Panel of experts

Hydrofracking Risk Assessment

Executive Summary

Study concerning the safety and environmental compatibility of hydrofracking for natural gas production from unconventional reservoirs

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Technical discussions were conducted during the Study Status Conference that was held in Berlin, Germany on 6 and 7 March 2012.

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The study was carried out by a panel of experts in conjunction with ExxonMobil's hydrofracking dialogue and information dissemination process. April 2012

Introduction

Prof. Dr. Dietrich Borchardt

Head of the Department of Aquatic Ecosystems Analysis and Management, Helmholtz Centre for Environmental Research – UFZ

Hydrofracking has been coming into increasing use in recent years – in Germany, primarily in order to allow for full exploitation of "conventional" natural gas reservoirs. However, since 2010, oil companies such as ExxonMobil have been laying plans to explore and exploit, likewise in Germany, "unconventional" reservoirs that in many cases would have been completely inaccessible without hydrofracking because the natural gas is trapped in dense rock.

Hydrofracking is widely practiced in various regions of the US. Media reports concerning earthquakes, contaminated waterbodies and groundwater, and flammable methane in drinking water wells are worrisome and have raised concerns among German citizens, politicians, and water companies that hydrofracking may be harmful to natural resources and in particular to drinking water.

These evolutions prompted us, a panel of outside experts, to conduct a year-long scientific analysis and assessment (from April 2011 to April 2012, within the framework of ExxonMobil's hydrofracking dialogue and information dissemination process) concerning the health and environmental aspects of hydrofracking as used for natural gas production from unconventional natural gas reservoirs. Our investigations centered around whether and under which circumstances hydrofracking is compatible with the exigencies of public health and environmental safety.

We began our work by compiling numerous questions that German citizens, municipalities and water companies have asked on the subject of hydrofracking and natural gas. At the same time, we also compiled and evaluated current knowledge on the subject, to which we added our own publications. We also traveled to the US to see at first hand the potential effects of hydrofracking and to conduct dialogues with the persons affected and the competent authorities. In a final step, we asked recognized German and foreign experts to assess our study design and the scientific quality of the work we have carried out thus far.

This pamphlet comprises an executive summary of our findings and recommendations concerning the relevant public policy issues and a number of other key issues that have thus far not been a main focus of public debate. Our study revealed that hydrofracking entails serious risks, as well as minor risks.

I was most eager to chair the panel of experts because for me the subject of hydrofracking poses a major challenge that I strongly feel the scientific community can and should make a key contribution to overcoming and shedding light on, using the specific tools and expertise they have at their disposal. The extensive collaboration between the nearly 40 panel members also presented a golden opportunity for us to study both the scientific and practical aspects of the key issues.

Hydrofracking Risk Assessment

- *The panel's scientific director is Dr. Dietrich Borchardt, who works at the Helmholtz Centre for Environmental Research – UFZ, which is Germany's largest environmental research institution.*
- *Dietrich Borchardt designed the scientific work program and selected the panel members, all of whom are recognized and experienced specialists in their chosen fields, and none of whom have ever worked for the gas industry prior to their affiliation with this study. They were ably assisted in their work by an additional 30 experts.*
- *ExxonMobil financed the study and the accompanying dialogue and information dissemination process and supplied data and information for the project.*
- *The project contract stipulates that ExxonMobil will have no say in the content of the report.*

Stakeholder questions

At the beginning of the study we compiled 500 questions, some of which we have included in this brochure and to all of which we have responded online (in German only) at **www.dialog-erdgasundfrac.de.**

For example:

Are there areas such as drinking water extraction areas, water conservation areas and other environmentally vulnerable areas where exploratory natural gas drilling, hydrofracking, and production should not be carried out?

To access the "Informations- und Dialogprozesses der ExxonMobil über die Sicherheit und Umweltverträglichkeit der Fracking-Technologie für die Erdgasgewinnung" web portal (in German only) containing all information, presentations, protocols and questions concerning the regions we studied, visit **www.dialog-erdgasundfrac.de**

On numerous occasions, we discussed our methodology and interim results with stakeholder working groups whose members were representatives of water companies, municipalities and the like. These dialogues ensured that our study focused on practical issues and on the concerns of people in the region affected. Absent this process, the thrust of our procedure and the issues we focused on would have been somewhat different and some matters would have been explored more superficially. Conversely, it was obvious to all concerned that this dialogical process promotes social dialogue concerning the matters addressed in this study and that it was based on more solid scientific foundations than would have been the case had the present study not been carried out.

One of the most striking aspects of how the study unfolded was our relationship with ExxonMobil, whose openness to a frank investigation and discussion at such an early stage of the risks entailed by one of its key areas of activity was anything but a given. We were impressed by how thoughtfully and seriously ExxonMobil reacted to our take on and questions about hydrofracking, which also opened up new perspectives for the company itself.

Our analyses focus in particular on worst-case scenarios, i.e. events that are extremely unlikely to occur but which, given the right confluence of unfortunate circumstances, could in fact occur – for example continuous underground fault zones that neutralize the compression effect of geological barriers; critical underground tectonic stress that could potentially damage a hydrofracking well; accidents; technical failures; and human error. If there are sound reasons for our having made such scenarios a lynchpin of our work, such scenarios could also falsely raise the specter that such events will occur without fail. And though this is of course not the case, we nonetheless operated on the assumption that it is – or rather could be – the case. For a technology should only be used if you're sure that you can get a handle on the worst scenarios to which that technology may give rise; and to do that, you need to know these scenarios backward and forward and understand them to the full.

Another aspect of our work also resulted in numerous dialogues with the relevant stakeholder groups as to how generally applicable assertions can be arrived at and how specific locations can be assessed. For in the final analysis, concrete assessments and calculations can only be carried out for real-world locations. But as our goal was to elaborate criteria and procedures that are applicable for the greatest possible number of locations, we developed models based on the geological conditions in Münster-

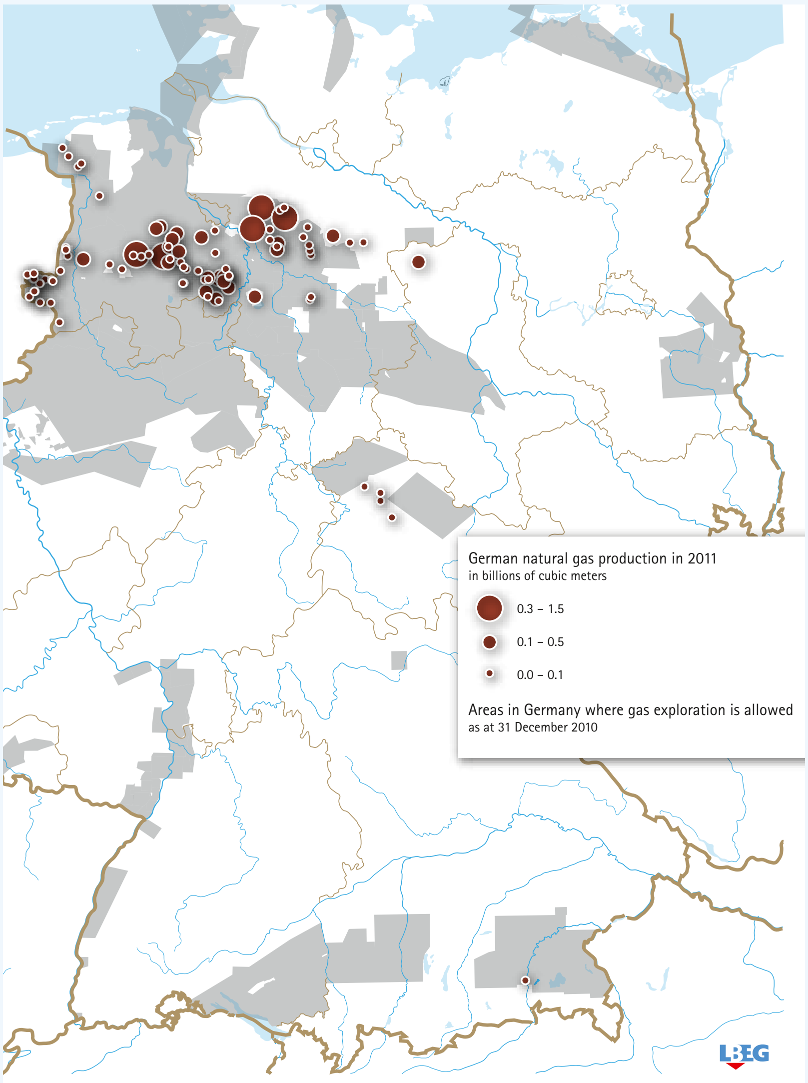
lander Kreidebecken (North Rhine-Westphalia) and Niedersächsisches Becken (Lower Saxony) and factored into these models a range of possible effects using characteristic scenarios.

The fact that neither myself nor any other members of the panel have ever had any dealings with the gas industry allowed us to see and investigate the big picture. Although we took account of the numerous studies that have been conducted by hydrofracking professionals from the fields of drilling technology, resevoir engineering and mining research, we regard our own study as a proactive attempt on the part of industry outsiders to take a long look at hydrofracking in a manner that encompasses the environment, water resources, and individuals that are located in the environs of actual hydrofracking operations. To this end, we considered all relevant aspects – namely:

- the installation and operation of individual drilling sites
- the realization of hydrofracking operations
- gas drilling and the subsequent sealing process and related long term considerations
- wastewater disposal
- the legal aspects of hydrofracking.

In the interest of clarity, certain passages of this report explicitly explore the following question: What changes would be wrought in, say, a 200 square kilometer area if hydrofracking were being carried out throughout that area by the year 2030?

We hope that the present report on our findings and recommendations will help to promote a thoughtful, realistic and fact-based debate on the vices and virtues of hydrofracking.



01 This figure displays (a) the areas in Germany where hydrofracking exploration is allowed; and (b) the areas in Germany where natural gas is currently being produced. (Data source: Landesamt für Bergbau, Energie und Geologie des Landes Niedersachsen - LBEG)

Contents



Graphics

The (possible) shape of things in 2030

In the interest of shedding greater light on our observations concerning the possible effects of hydrofracking, the remainder of this report contains various "interludes" comprising a thought experiment as to how the hydrofracking domain may have evolved by the year 2030.

Glossary of Terms

B

Barrier layers are rock layers of low hydraulic conductivity that prevent groundwater from percolating downward and prevent hydrofracking fluid from percolating upward. Barrier layer conductivity is measured in meters per unit of time. In the presence of a pressure difference, water in highly conductive strata is transported at a rate of around a meter a day, whereas in clay barrier layers it takes hundreds of years for water to be transported just a few meters.

C

A conservative research paradigm is a concept that takes as its starting point a great number of improbable circumstances that are nonetheless within the realm of possibility. As a result, in this type of paradigm a given effect has a sustained impact that does not subside after the event has occurred.

D

Deep groundwater is groundwater that is found deep underground and that contains salt, heavy metals and/or radioactive substances. When such water occurs in rock strata containing natural gas, it is referred to as formation water. The amount of formation water in flowback water varies greatly from one gas reservoir to another.

Detection involves monitoring specific technical safety installations, including monitoring well pressure to detect leakage rapidly.

A deterministic risk assessment takes account of various incidents that could potentially occur during the hydrofracking process, but provides no insight into the causes of such incidents or the probability of their occurrence. In contrast, in a probabilistic risk assessment the potential causes of an assumed incident are analyzed, and the probability of failure arising from such events as well as the consequences of such events occurring are calculated.

A drilling site is an asphalted area where drilling is carried out and where the necessary materials are stored. Normally, multiple wells are drilled at a given drilling site, and on completion of the hydrofracking process these wells comprise surface wellheads.

F

In geology, a fault is a planar fracture or discontinuity in a volume of rock, across which there has been significant displacement along the fractures as a result of earth movement. Geological faults are not hollow, but are instead filled with rock material. Gas and fluid conductivity is usually higher along the fault line than in the surrounding rock.

G

Groundwater refers to all water that is found in highly permeable rock layers (e.g. sand or sandstone), fills porous cavities, and lends itself to pumping. A distinction is made between “fresh” groundwater that is up to 200 meters below the surface and that can be used for drinking water, and “saline” groundwater, which is more than 200 meters down. These two ground water strata commingle in the absence of barrier layers.

H

Hydraulic fracturing or hydrofracking, is a technology that allows for natural gas production from unconventional reservoirs. In this process, a fluid known as hydrofracking fluid is blasted into deep rock strata for the purpose of inducing cracks known as hydrofracking cracks. Materials called proppants (e.g., usually sand or ceramic beads), as well as chemicals known as hydrofracking chemicals, are added to the hydrofracking fluid.

Hydrofracking wastewater, for which the technical term is “flowback water,” is composed of a mixture of aquifer water and hydrofracking fluid that is channeled back into the rock.

M

A model helps us to gain greater insight into complex events or phenomena that occur over an extended period and for which relatively little empirical data are available. The **modeling** process is based on assumptions that reflect reality and which for our study were conservative (i.e. cautious). Using this model and the attendant assumptions, simulations are conducted concerning the phenomena or events that the researcher wishes to gain insight into. Models can be validated using real-world data. In other words, modeling findings are compared with real empirical data so as to determine whether a given model provides reliable results. Climate

models, for example, are used to predict what will happen if greenhouse gas levels rise.

Monitoring in the present context refers to a process of tracking and observing various environmental changes and states, whereby systematic observation is combined with alarm or action thresholds which, when exceeded, trigger the implementation of previously elaborated action plans.

P

A Peer Review is a process commonly used in the academic community whereby colleagues assess each other's work. For example, prior to publication of an article in a leading scientific journal selected experts are asked to review the article and assess whether its results are viable and if its methodology is consistent with good scientific practice.

R

Risk refers basically to the possible effects with a given probability. A worst case scenario describes all possible losses, damages and/or injuries provoked by the assumed incident, but also takes into account the precautions and the measures taken to minimize loss, damage or injury. **Hazard** on the other hand merely refers to possible loss, damage or injury only.

S

Scenarios are putative cases that are elaborated in order to describe chains of events that could potentially occur. **Worst-case scenarios** are based on the worst possible chains of events that could possibly occur in the technical, human, and/or organizational domains.

Settings in the present context refer to the locations that we selected for our simulations and analyses. Such settings describe the typical hydrogeological and geological scenarios in the area we investigated.

Sour gas is natural gas containing concentrations of the toxin hydrogen sulfide. It is unlikely to occur in the unconventional gas reservoirs discussed in this report, but can potentially occur in tight gas and coal bed methane areas. **Sweet gas** is natural gas that contains no hydrogen sulfide.

