality and methane leaks

The issue of air quality and of methane leakage must also be taken into account. This risk has been well identified by the oil and gas industry and must be reduced by strengthening efforts to control methane emission. To this end, the monitoring and control of emissions at the level of well equipment should be implemented. In all cases, methane should be captured and flared rather than freed and at a later stage alternatives to flaring should be developed.

Nuisances

Local populations and communities are concerned about land use, landscape modifications due to the deployment of large-scale drilling operations with multiple wells and disturbances induced by the works associated with exploitation and production of shale gas. These operations are noisy, they increase truck circulation, modify the landscape and impact property value. Nuisances should obviously be taken into account and measures taken to reduce them. Exploitation of shale gases indeed requires a higher density of wells than conventional natural gas exploitation, however it is possible to concentrate several wells to one platform, optimize the use of multi-well drilling pads using horizontal drilling to access a wider underground area and develop technologies to reduce water consumption. It is also possible to integrate the installations into the local landscape and minimize nuisances during drilling and subsequently throughout the whole exploitation stage, and to develop and implement methods to attenuate noise. Overall, before any exploration/exploitation it is important to communicate clearly and honestly the potential disadvantages and benefits and to establish a dialogue with all the stakeholders.

The water resource

The large quantities of water required for hydrofracturing are generally considered excessive *relative to the increasing scarcity of resources available.* Water is consumed only during the drilling and exploitation stages, but the amount consumed should be compared to other uses. The quantity of water required to recover a given amount of energy is usually expressed in liters par million BTU (*the* British Thermal Unit, is widely used by the oil industry in the United Kingdom and the United States, 1 MBTU is approximately equal to 1 GJ). While one should be sceptical of the figures, it is noted that 2 to 20 L of water are required to recover 1 GJ of conventional gas, 30 to 80 L per GJ of shale gas and 20 to 120 L/GJ of coal. The amount of water required to produce biofuels are two orders of magnitude higher, about 1,000 L/GJ.

Typically, 15,000 m^3 of water are consumed per bore well during drilling and subsequent hydraulic fracturing operations (to provide a basis for comparison, drinking water consumption of a city like Paris is about 550,000 m^3 per day or 200 million m^3 per year, a high end 18-hole golf course in France consumes an average of 90,000 m^3 per year). In considering such examples, the amounts of water actually consumed should also factor in the amount of water recovered and its quality.

In any case, water management is a major issue and must take into account resource availability, water recovery and prevention of aquifer contamination by borehole water. Regarding the latter point, wells must have multiple casings and be completely sealed to protect aquifers that are traversed. Flow-back water may leach out heavy metals and radioactive elements that are naturally present in rocks and must therefore be treated. There are also possibilities for recovering compounds of commercial interest from waters discharged by the wells.

After the drilling stage, water consumption decreases noticeably during exploitation as sand is used to maintain fractures open. Water discharged from the wells is recycled. Hence, shale gas exploitation depends on water availability.

Induced seismicity

Questions have also been raised about the seismicity induced by hydraulic fracturing. An analysis carried out in the United Kingdom noted that earthquakes of magnitudes 5 and 4 on the Richter local magnitude scale occur in that country every five years and three to four years, respectively. The seismicity associated with coalmine exploitation is usually lower than the natural seismicity and does not exceed a magnitude of 4. Hydraulic fracturing can induce small earthquakes of magnitude 3 (a level which is felt by a few people and that may induce some surface effects). The earthquakes induced by hydraulic fracturing in the United Kingdom were of magnitude 2.3 (unlikely to be felt). The studies carried out point to lower levels than those of natural earthquakes or those associated with mining activities, which are already quite low. One must however distinguish the case of areas with high natural seismicity due to local movements of a fault. In any case, seismicity must be strictly and efficiently monitored.

4. Global balance of shale gas exploitation in terms of greenhouse gas emissions

One of the criticisms raised about exploitation of shale gases is their impact in terms of emission of greenhouse gases. A few points that deserves further examination are outlined below.