Substance flow analyses allow for the modeling of biological substance flows, with a view to determining which substances are input into a given system, the transformation processes that occur there, and the amount of substances output by the system. A **regional substance flow analysis** refers to the substance flows for the region under study here, as regards the amount of water and chemicals that are used for gas drilling in a given region, the transformation processes that occur, and the identity and location of the substances that remain in the system.

T

In this report, a tracer is a hydrofracking fluid component or additive that is conducive to measurement. In the case of a leak, a tracer provides rapid and reliable evidence that hydrofracking fluid is seeping into the surrounding rock.

U

Unconventional reservoirs: Until recently, natural gas came from wells out of which the natural gas in these **conventional reservoirs** flowed spontaneously. But for the past decade or so, so-called unconventional reservoirs whose gas is found in minute spaces (pores) in the rock are being increasingly developed, particularly in the US. To release this gas, it is necessary to crack open the rock. A distinction is made between shale gas and coal bed methane reservoirs, where the gas is located in the rock in which the gas was originally formed. Tight-gas reservoirs, which are found in sandstone and limestone, combine the features of conventional and unconventional reservoirs.

W

A well (or gas well) is a technical structure that is created by first drilling, then installing steel pipes (casing) in the well, and cementing the spaces between pipes of varying diameters and between the outer pipes and the rock.

What is at Issue?

Defusing the Controversy over Hydrofracking via a Public Information Dissemination and Dialogue Process

Natural gas production has been a feature of life in Germany for over six decades now, and many municipalities have a perfectly harmonious relationship with the natural gas industry. City and gas company fire departments carry out joint emergency drills, and taxes paid by gas companies benefit municipal treasuries.

But this halcyon era ended in 2010 when ExxonMobil and other oil and gas companies announced plans to blast chemicals into underground rock strata in order to access natural gas reservoirs that had hitherto not been worth exploiting. This announcement provoked protests in many German cities.

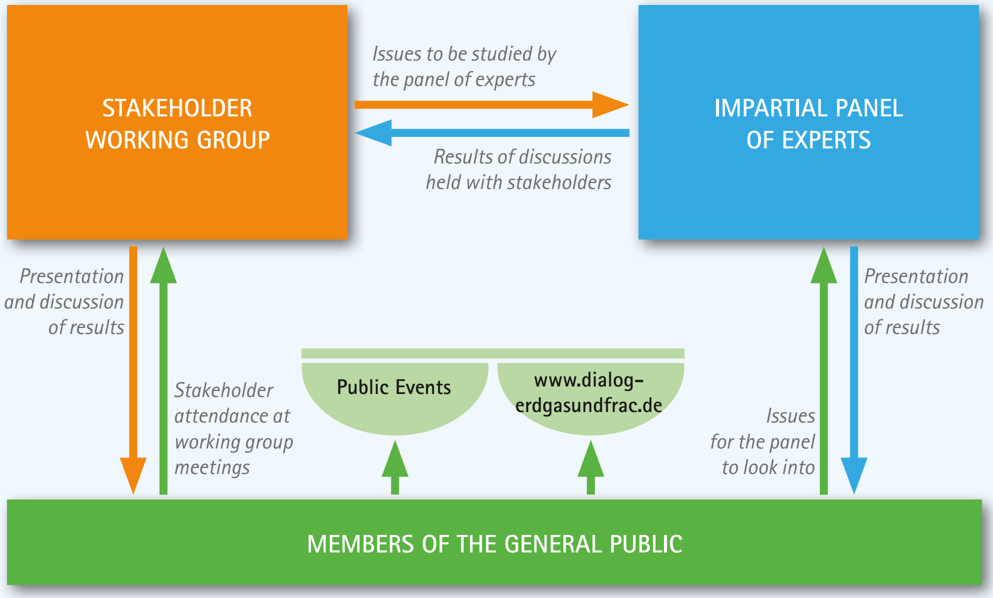
German citizens, water companies, environmental organizations, and politicians are opposed to hydrofracking and new natural gas exploration projects, and popular movements against hydrofracking have sprung up in numerous places where exploratory drilling is slated to take place. The main concern raised by the prospect of hydrofracking in one's own back yard is that it will result in chemical and methane pollution of drinking water. These concerns have been fueled by US media reports to the effect that methane has been detected in drinking water, drinking water wells have been rendered unusable, and groundwater has been sullied.

The German ExxonMobil affiliate ExxonMobil Production Deutschland GmbH (EMPG) takes these concerns about and popular opposition to hydrofracking in Lower Saxony and North Rhine-Westphalia very seriously. The company wishes to maintain good relations with all concerned and realizes that to do this, it is necessary to respond to these concerns (and the attendant opposition), for unless these issues are addressed and an understanding is reached with the relevant stakeholder groups, social harmony will suffer.

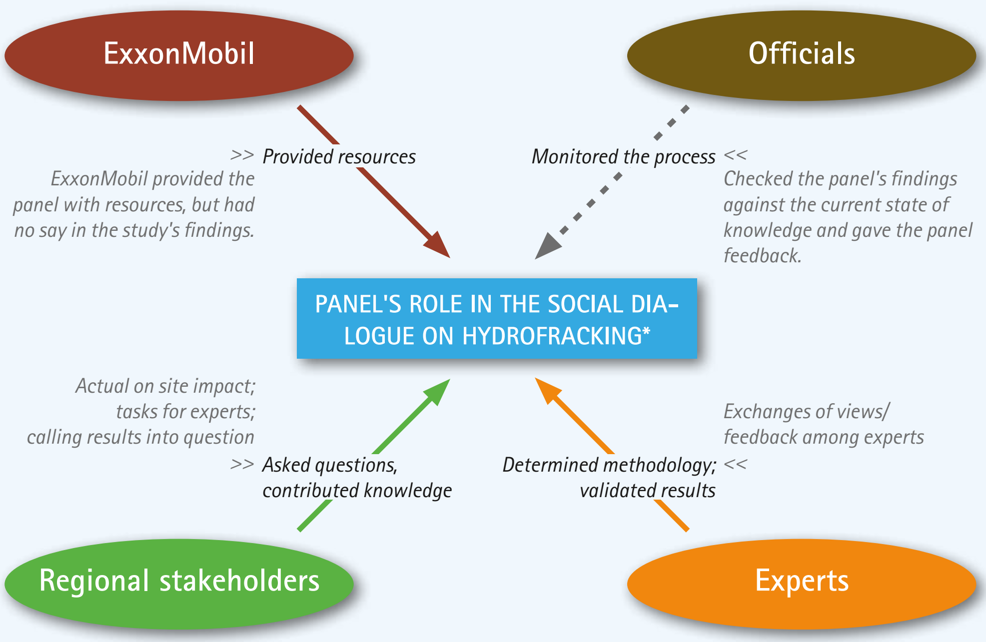
Faced with this situation, ExxonMobil decided to eschew the usual approach of going to court and lobbying legislators, and instead engaged in a process involving open communication and dialogue whereby independent scientists would conduct a study of the environmental and safety risks entailed by hydrofracking. ExxonMobil asked two outside experts to develop a concept for this undertaking, accepted their proposed concept, and provided funding for a study by a panel of outside experts, as well as for a social dialogue. And thus in April 2011, around 50 stakeholder groups (municipalities, citizens' action groups, church groups, and associations) began participating in a dialogical process and monitored the work carried out by the panel of experts in the spirit of a devil's advocate. The competent authorities from the German regional states of North Rhine-Westphalia and Lower Saxony acted as observers.

Needless to say, it is essential that the panel of experts be able to carry out its work without interference from ExxonMobil, and in a transparent, open manner that meets the highest scientific standards.

In 2012 the state of North Rhine-Westphalia and the German EPA commissioned hydrofracking studies of their own, for which both we and ExxonMobil made proprietary data and knowledge available. This has resulted in exchanges of views between the various research teams, which represents a further step toward ensuring that quality scientific findings are obtained.



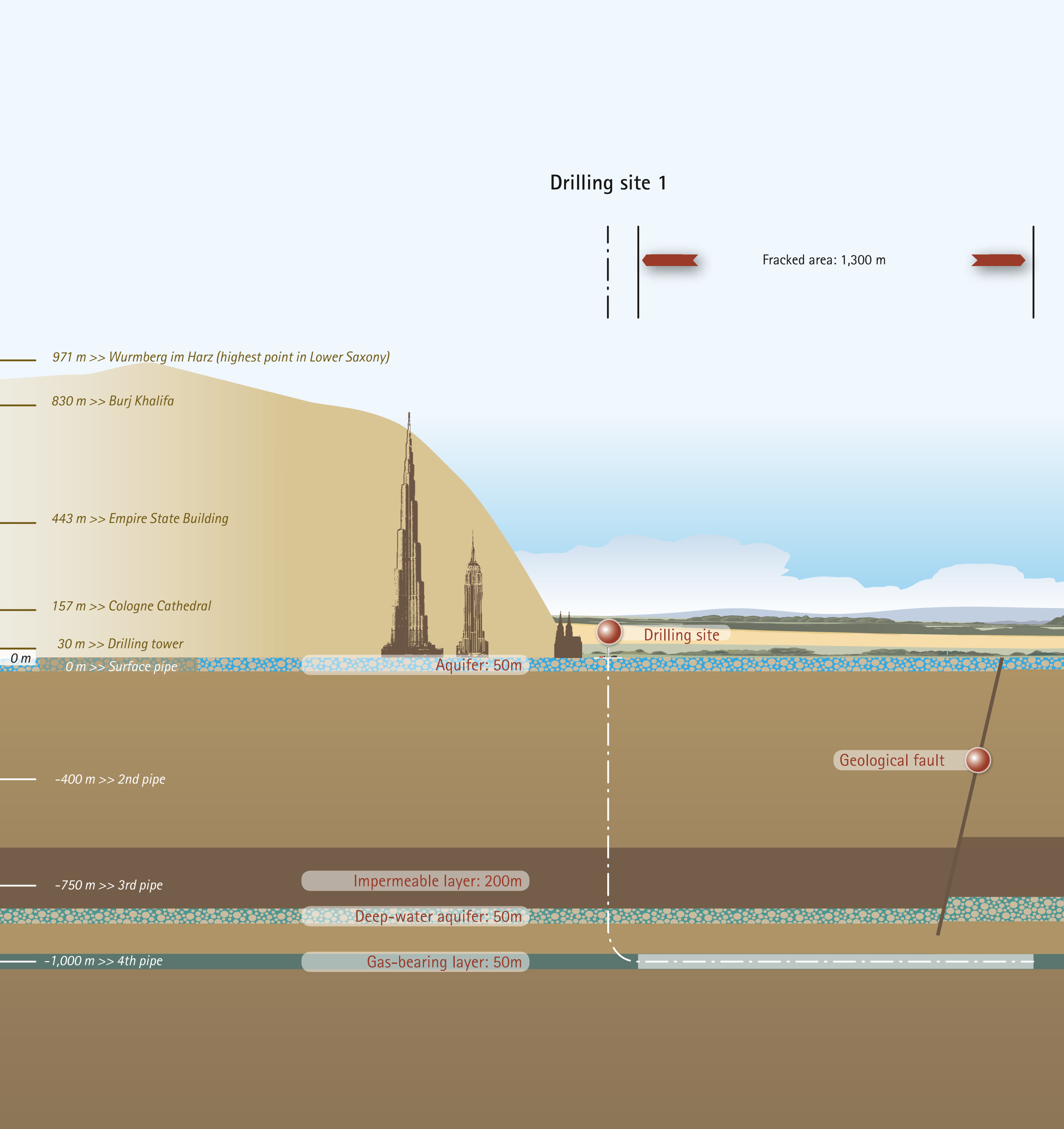
02 The ExxonMobil information and dialogue process concerning the environmental and health risks of using hydrofracking for natural gas exploration and production.



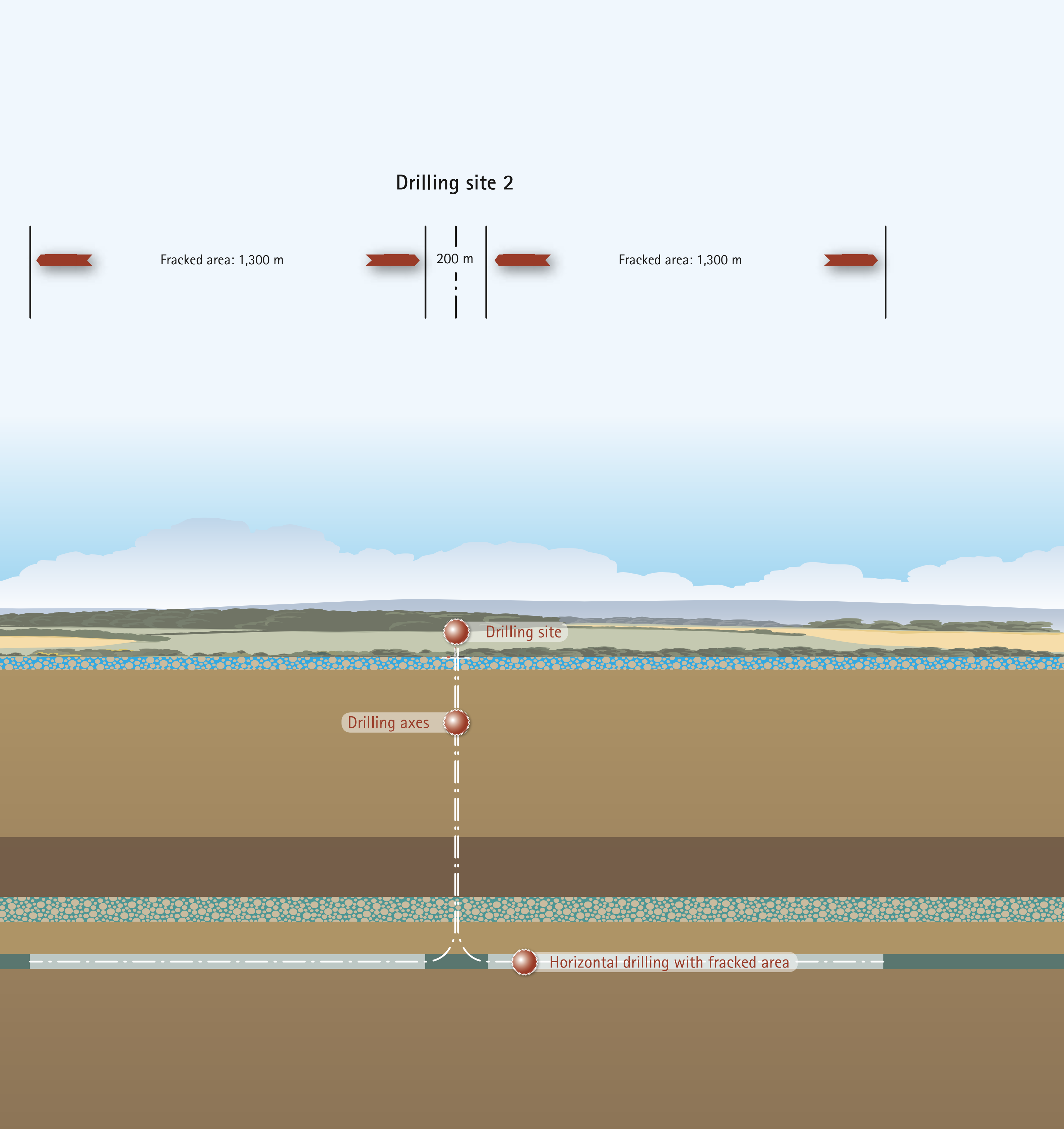
03 How the panel's impartiality was assured and maintained

*None of the eight scientists had previously worked for the oil, gas, or hydrofracking industry.

Aspects of Hydrofracking



04 Schematic drawing of a geological profile, with building and mountain heights indicated for purposes of comparison.
This graphic shows how drilling at depths in excess of 1,000 meters can "turn a corner" and proceed horizontally within a shale gas stratum.



Hydrofracking: What's it all About?

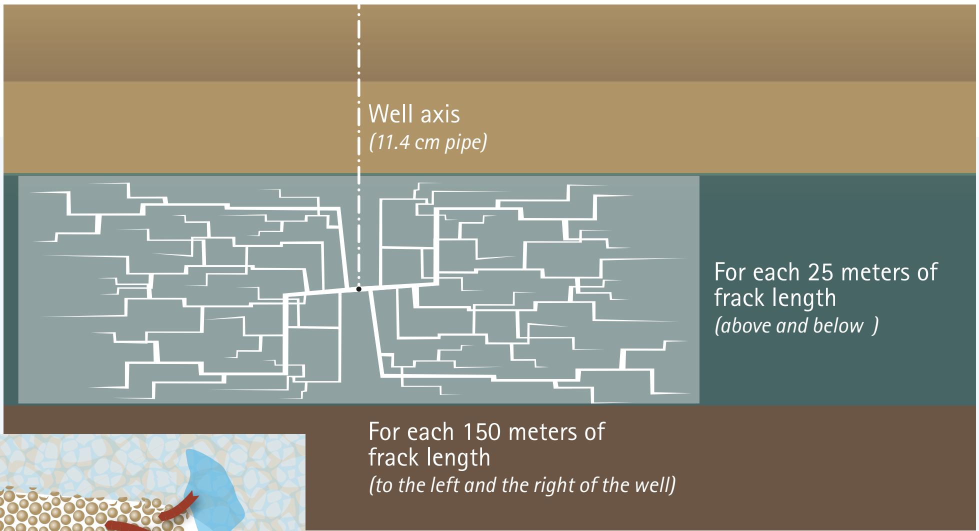
Hydrofracking is a process whereby gas companies extract natural gas from so-called unconventional reservoirs.

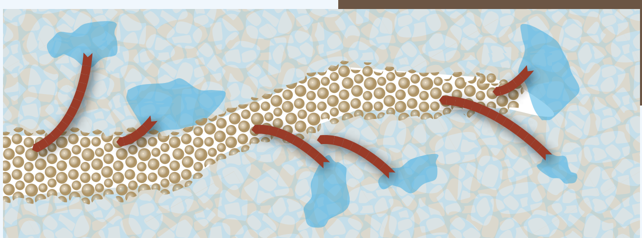
The greenhouse-gas footprint of natural gas is currently considered to be lighter than that of oil and coal. Just under 25 percent of Germany's energy is currently supplied by natural gas, the lion's share of which is imported from Russia, although 14 percent is produced in Germany.

If domestic natural gas cannot hope to cover all of our nation's energy needs, it nonetheless makes a contribution to the German energy mix and will take on even greater importance as this mix undergoes substantial change going forward. Germany's supplies of natural gas will be depleted in the foreseeable future if unconventional reservoirs aren't used. Hydrofracking is a process that allows for extraction of the gas from such reservoirs.

First used in the US in the 1940s, hydrofracking, or hydraulic fracturing, is a process where cracks are created in underground rock strata by injecting massive amounts of water into the rock under extremely high pressure.

05 Side view of hydrofracking crack formation in a 50 meter thick shale gas stratum.

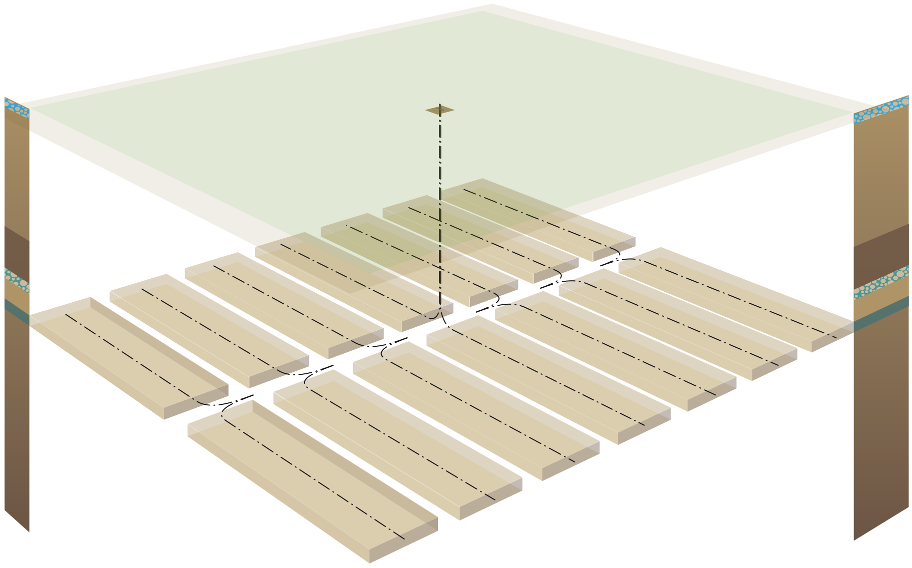




06 This figure shows a hairline crack that is being kept open using ceramic pellets so as to enable the gas in the rock to escape.

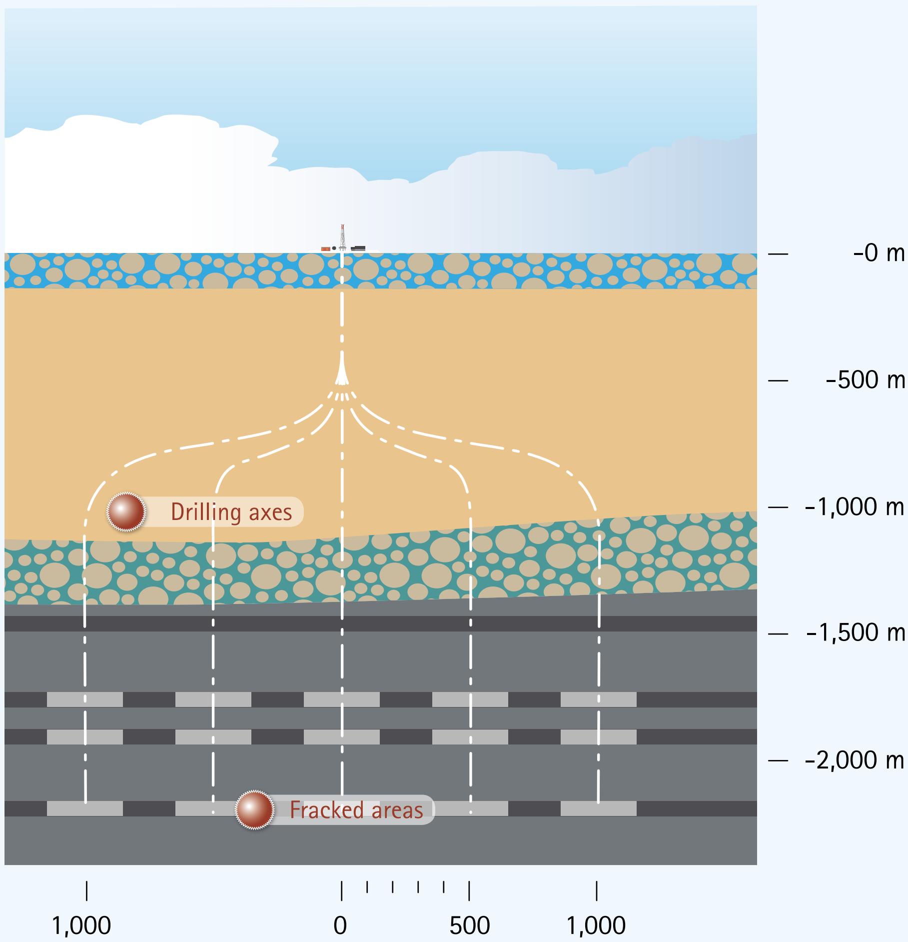
But if a one kilometer thick rock stratum presses down on a crack, the crack will soon close. To avoid this, sand or ceramic beads known as proppants that lodge in the cracks are added to the water to keep the cracks from closing. Chemicals are added to the hydrofracking fluid so as to enable the water and sand to penetrate the hairline fractures in the rock. A list of the hydrofracking chemicals used by ExxonMobil is available (in German only) at www.erdgassuche-in-deutschland.de.

Hydrofracking, which was first used some seven decades ago in the US, is used in extremely deep vertical wells for conventional reservoirs whose gas no longer flows upward spontaneously. Hydrofracking is also used for geothermal energy. Decreasing costs and rising energy prices now make it economically feasible to drill first vertically and then horizontally so as to allow for the use of hydrofracking, which is the only method that allows for extensive drilling into thin strata of natural gas.



Animated films produced by the German gas industry show how hydrofracking works (see for example www.erdgassuche-in-deutschland.de/mediathek/index.html).

07 A 14-well production site allows for exploration of an underground area comprising nine square kilometers (3 x 3 kilometers).



08 Coal bed methane is extracted using vertical wells that pass through a number of coal bed methane strata.

Hydrofracking Sites in Germany

German gas companies are currently prospecting for unconventional natural gas reservoirs in many parts of the country, with ExxonMobil's efforts in this regard focusing on the following regions:

Tight gas

Cloppenburg region: Tight gas is found in this region at depths ranging from 3,500 to 5,000 meters, and hydrofracking has been used here for around the past 35 years.

Experts disagree as to whether tight gas even counts as an unconventional gas source; we took this type of gas into account only marginally owing to the great depths at which these reservoirs are located and the fact that they are virtually indistinguishable from conventional reservoirs.

Shale gas

Southwest Lower Saxony: This region contains shale gas reservoirs at depths ranging from 1,000 to 2,500 meters. Hydrofracking testing began here in 2008.

We mainly focused on shale gas, because if hydrofracking ever becomes a widespread practice in Germany it will begin with this resource.

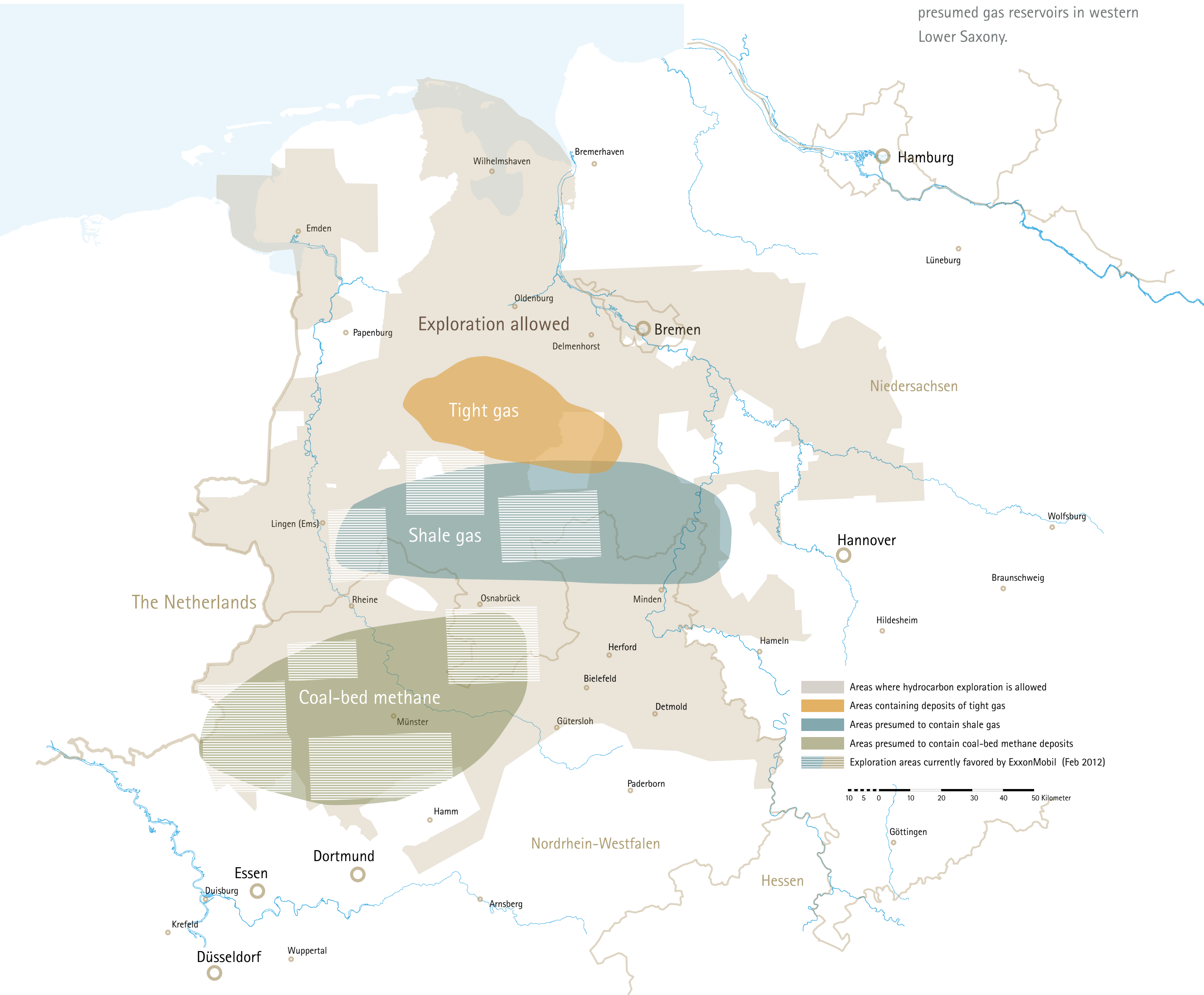
Coal bed methane

The Münsterländer Becken region: The coal bed methane reservoirs in this region are thought to lie at a depth of some 1,000 meters.