One may first note that 1 kg of methane generates 50 MJ of energy and results, after complete combustion, in 2.75 kg of CO_2. To generate the same energy, 1.25 kg of coal is required and produces 5.58 kg of CO_2. For the same amount of energy produced, there is a two-fold increase in CO_2 emission. In other words, replacing coal by natural gas in fossil fuel plants halves the amount of greenhouse gas produced. With combined cycle power plants (combining gas and steam turbines), the thermal efficiency can reach 60% or about double that of a conventional coal power plant. In the United States, the direct impact of replacing coal has been a decrease in CO_2 emissions in recent years. From the viewpoint of the climate constraint, replacing coal by natural gas is only positive if the level of methane leakage remains small (an issue addressed below). It also avoids the emission of pollutants specifically associated with coal (dispersion of heavy metals and natural radioactive elements) and decreases the amount of sulphur oxides (20-fold), nitrogen oxide (4-fold) and particles (70-fold).

The benefits in terms of CO_2 emissions would be voided if methane leakage during exploitation, storage and transportation of the natural gas were too large. Methane is itself a greenhouse gas with greater radiative forcing than CO_2 but much shorter atmospheric lifespan.

There is no consensus on the potential impact of methane leaks associated with the exploitation of shale gas. Some publications such as [10] observe that methane leaks due to the exploitation of shale gas range from a third to twice the amount from conventionally exploited gases and could lead to a higher greenhouse effect than coal or oil within 20 years that could last 100 years, but other studies such as [11] reach the opposite conclusion concerning shale gases. Their exploitation would result in a two-fold and even a three-fold reduction in greenhouse gas emissions. Leakage is also an issue raised by conventional natural gas exploitation. Whether the exploitation is conventional or not, methane leakage must be minimized in all cases.

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Les conférences [1] à [5] peuvent être visionnées sur le site de l'Académie : *http://www.academie-sciences.fr/video/v260213.htm*

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Roger Balian – Membre de l'Académie des sciences
Sébastien Balibar – Membre de l'Académie des sciences
Yves Bréchet – Membre de l'Académie des sciences
Édouard Brézin – Membre de l'Académie des sciences
Sébastien Candel (président) – Membre de l'Académie des sciences
Catherine Césarsky – Membre de l'Académie des sciences
Michel Combarnous – Correspondant de l'Académie des sciences
Vincent Courtillot – Membre de l'Académie des sciences
Jean Dercourt – Membre de l'Académie des sciences
Jean-Claude Duplessy – Membre de l'Académie des sciences
Pierre Encrenaz – Membre de l'Académie des sciences
Marc Fontecave – Membre de l'Académie des sciences
Robert Guillaumont – Membre de l'Académie des sciences
Marc Pélegrin – Correspondant de l'Académie des sciences
Olivier Pironneau – Membre de l'Académie des sciences
Michel Pouchard – Membre de l'Académie des sciences
Paul-Henri Rebut – Correspondant de l'Académie des sciences
Didier Roux – Membre de l'Académie des sciences
Bernard Tissot – Membre de l'Académie des sciences

List of interviewed experts

Committee on Energy prospective

November 22 2011

- Olivier Appert – Président de l'IFP Énergies nouvelles – Président de l'Ancre
- François Kalaydjian – Directeur de la Direction des technologies de développement durable – IFP Énergies nouvelles
- Nicolas Arnaud – Directeur de recherche – OSU-OREME – CNRS
- Françoise Elbaz-Poulichet – Directrice de recherche – OSU-OREME – CNRS
- Michel Séranne – Chargé de recherche – OSU-OREME – CNRS

Conference-debate February 26 2013

- Nicolas Arnaud – Directeur de recherche – OSU-OREME – CNRS
- Bruno Courme – Total
- Bruno Goffé – Insu-CNRS
- Robert Mair – Cambridge University and Royal Society
- Robert Siegfried – Research Partnership to Secure Energy for America (RPSEA)

Committee on Energy prospective

February 27 2013

- Robert Siegfried – Research Partnership to Secure Energy for America (RPSEA) – *Environmental concerns with shale gas development in the United States*

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