It remains to be determined whether hydrofracking is needed for coal-bed methane production – and if so whether it will be necessary to use chemicals. This matter cannot be determined without further gas exploration, which is currently on hold.

Only sandstone and limestone, both of which contain tight gas, are porous enough to allow water to pass through them, unlike shale and coal, which shed water because their pores are far smaller.

09 This graphic displays the various North Rhine-Westphalia areas where gas exploration is allowed, and shows the locations of presumed gas reservoirs in western Lower Saxony.



Study Methodology

We investigated the following three issues:

Can hydrofracking potentially result in contaminants rising to the surface from deep underground?

> This issue was investigated by the Risks in Geological Systems working group.

How hazardous are the substances used for hydrofracking?

> This issue was investigated by the Toxicology and Groundwater working group.

What kinds of risks are entailed by the technical processes that are carried out in hydrofracking wells, at hydrofracking production sites, and in connection with the relevant transport processes? How can these risks be successfully managed?

> This issue was investigated by the Risk in Technical Systems working group.

The various studies described in the present report are the work of around 40 scientists, whose methodology and interim results we communicated very extensively and openly via a scientific conference, six working meetings attended by the relevant stakeholder groups, nine meetings held with other experts and stakeholders and a study status conference that was held in early March of this year. We took into account the feedback from these discussions.

In the interest of making absolutely certain that the study results are scientifically sound and of the highest possible quality, we also asked ten German and foreign experts to give us feedback about the study and to discuss their views of the study's methodology and interim results with us and other members of the scientific community at a conference in Berlin on 6 and 7 March of this year.

Design, scientific director, compilation

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Head of the Department of Aquatic Ecosystems Analysis and Management

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University of Stuttgart

Toxicology and Groundwater working group

Drinking water

Prof. Dr. Fritz Frimmel
Professor of Water Chemistry,
Karlsruhe Institute of
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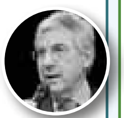

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Risks in Technical Systems working group

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Umweltplanung Bullermann
Schneble GmbH

Wastewater

Prof. Dr.-Ing.
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University of Hanover

Energy balance and global warming footprint

Uwe R. Fritsche
Department of Energy and Climate Protection, Institute for Applied Ecology (until 03.2012), International Institute for Sustainability Analysis and Strategy (IINAS)

Regional economics

Prof. Dr. Kilian Bizer
Professor of Economic Policy and
SME Studies,
University of Göttingen

10 As a panel, we divided ourselves into three working groups and also consulted outside experts for topic areas that lie outside our own areas of expertise.

Modeling and Measurement

In this report, we present our views on the following: Under which circumstances are hydrofracking and extracting natural gas from unconventional reservoirs compatible with public health and environmental safety? Or should this kind of activity simply be foregone?

That said, it should be borne in mind that opportunities to conduct formal empirical studies of actual shale and coal bed methane hydrofracking operations have been few and far between in Germany, in contrast to the US where the EPA is authorized to conduct such studies.

This situation prompted us to study these matters closely and to develop models for them, based on the following:

> The geological conditions in the Münsterland region and southwest Lower Saxony.

> Our own review of the international literature concerning incidents and accidents, as well as a series of studies of gas wells, in hydrofracked rock layers, and in water wells.

> Experience acquired in other areas such as the chemical industry.

> The relevant views and experience of the experts involved in the study.

While general findings can be obtained through modeling, these results require validation. Models are particularly useful in cases where quantitative measurements are scarce, or where such measurements would be difficult to perform – for example for long term safety or very deep underground areas. Models provide a basis for the formulation of general recommendations, but in certain cases show that the available information is too meager to allow for the description of specific effects. Genuinely sound scientific findings are only obtainable if measurements for a specific site are available that would close the existing knowledge gap and demonstrate the validity of a given simulation model.

Visit to the US

In January 2012 we took a trip to Pennsylvania, where we saw at first hand the visual impact of extensive hydrofracking in a specific geographical area. We also discussed hydrofracking in detail with US environmental officials, as well as with many experts in the field and representatives of the gas industry and environmental groups.

The panel of experts at a production site during their visit to the US. From left: Alexander Roßnagel, Sandra Richter, Andreas Polzer, Dietrich Borchardt, Hans-Joachim Uth.

Precautionary Measures and Emergency Action Plans

Our study reveals not only the possible effects of hydrofracking, but also addresses the issue as to whether it is possible to provide safeguards against possible hazards through technological measures, organizational measures, planning, or regulations. For only if all of this is elucidated can existing risk be characterized adequately and good decisions be made by (a) companies and policy-makers who need to decide to what extent (if any) and under which circumstances hydrofracking should be allowed; and (b) stakeholder groups and concerned citizens, who need to be able to reach an informed opinion on such matters.

Worst Case Scenarios and Conservative Assumptions

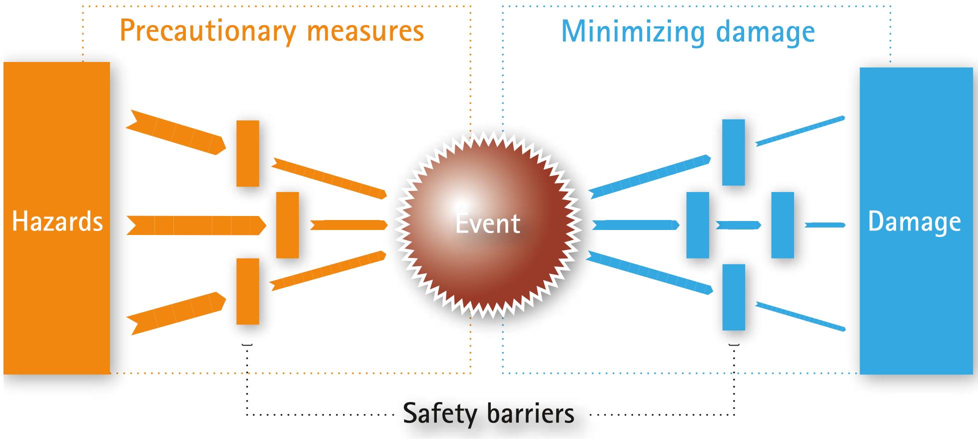
Our study is predicated on the following:

> The current state of the art and current approval procedure in Germany were applied, and it was on this basis that the effects of hydrofracking were assessed. However, this has not prevented us from pointing out in this report that there is room for improvement in many different areas.

> Our simulations are based on unfavorable conditions such as geological faults. Scientifically speaking they were conducted in a conservative manner so as to avoid underestimation of the relevant risks and threats.

We also operated on the assumption that accidents and leakage may well occur. We predicated our simulations on the worst-case scenarios so as to enable us to investigate the impact and the emergency-management options in the face of such an event.

The study findings comprise plausible assessments, which are intended to show where the greatest hazards lie, which concerns are unfounded, and how to move forward with risk management. However, these findings are not intended to be a substitute for thorough case studies, which are essential in this domain.



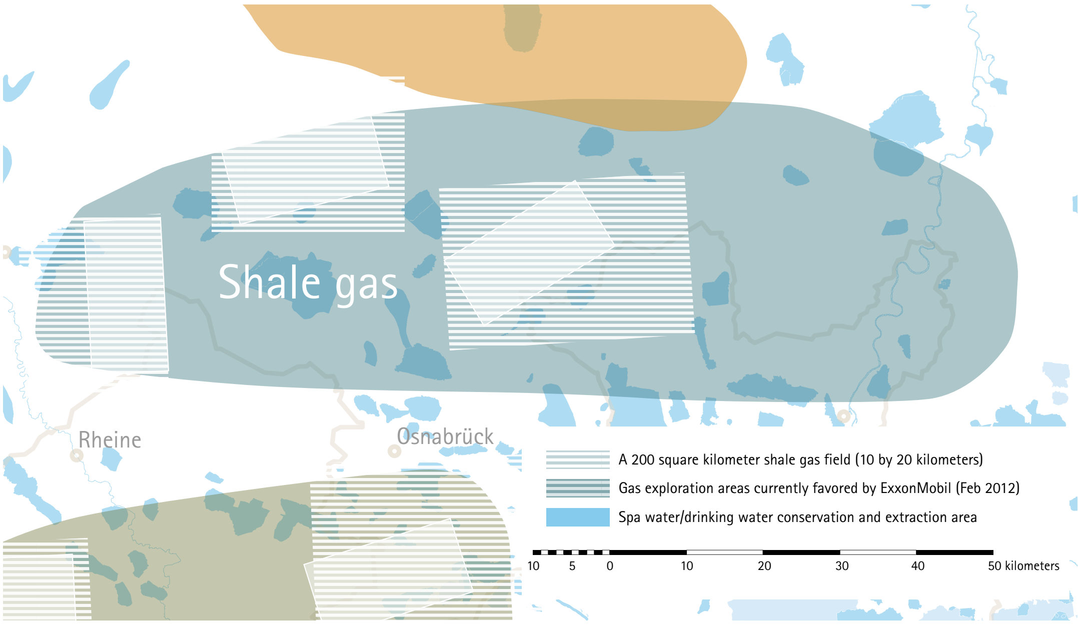
11 A scenario describes the potential aftermath of an event such as an explosion, the damage and injury caused by the event, and the precautions that can be taken to avert the event or limit its impact.

Impacts of Hydrofracking on the Immediate Environs and Urban Areas

Site Selection

Large-scale gas production in the Münsterland region and/or southwest Lower Saxony would entail the establishment of numerous drill sites.

Once natural gas reservoirs are discovered, it is necessary to decide on specific drill sites, which is no easy matter as such areas may contain villages, towns, cities, recreational areas, nature conservation areas, water protection areas, farming areas and forests.

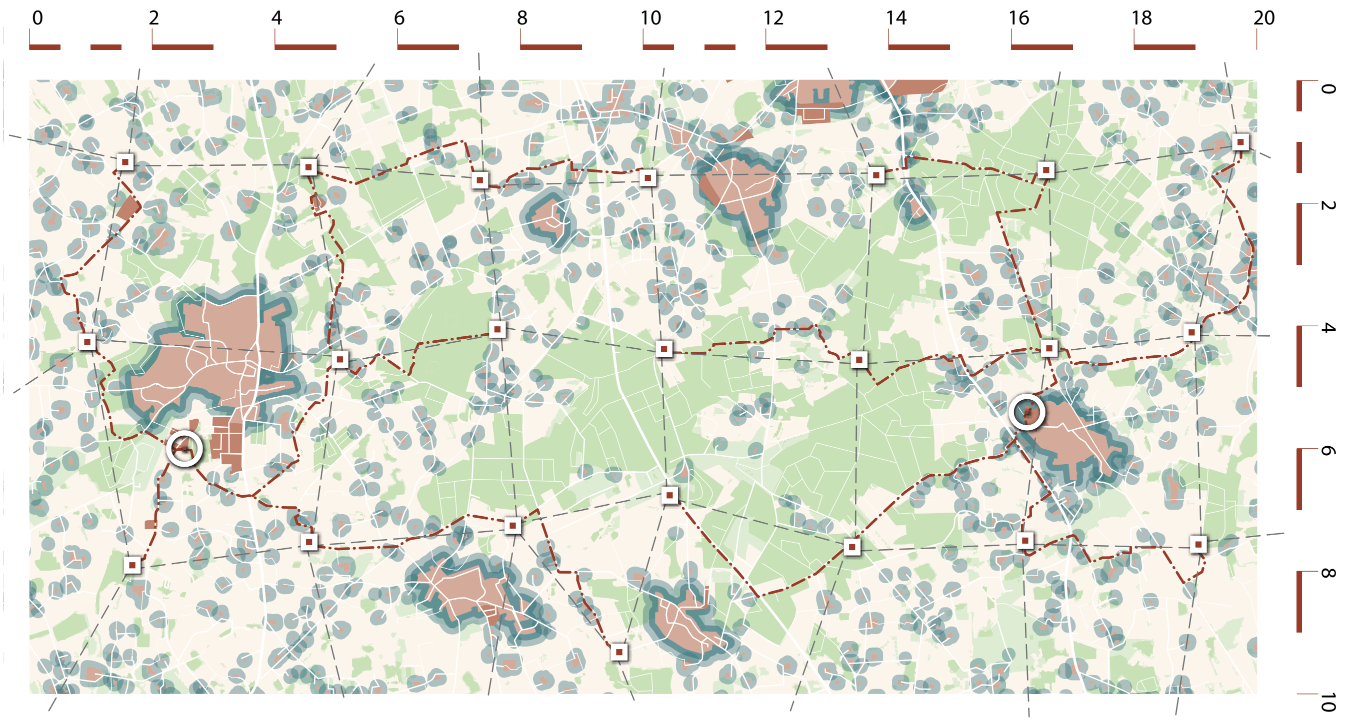


12 Selected 200 square kilometer zones in the Lower Saxony shale gas area.

Under current gas industry standards, production sites must be situated at least 200 meters from populated areas, and compensatory measures are taken in the event of any intervention in the natural environment or the landscape. These measures involve compensatory upgrading of other areas through the aforementioned afforestation, biotope creation or the like. Most hydrofracking in Germany is carried out on farmland that is relinquished after 20 to 30 years of use and that is then plowed so as to rehabilitate it for agricultural use.

The (possible) shape of things in 2030

2030. Following lengthy negotiations in the early 2010s, ExxonMobil obtained a permit to carry out shale gas production in a 200 square kilometer area, i.e. an area that is 20 kilometers long and 10 kilometers wide.



13 Possible distribution of production sites, pipelines and processing installations in a landscape that is typical for the region under study.

Drilling Site Realization

With today's technology, a given drilling site needs an around 1,000 square meter area (100 x 100 meters). The site is paved, the soil is stored for later recultivation, trees are planted, roadways are constructed, pipelines are laid, and one gas purification facility for every five drilling sites is built.

Anywhere from 10 to 20 closely spaced wells are then drilled successively at the site 24/7 over a 14 month period. The drilling rig, which can be up to 40 meters high, is installed at the site during this entire period and is visible from afar, particularly at night.

The landscape is sullied for the most part during the drilling phase. The problem here is not so much any particular drilling site per se, but rather the myriad drilling sites that can spring up if an area develops rapidly into a gas production zone.

Drilling noise is audible during the 14 month drilling period; the trucks used for transport and the diesel engines that drive the drilling rigs emit exhaust.

The noise, vibrations and exhaust generated by hydrofracking carried out near populated areas can have an adverse effect on local residents' quality of life.

The (possible) shape of things in 2030

Between 2016 and 2030 a total of 22 drilling sites will be established in the area in question, which is 10 x 20 kilometers in size. This will involve the drilling of 300 gas wells, and development of this gas field will take around ten years, assuming that four drills are in operation simultaneously. (By way of comparison: ExxonMobil currently operates around 1,000 oil and gas wells in Germany).

However, it is possible that owing to technological advances drilling rigs in 2030 will no longer be as high as they are today (30 to 40 meters), and lighter-weight or endless pipes may be installed from a lower height. It is also conceivable that drilling rigs located near populated areas will be accommodated in noise and light attenuation enclosures. It is also likely that the drills will be driven by electric engines, which means that noise and air emissions will be lower.

In the area under consideration here, two processing installations will have been built, a 22 hectare drilling site will have been constructed, and around 70 kilometers of underground pipeline will have been laid.

Truck transport operations will be as follows for each drilling site: around 70 truck trips during the drilling site construction phase (a few weeks); at least 1,000 trips for drilling site supply purposes over an around ten month period; around 50 trips a week for hydrofracking supplies; around 300 trips a week for the delivery of hydrofracking chemicals and proppants (sand or ceramic beads); around 50 trips a week for hydrofracking equipment dismantling; and around 70 trips a week for dismantling drilling equipment – for a total of around 1,500 truck trips per drilling site over a 14 month period. This also means that local residents whose homes are on the routes used by the trucks would have 3,000 trucks going past their residences over a 14 month period, i.e. seven trucks a day on average.

Regional Economic Impact of Hydrofracking and Gas Production

Hydrofracking and natural gas production have an impact on regional economies from various standpoints: (a) funds flow into the region in the form of royalties, salaries and tax revenue; (b) agricultural land is lost; (c) growers are forced to compete for ever scarcer water resources; and (d) a drastically altered agricultural landscape reduces the region's tourist appeal. Hydrofracking-induced incidents can do substantial harm to water resources; and for particularly sensitive sectors such as the food processing industry, for which the mere fact that toxic emissions occur near a food processing plant can cause problems. But this cloud also has a silver lining in that businesses whose products or services are needed for hydrofracking are likely to benefit economically.

Stakeholder question

> What impact is unconventional gas production likely to have on the job picture and on the overall economic situation in North Rhine-Westphalia?

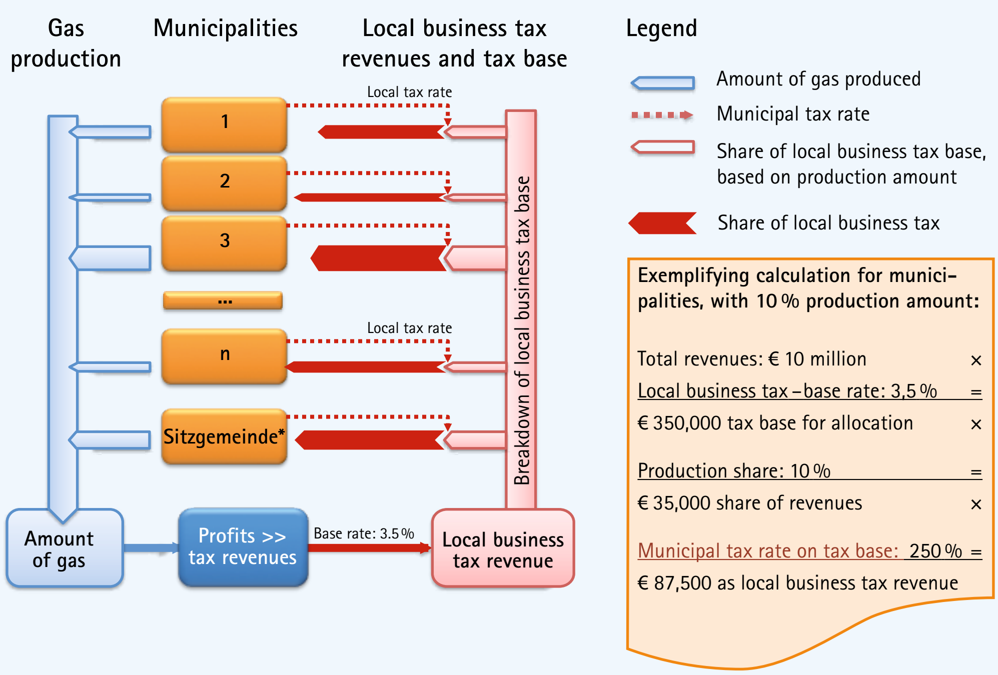
On the occasion of our trip to the US in January 2012, we added "impact on regional economies" to our list of topics of study. In the US hydrofracking operations create jobs and generate tax revenue; but would that also be the case in Germany? We decided to address this issue by conducting a preliminary study concerning the methodology that can be used to calculate the regional economic impact of hydrofracking. A regional economic analysis seeks to determine (a) whether hydrofracking has a positive or negative economic impact on a given region; and (b) which stakeholders benefit and which stakeholders come up short in such settings.

Fiscal Considerations

Municipalities within whose city limits hydrofracking sites are located can reap considerable tax revenues from these activities. This may also be the case for municipalities reached by horizontal drilling. In such cases, all concerned need to agree on a tax revenue allocation arrangement that takes this "cross-boundary" factor into account (see graph). This type of arrangement helps to ensure that the relevant municipalities derive tax revenues from the natural gas that is produced in their region; not only Germany's regions but also its states benefit from tax revenues by way of not only corporate income tax, but also and most importantly through mining royalties, which accrue to the regional states. And even if a substantial portion of revenues is swallowed up by pooling tax revenues on the level of states (state fiscal relations), the fact remains that an appreciable amount of money stays in the state where it is generated. This also holds for the municipalities, where additional revenues also reduce funds from the local fiscal relations, so that tax revenues and the redistribution of funds via fiscal relations would be beneficial not only for specific municipalities, but for regions, the states and the country as a whole.

Socioeconomic Considerations

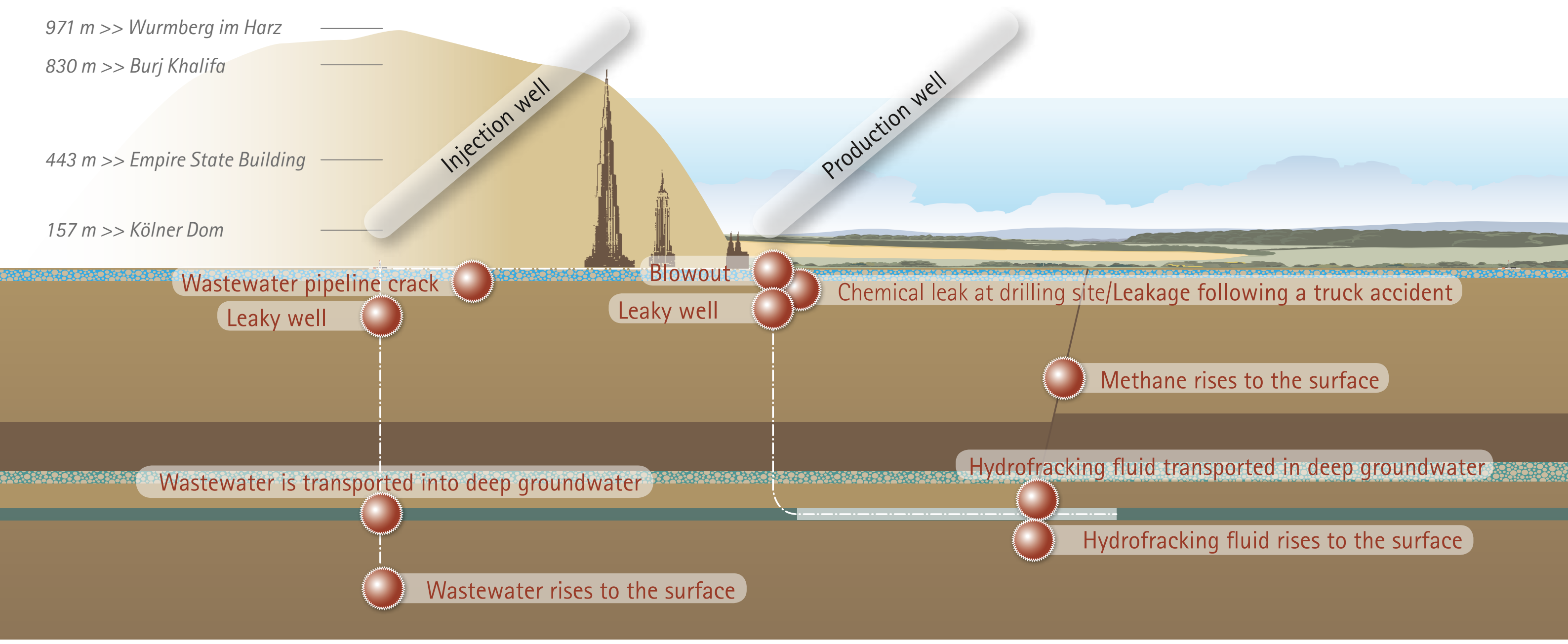
In the interest of assessing (a) the probability that hydrofracking will have a negative impact on a given regional economy; and (b) the extent of this impact, we investigated the manner in which hydrofracking can potentially affect economic actors. This can vary from one region to another and is mainly determined by the nature and density of the region's settlement structure, its agricultural land use structure, and the land use patterns of its tourist industry. It is also necessary to take account of local residents, growers, the food processing industry, water resource management, and nature conservation, which in many cases are closely interrelated as is the case with agriculture and food processing in the affected regions. In contrast, local businesses such as tanker freight companies may benefit economically from hydrofracking.



14 How local business tax is shared between municipalities where gas is extracted.

*Sitzgemeinde is the municipality where the firm is legally registered

Possible Environmental and Health Hazards



15 Locations of the scenarios described below (buildings and mountains are shown for purposes of comparison).

The graphic on the facing page displays the locations of possible hazards, as well as the potential contaminant emission paths that are described below – including surface or near-surface worst-case leak/accident scenarios, as well as underground scenarios involving hydrofracking fluid and methane transport. Such scenarios could also occur in connection with pipeline transport and wastewater storage wells.

Worst-case scenarios involving technical installations

> Blowouts

> Chemicals leaking from a chemical tank onto a drilling site, or from a truck following a traffic accident

> Wastewater pipeline leak

> Leaky well

Scenarios concerning contaminant transport based on conservative assumptions

> Hydrofracking fluid rises to the surface

> Hydrofracking fluid is transported within deep groundwater

> Methane rises to the surface

> Wastewater rises to the surface

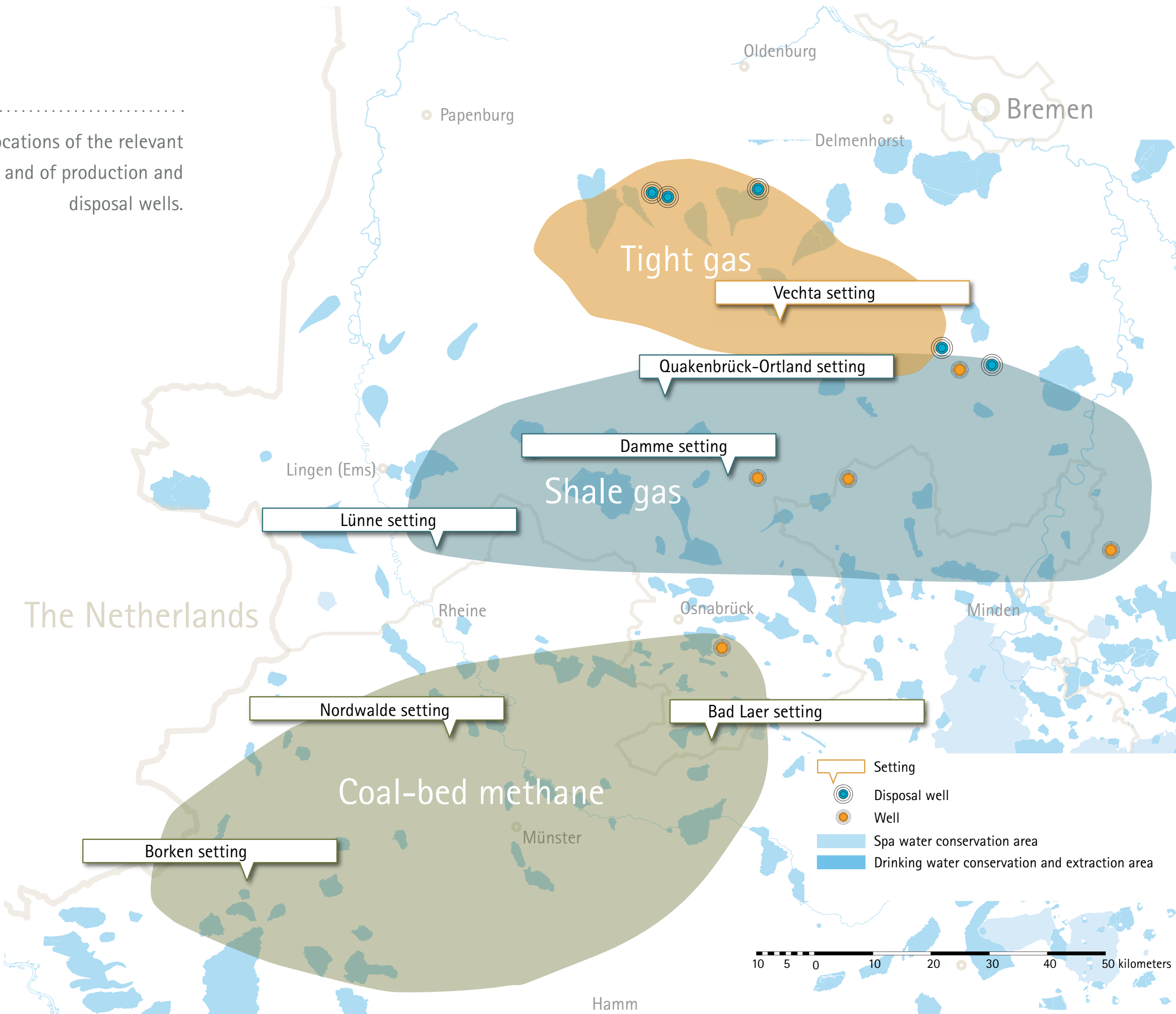
> Wastewater is transported within deep groundwater

As these scenarios are essentially the same as the hydrofracking and production scenarios, they will not be discussed further here.

Settings: A Handy Heuristic

The sequences of underground strata that occur in any given well vary tremendously from one drilling location to another, and thus it is difficult to formulate one size fits all scenarios in this regard.

However, in the interest of doing so nonetheless, we decided to precisely describe seven typical geological and hydrogeological scenarios that occur in the study region, based on seven sets of settings for which the modeling referred to above was carried out.



16 Locations of the relevant settings and of production and disposal wells.

The following hydrofracking fluid transport barriers are crucial:

- The presence of massive sealing clay strata and other strata.
- The barriers resulting from the fact that salt fractures close up naturally.
- The absence of faults or fault zones, i.e. underground areas that are more porous owing to fractures in geological materials.

Bad Laer in the Münsterländer Becken region (thin coverage and fault zone) and Damme in the Niedersächsisches Becken region (no protective salt boundary, but coverage thickness amounting to around 1,300 meters nonetheless) respectively comprise a relatively critical setting.

Even though Vechta lies in the tight gas zone, it was included as an additional setting by virtue of its also being located in a drinking water protection zone.

17 Characteristics of the relevant settings

Niedersächsisches Becken region (shale gas)	Salt-free	Contains salt
	Damme	Quakenbrück-Ortland
		Lünne

Münsterländer Becken region (coal bed methane)	With fault zones	Without fault zones
	Bad Laer	Nordwalde
		Borken

The Drilling Process

In areas containing groundwater, the drill is rammed into the ground for the first hundred meters; no drilling fluid is needed for this process, which provides the greatest protection for near-surface groundwater that can be used as drinking water. Once this near-surface section of the well is sealed off against the surrounding environment by the rammed-in driver pipe, drilling proceeds, and as the drill goes deeper the well is irrigated using a heavy fluid known as drilling mud to cool and stabilize the well during the drilling process and bring rock debris to the surface.

Pipes of various thicknesses are inserted in the well so as to stabilize it and seal it off. These pipes are inserted from the surface to various depths, whereby the innermost pipe is inserted one level lower. On the very inside of this arrangement is a 10 cm thick pipe that goes all the way down to the bottom of the well and that is used to pump out hydrofracking fluid and transport natural gas.

The well is completely sealed off from the surrounding rock strata using a special type of cement. In addition, each new pipe is cemented into the next widest pipe over a 100 meter stretch. The interstitial spaces are filled with water and drilling mud so as to allow the pressure sensors to detect any leaks.

It takes anywhere between 50 and 100 truck trips a week to deliver the requisite materials to the drilling site.

During the drilling process, the drill can potentially hit gas that is under higher pressure than expected; or in some cases the gas may contain naturally occurring (but toxic) hydrogen sulfide. Such events are rare, however. In the past, a risk of blowouts existed (the entirety of the drilling mud is expelled from the well), and sometimes the gas could catch fire.

Model of a well casing after the cement has been poured.

The gas industry averts such incidents via blowout preventers, whose use is demanded by law but which can fail just like any other safety system. Such a failure, which constitutes the worst-case scenario accident in the gas industry, can cause mixtures of toxic gas to spread for miles around. Emergency action plans, technical precautions, and extensive quality assurance measures have been put in place to prevent blowouts and limit their consequences.

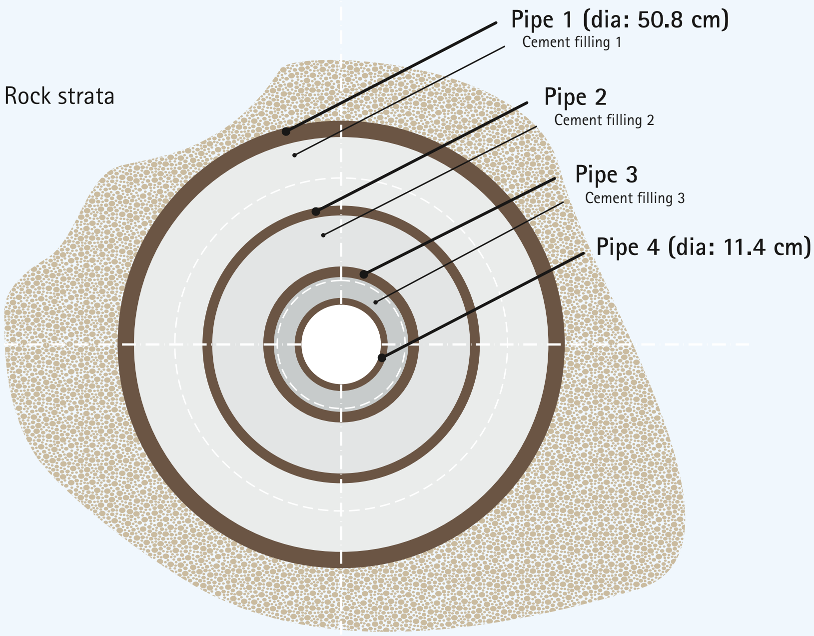
The gas industry assumes that blowouts occur on average less than once per 1,000 drilling operations. ExxonMobil Production Deutschland GmbH has carried out 73 drilling operations since its founding in 2002 without incurring a single blowout. The company's predecessor BEB experienced a blowout in the storage area in the early 1980s and a second blowout in the oil fields in the mid-1980s. Blowouts are more frequent in the US. In Texas for example – where according to official statistics more than 7,000 new wells were started last year alone and more than 250,000 are currently in operation statewide – there were 127 blowouts from January 2006 to July 2007, 14 of which caused fires. There were also three deaths and 14 injuries from blowouts during this period. In Pennsylvania, where some 3,000 wells have been started since 2008, two incidents have occurred in which the operators "lost control" of their wells. As the result of a blowout in 2010, natural gas spewed into the atmosphere for 16 hours, and though no fire occurred, some local residents experienced medical symptoms. In April 2011 an operator in Bradford County, Pennsylvania lost control of the drilling process, which resulted in 40 cubic meters of hydrofracking fluid rising to the surface and landing on a field and pond.

Blowouts are extremely rare events that can nonetheless occur, are mainly hazardous for gas drilling workers, and can result in substantial amounts of contaminated soil that must be decontaminated, removed and replaced with fresh soil.

The (possible) shape of things in 2030

A blowout may occur due to preventer failure in one of the 300 wells that will be drilled in the run-up to 2030. If the gas catches fire and flows out of the well horizontally at a rate of 5,000 cubic meters an hour, it will scorch everything in its path within a 30 meter radius, which in the worst-case scenario could result in worker fatalities.

A well that is relatively far advanced could contain up to 150 tons of drilling mud, which in a blowout would be expelled into the area around the well. As this is a heavy and viscous fluid, it would not be absorbed directly into the soil, although the upper layer of soil would have to be removed and disposed of in a radius of 100 meters.



18 Structure of a 1,000 meter well. Other sizes may come into play for deeper wells.

Chemicals Used at Drilling Sites

In the past, ExxonMobil has used around 150 different chemicals for its hydrofracking operations in Germany. (A complete list of these chemicals (in German only) is available at www.erdgassuche-in-deutschland.de). Hydrofracking fluids are composed of proppants, gelling agents, solvents and biocides. The proppants are necessary to prop open the hydrofracking cracks in the rock. In order for the proppants to seep into these cracks, a gel must first be formed that is then removed using solvents. The biocide added to hydrofracking chemicals keeps the cracks from being clogged by bacterial growth and biofilm formation.

We conducted an exhaustive study of the health and environmental impact of hydrofracking chemicals.

Hydrofracking chemicals include substances that are legally classified as hazardous substances and must be labeled, packaged and handled accordingly. They are also employed for many other purposes for industrial, professional and domestic use, e.g. as components of cleaning products. The environmental and health effects of these chemicals are determined by their concentration, as well as by the composition of the mixtures used. Fracking chemicals are transported and delivered in unmixed form. On-site, they are mixed and diluted by water to make up the final hydrofracking fluid. Therefore, our assessment covers both the bulk components and the hydrofracking fluids.

The amounts of chemicals ExxonMobil uses and the hazards entailed by them have greatly diminished in recent years. If ExxonMobil continues its shale gas hydrofracking operations, the company plans to use only five different chemicals.

19 Chemicals that ExxonMobil intends to use for its future shale gas hydrofracking operations (an aggregate 0.3% concentration of chemicals in hydrofracking fluid on average).

Chemicals in hydrofracking fluid used for shale gas Concentration Function	Mass fraction	Function
Ethylene glycol (bis)hydroxymethyl ether	0.06 – 0.1 %	Biocide
Butyldiglycol	0.02 – 0.035 %	Lubricant
Cholinchloride	0.07 – 0.075 %	Clay stabilizer
Carbohydrate derivative	0.108 – 0.18 %	Water gel formation
Ethylene glycol monohexyl ether (optional)	0.007 – 0.013 %	Tenside/solvent

It is currently unknown whether it will be possible to carry out shale gas hydrofracking operations without the use of chemicals (so called clean fracking). Potentially chemicals will be not necessary for coal bed methane production. However, around 30 different chemicals are still used for hydrofracking of tight gas and conventional gas reservoirs, resulting in a mass fraction up to 5% chemicals in hydrofracking fluid.

Stakeholder question

In light of the experience that has been acquired to date, how great a risk is there of pipe ruptures, transport accidents, operator errors or the like per year and production site?

Hydrofracking chemicals are transported to drilling sites in tank trucks, and are stored and mixed at the sites.

Chemical and wastewater transport vehicles can of course potentially be involved in traffic accidents, and it is estimated that a 30 ton tank truck will have an accident every 333,000 kilometers. And while this does not necessarily mean that chemical emissions will occur each time, they can potentially occur nonetheless. Moreover, truck accidents that occur on public roads could result in chemicals being spilled on unpaved areas.

At drilling sites per se, armed hoses can rupture and chemical tanks can leak – although as these sites are paved such incidents would not result in any groundwater pollution. However, hydrofracking chemicals are flammable, which would of course be hazardous for site workers. It is estimated that such an accident can potentially occur every 80 years.

The chemical industry is required to abide by safety regulations that are more stringent than those that apply to "standard" accidents, since the chemicals used in the chemical sector are considerably more hazardous than hydrofracking chemicals and far greater quantities of them are present at chemical plants than at hydrofracking sites. Hydrofracking risk could be reduced if established chemical-industry procedures were applied that are currently not the norm for gas drilling and production.

We also elaborated worst-case scenarios in this regard that underscore the wisdom of adopting methods that are used in the chemical industry. These scenarios include sabotage and airplane crashes, which could set the entirety of a hydrofracking site's chemicals on fire or cause them to seep into the ground. However, for such events to occur, all precautionary and mitigation measures would have to fail.

The seriousness of the types of accidents described above and their untoward consequences can be substantially reduced through the use of modern technology and extensive safety management. The scope of such accidents and their repercussions can be kept within reasonable bounds.

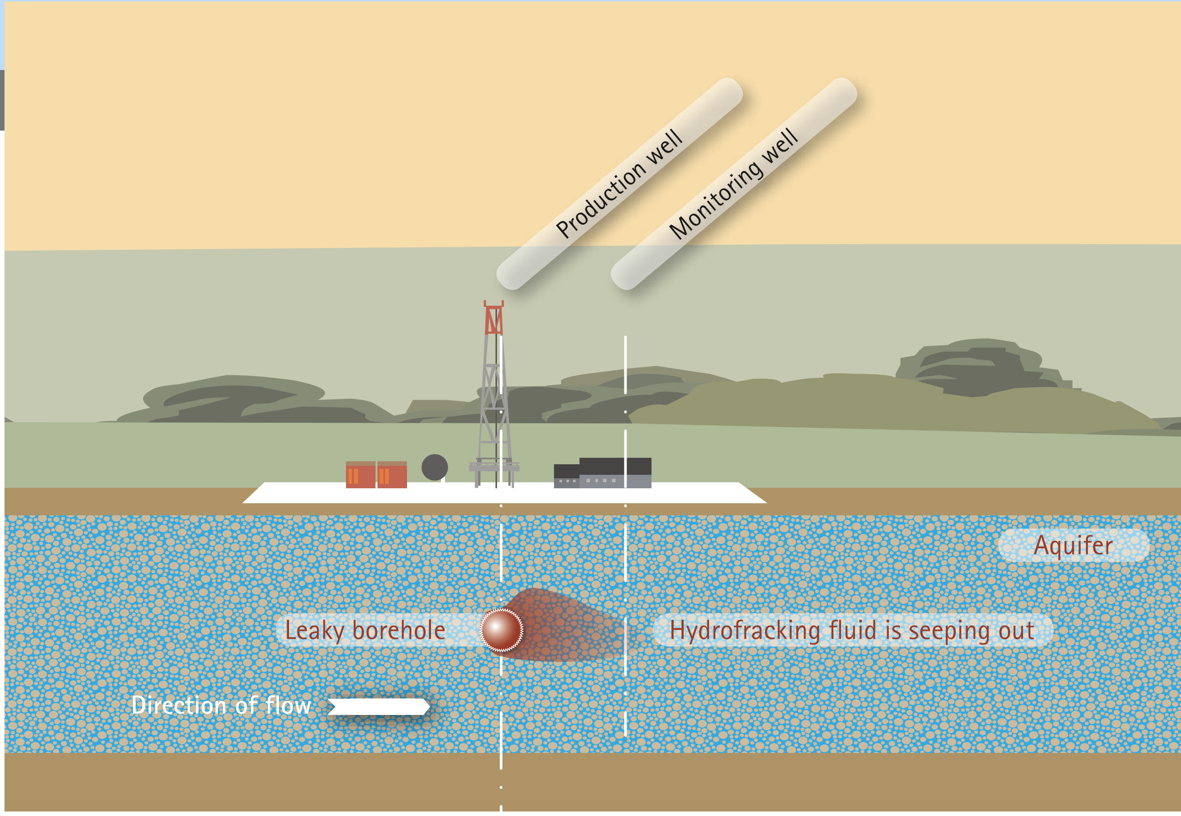
But even if efforts are made to recover hydrofracking fluid from subsurface areas following hydrofracking operations, a substantial portion of this fluid remains underground. The risks and hazards entailed by this situation will now be discussed.

The (possible) shape of things in 2030

Drilling 300 gas wells using current hydrofracking technology would involve the use of around 18,000 cubic meters of chemicals, supplying which would require around 1,500 truck trips using 12 ton tank trucks that would need to cover an aggregate 420,000 kilometers. In this scenario, a truck accident is likely to occur every 29 years, and any truck involved in such an accident would probably be a total loss. An accident of this nature would result in the truck's entire 12 ton chemical load being spilled on exposed ground. Another scenario involves an accident with a tank truck carrying 30 tons of diesel fuel, in which case the truck's fuel load would contaminate 13,000 tons of soil and the remediation and/or disposal cost would be around €1 million.

It is also a reasonable assumption that over the years at least one drilling site's wastewater tank would leak 1 cubic meter of a chemical such as butoxyethanol, resulting in (a) exceedance of the allowable workplace concentration in an area up to 65 meters away from the tank; and (b) in case of fire, injuries in a radius of six to eight meters around the tank.

Injecting Hydrofracking Fluid into Wells



20 Schematic drawing showing possible transport of well hydrofracking fluid into groundwater.

Once the target horizon (upwards of 1,000 meters below the surface) for shale gas or coal bed methane is reached, hydrofracking fluid is injected into the ground through holes in the shaft pipes under 1,000 bar pressure for a number of hours, during which time individual horizontal pipe sections are opened successively so as to allow defined amounts of fluid to penetrate defined sections of the rock.

In cases where gas output declines considerably as time goes on, hydrofracking is repeated – which means that around one out of every four boreholes is re-hydrofracked after a number of years.

A shale gas well normally requires 10 hydrofracking operations each of which uses 1,600 cubic meters of water, 32 cubic meters of proppants, and five tons of chemicals. The water is taken from the public drinking water supply or from proprietary drinking-water wells.

The chemical mixtures that are pumped underground under high pressure propagate in the final depth of the shale stratum. But if there is a leak in the well piping resulting from a minor earthquake, corrosion, or a leak that has gone undetected due to faulty quality control, the hydrofracking fluid will escape and in the worst-case scenario can reach usable groundwater.

And so the question arises: How likely is it that such a leak will occur? An earthquake right at a hydrofracking well is a highly unlikely occurrence in the study regions. The production companies, which operate on the assumption that they can reliably prevent such leaks, say that the leaks that have been reported in the US resulted from faulty cementing and piping, as well as sloppy work, and that the state of the art for the cement used in hydrofracking and the attendant cementing techniques have greatly improved. Nonetheless, we presume that leaks can definitely occur.

Stakeholder question

How does cement react to the following: (a) up to 1,000 bar of pressure applied to the cement by hydrofracking; (b) subsurface subsidence; (c) earthquakes; and (d) tectonic plate movement?

Workers quickly notice major leaks by virtue of the fact that no pressure is built up by the hydrofracking fluid being pumped into the well – a phenomenon well known to anyone who has ever experienced a flat tire while riding a bike. In such cases, the well is repaired. If this proves impossible, the well is abandoned and is sealed with cement. But during the time it takes to do this, a considerable amount of contaminants may well have seeped into the groundwater, and this in turn necessitates comprehensive groundwater remediation that takes years to complete and is extremely cost intensive. And even in cases where a full cleanup is likely to be beyond reach, experience from remediation of other sites has shown that the remaining contamination is tolerable.

On the other hand, minor hydrofracking fluid leaks may go unnoticed for a lengthy period in some cases.

By the same token, groundwater can be contaminated by wastewater or deep groundwater pipeline leaks (also see p. 47).

Under normal circumstances, cement and piping leaks can be avoided through the use of extensive technical measures. However, any leak that does occur will result in groundwater pollution, and precautionary measures must be taken to avoid such incidents. Monitoring wells surrounding the borehole are necessary and groundwater cleanup methods should be at the ready.

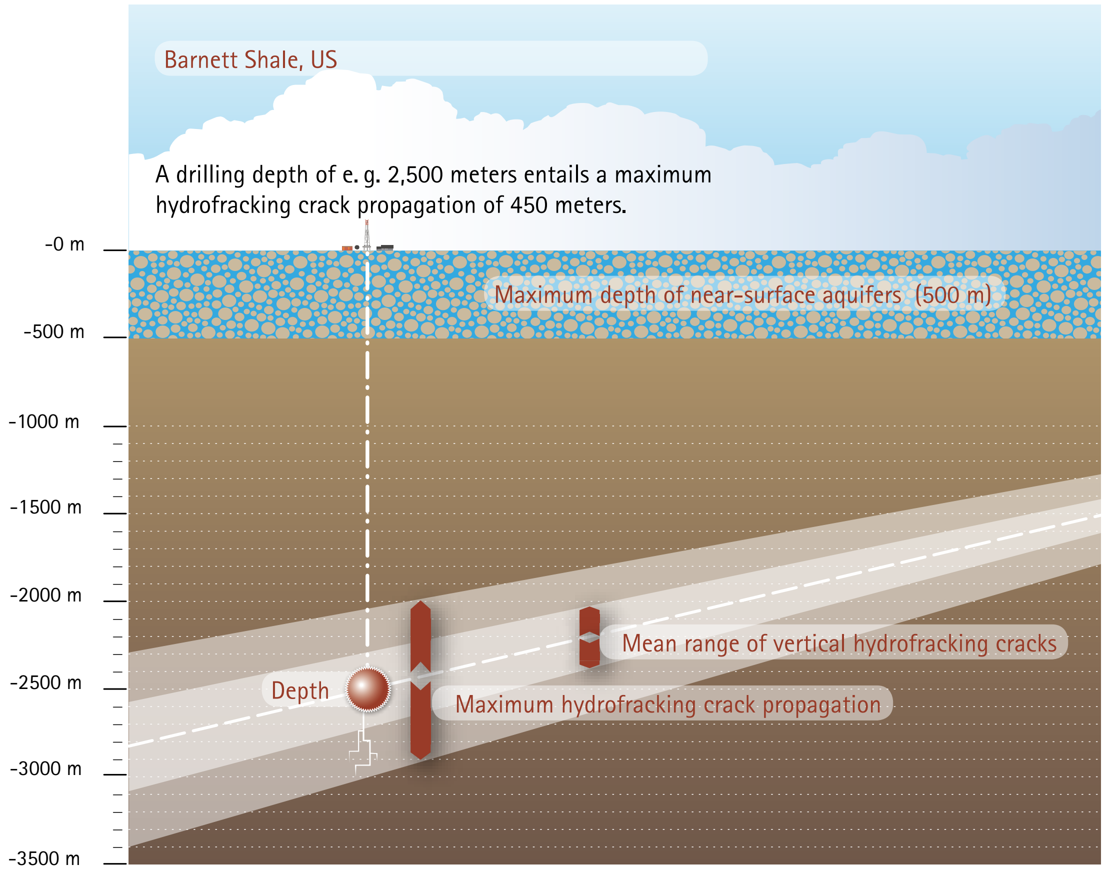
The (possible) shape of things in 2030

We predicated our forecasts on the assumption that with 300 wells and 4,000 hydrofracking operations, at least one leak will occur at some point. It would probably take around five minutes for a relatively large leak to be detected, and during this time 35 cubic meters of hydrofracking fluid would leak into the groundwater. A small hydrofracking fluid leak would result in around six cubic meters of fluid seeping into the groundwater until the leak was detected. The larger leak would be stopped and the groundwater remediation process would begin immediately, while with the smaller leak the contaminant plume would progress at a rate of up to three meters a day in the direction of flow, depending on the geological properties that come into play. With monitoring wells located 20 meters from the gas well, it would take seven days to detect a small leak, and only then would the remediation process begin. Nearby waterworks would be notified immediately as a precaution.

For example, cleanup measures would involve actions such as drilling protective wells (at the gas company's expense) that would allow a portion of the contaminated groundwater to be pumped out so as to prevent the remainder of the water from advancing toward drinking water wells that lie at a distance from the contamination site. The water that is pumped out would need extensive purification.

The natural hydrofracking degradation processes that occur underground could be supported, although the level of the pollution in such a case would make it necessary to carry out such measures over a lengthy period. The remediation could cost upwards of €10 million and it is uncertain whether the well could even be repaired. If it cannot be repaired, it would have to be abandoned.

Injecting Hydrofracking Fluid Deep Underground



21 Propagation of hydrofracking cracks associated with hydrofracking, as measured in the Barnett Shale in the US, broken down by the depth at which hydrofracking was carried out (from 2,800 meters (left) to 1,500 meters (right)). The Barnett Shale groundwater extends to a depth of 500 meters. (Data source: Fisher and Warpinski 2011, Hydraulic Fracture Height Growth, SPE 145049).

Hydrofracking fluid is injected into the shale stratum under high pressure, where it creates cracks in the rock at a depth of upwards of 1,000 meters. These cracks can propagate upward by as much as 300 meters, depending on well depth and provided that the cracks do not terminate at a stratum boundary beforehand.

There are various underground rock strata, some of which carry water and are highly porous, while others are so nonporous that water takes centuries to flow just a few meters. The water nearer the surface is "fresh" water and can be used as drinking water, while the water in the lower strata is saline and can potentially be used for thermal baths and for bottled mineral water.

Nonetheless, there are recurring geological faults where the various strata are shoved up against each other and that do not constitute open breaches in the rock. It is possible that water can flow upward or downward more easily at such locations. Bounded near-surface areas containing saline groundwater are indicative of possible connections.

Stakeholder question

Could the chemically enriched water that is injected into the ground under ultra-high pressure enter the aquifer network and ultimately reach the nearby gravelly sand bed?

The Possibility that Contaminants will Percolate upwards into Usable Groundwater

Using model-based simulations predicated on the following conservative assumptions, we investigated the possibility that contaminants could percolate upward into usable groundwater:

> Any given hydrofracking crack will extend beyond the boundaries of the stratum in which it occurs, will measure more than 300 meters in length or height, and will ultimately intersect a geological fault.

> Faults with a running length of more than 1,000 meters will occur that allow for more rapid fluid "migration."

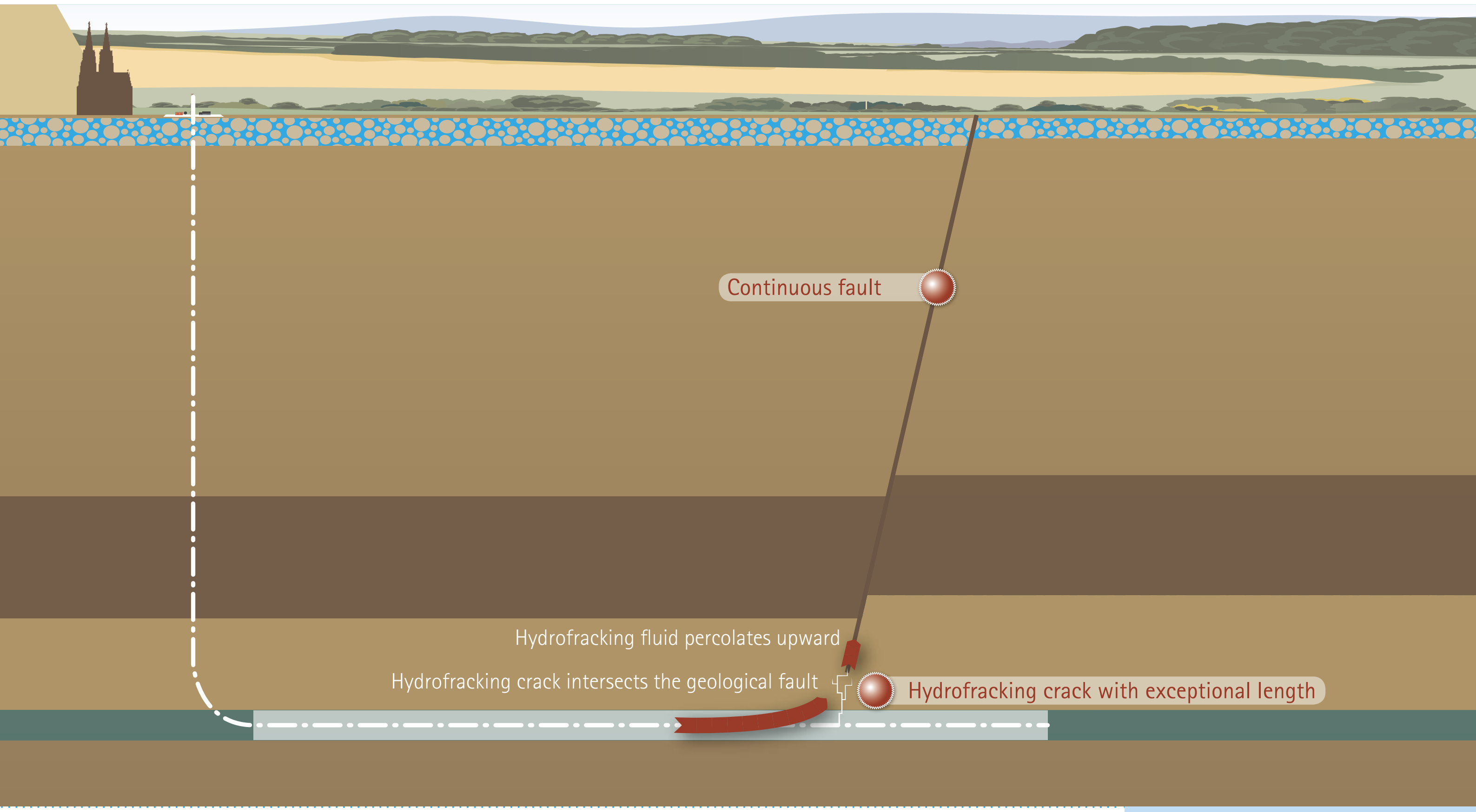
Our simulations showed that even under the circumstances entailed by these very conservative assumptions, hydrofracking fluid that is forced into underground rock can only percolate around 50 meters upward, and only while hydrofracking fluid is being pumped into the well. This means that pumping hydrofracking fluid into hydrofracking wells cannot cause any contaminants to flow into usable groundwater.

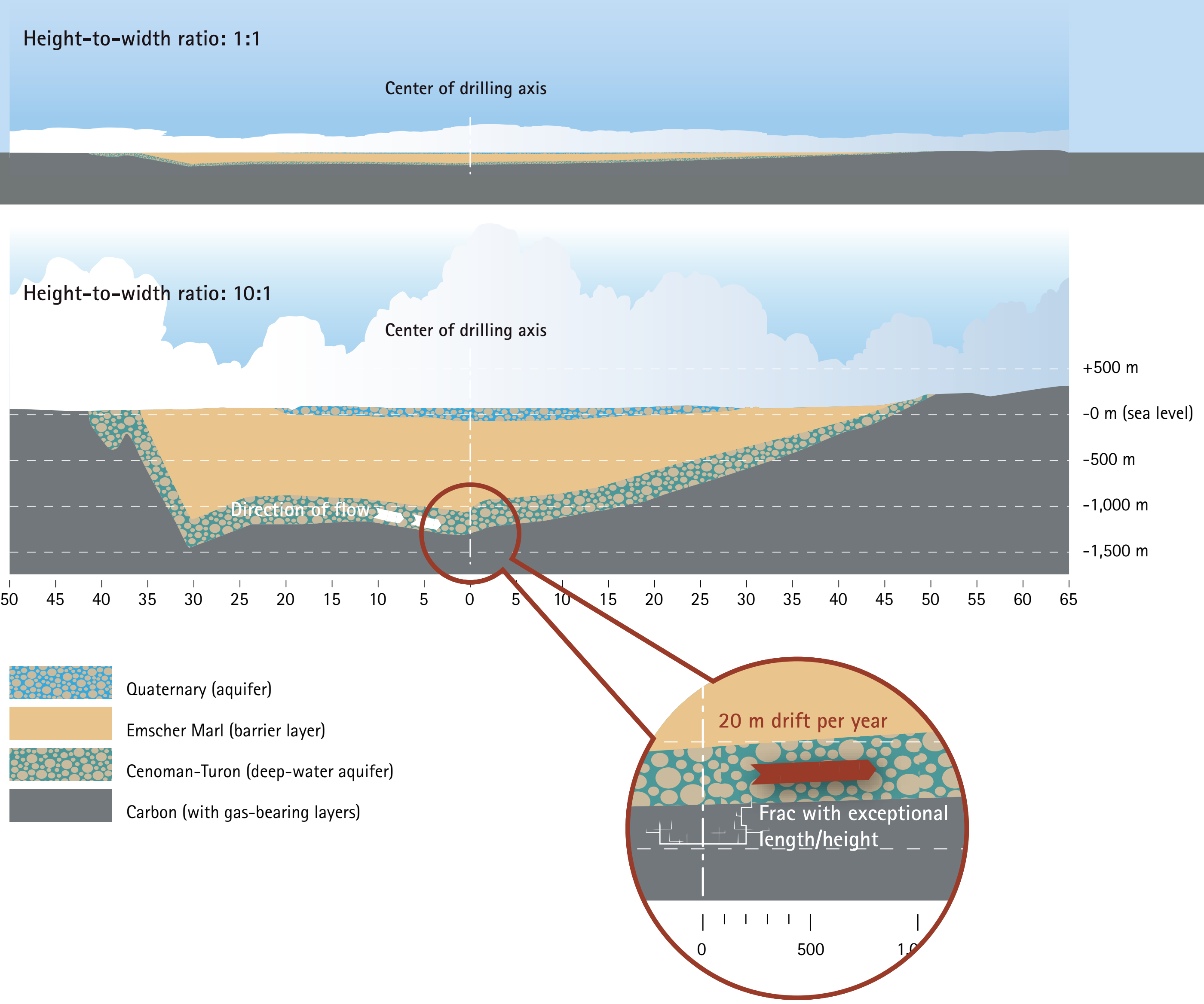
However, there is one exception to this rule, because when deep groundwater (confined groundwater) is under higher pressure than the groundwater being used, hydrofracking fluid can percolate upward in the concurrent presence of continuous and porous faults. It is safe to assume that this scenario will not arise.

The (possible) shape of things in 2030

Hydrofracking activities will result in a total of six million cubic meters of hydrofracking fluid being pumped into a 200 square kilometer area, which would result in a three centimeter-deep layer of fluid on average. By way of comparison: over the course of a given year seven times as much new groundwater is formed, i.e. around 22 centimeters in the Münsterland region.

22 Schematic drawing showing the possible upward percolation of hydrofracking fluid.





23 The Cenoman-Turon shown in the figures displays a deep-water aquifer in the Münsterländer Becken that rises to the surface. The height of its geological formations are for the most part exaggerated in the figures, but if they were true to scale this area would appear as flat as in the upper graphic. Coal bed methane is located in thin strata across the entire 2,500 meter Carbon.

The Possibility that Contaminants will be Transported with Deep Groundwater

Deep groundwater (also known as brine), which normally does not reach plant, animal or human habitats, is naturally occurring water that contains salt and heavy metals, as well as, in some cases, radioactive substances and hydrocarbons.

Nonetheless contamination of deep groundwater, which by law is classified as groundwater, should be avoided at all costs.

However, there are cases where deep groundwater is used for purposes such as bottled mineral water. Moreover, the Münsterland area's thermal springs owe their existence to a geological oddity whereby deep groundwater occurs near the surface at certain locations, unlike in the underground areas of Lower Saxony where no water flows toward thermal springs.

Stakeholder question

Assuming that hydrofracking will generate fractures in the entirety of the Carbon in hundreds of meters of stratum thickness, it stands to reason that brine will reach these fracked areas. How long will it take before brine-containing formation water and the remainder of the hydrofracking fluid reach the surface?

Here, too, we carried out simulations that were predicated on the assumption that any given hydrofracking crack will propagate to the boundary of the next deep groundwater stratum. This in turn would allow a portion of the hydrofracking fluid to seep into the deep groundwater. Hence the extent of the risk in such settings is determined by the vertical gap between the fracked coal bed methane strata and the deep water aquifers.

Our simulations revealed the following: Under the (conservative) assumptions posited for these simulations, contaminants could potentially be transported a number of kilometers, at a rate of around 20 meters a year, and ultimately could reach thermal springs – although this is a highly unlikely (though theoretically possible) occurrence. The shale gas zone in Lower Saxony can be regarded as a closed system, including in deep underground areas; whether or not this is the case in Münsterland is determined by the distance between deep groundwater and hydrofracking operations.

The Long View

While the well monitoring and repair processes for gas production, hydrofracking and gas transport have been tested and are known to be reliable, this may not be the case over the long haul. The industry's eight decades of experience with the long-term stability of cement shows that gas well cementing does not remain leak-proof indefinitely.

This also means that abandoned and sealed wells need to be monitored so as to detect any gas or contaminant emissions early enough to take the necessary countermeasures.

Possible Methane Emissions

It is currently not known whether all methane released by hydrofracking actually flows upward through the well, and it is possible that methane may rise to the surface by circumventing the well. Methane has been detected in more than 50% of Münsterländer Becken household wells tested in areas where no hydrofracking was carried out nearby. This has prompted German authorities to issue a warning to the effect that methane in well water can provoke explosions.

According to reports from the US, methane has been detected in the ambient air around hydrofracking wells and can result from the following factors:

- Well leaks provoked by irregularities such as faulty joints between the cement and surrounding rock.
- The fact that in some US states ponds are still commonly used as wastewater storage facilities (a practice banned in Germany) whose wastewater can release the methane contained in it.
- Leaky pipelines and leaks that occur during the gas cleaning and drying process.
- Underground fault zones that allow underground methane to rise to the surface..

Leaks in gas pipelines and gas purification installations are amenable to management (and in any case by law wastewater in Germany must be stored in closed systems); but little is known about the upward movement of underground methane; nor do we know how much underground methane escapes into the atmosphere that is unrelated to hydrofracking or whether hydrofracking adds to this amount, and if so, to what extent. Gas-tight strata are found at many locations, for otherwise there would be no natural gas reservoirs because all the gas would have long since escaped into the atmosphere. However, whether the rock strata above the shale are nonporous has yet to be determined; and after all, the gas is trapped in the shale until hydrofracking is carried out.

Apart from the risk of explosion, methane emissions pose no major threat to human health, but are a threat to the earth's climate, as methane's global-warming footprint is 25 times greater than that of carbon dioxide.

The extent to which methane emissions contribute to global warming is determined by how rapidly the methane rises to the surface. In view of the fact that it is presumed that individual methane molecules exert an atmospheric effect for 100 years, the slower the methane's rise to the surface through the subsurface, the less effect it will have on global warming.

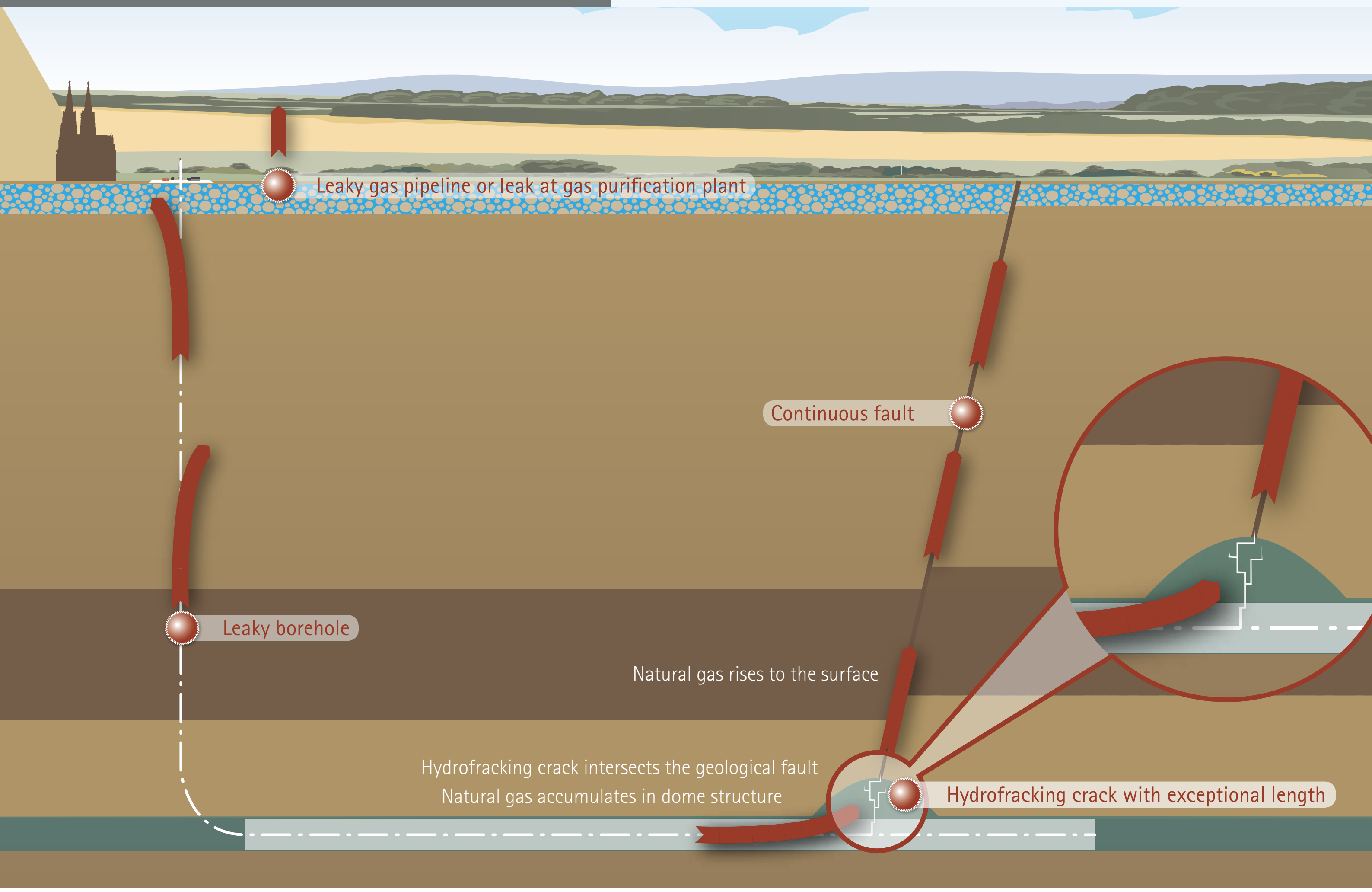
Methane Emissions in Münsterland

A large proportion of the atmospheric methane in Münsterland appears to stem from biological conversion processes – although coal bed methane also occurs in the southern part of the region, particularly its coal mining areas. Decades upon decades of coal mining shook up the geological strata, resulting in numerous faults – although there is no evidence that these faults provide a particularly favorable pathway for methane emissions from underground sources.

When hydrofracking is started at a given location, a "zero-sum" determination must be made for the location. In other words, how much methane already rises to the surface at that location in the absence of hydrofracking?

Stakeholder question

Is it certain that the sporadic natural methane emissions in the Münsterland region are not composed of coal-bed methane? Is there such a thing as "natural" methane emissions?



24 Schematic drawing showing the emissions pathway for natural gas.

Possible Effects on Global Warming

Here too, we ran simulations which, however, provided considerably less viable results than was the case with fluid transport. The global warming simulations were intended merely to provide a general idea concerning which correlations of variables and assumptions might potentially be viable.

These simulations were predicated on the following assumptions, whose confluence in nature is extremely unlikely:

> Only 80% of the methane that is mobilized by hydrofracking is transported through the well, while the remaining 20% can potentially rise to the surface via another pathway, assuming one is available.

> Natural gas can accumulate in what are known as dome structures in the presence of suboptimal stratification, and porous faults occur right at these domes.

> Such faults, which occur and are permeable across the entire depth of the relevant strata, exhibit low conductivity and contain only minute amounts of methane. The displacement provoked by the fault in such cases is so extreme that the salt stratum ruptures and no longer acts as a barrier.

Methane emissions were calculated solely for the Lünne setting, whose parameters are unfavorable in this regard. Our simulations showed that 23% of the Lünne shale gas that hydrofracking mobilizes (but does not extract) could theoretically rise to the surface in 100 years.

Natural Gas versus other Energy Sources

The extent to which natural gas is genuinely a superior fossil fuel relative to other energy sources also hinges on its greenhouse gas emissions. This determination was made using the life cycle assessment method, which entails the following:

> All of the steps in the life cycle of a given energy resource are taken into consideration – namely production, processing, transport and combustion. Across all of these steps, classic natural gas is superior to energy resources such as coal and oil. Drilling, as well as transport (usually via pipelines), are less complex processes than for coal, while coal combustion produces far more carbon dioxide than natural gas combustion as measured by a unit of generated electricity or heat.

> In addition to carbon dioxide, atmospheric methane emissions are also factored into the calculations. Methane, whose global warming footprint is 25 times greater that of carbon dioxide, is released owing to abnormalities such as pipeline leaks.

> The cost of chemicals and piping was also factored into the calculations.

The calculations were predicated on the assumption (based on actual and estimated US figures) that each well will produce 100 million cubic meters of natural gas.

Stakeholder question

How does the extent of the greenhouse-gas footprint resulting from producing, transporting and burning shale gas stack up against the greenhouse-gas footprint of conventional natural gas?

Shale Gas Methane Emissions versus those Generated by Conventional Gas Production

Our calculations concerning shale gas production in Germany revealed the following differences between shale gas and classic natural gas:

1. Considerably more energy is needed to drill the many wells required for hydrofracking operations, and shale gas wells yield less gas than their conventional counterparts. The global-warming footprint of shale gas extracted at a depth of 1,000 meters is 30% larger, and is twice as large for gas obtained 2,500 meters down, compared to the natural gas currently used in Germany. And as most hydrofracking drills are driven by diesel engines, the hydrofracking process generates carbon dioxide and other air pollutants – although this environmental performance would greatly improve if electric motors were used instead. In terms of the 2030 scenario (according to which the lion's share of Germany's electricity will comprise renewables), drilling for shale gas 1,000 meters below the surface will entail only marginally greater greenhouse gas emissions relative to conventional natural gas.
2. Methane emissions resulting from the gas circumventing the well (diffuse emissions) can potentially have a negative carbon-footprint effect, depending on the assumptions used. But as such calculations are far from being an exact science, maximum emissions were set at 23% of mobilized methane for purposes of our calculations.

The other aspects – namely transport, gas cleaning, chemical manufacturing and piping – had only a negligible impact on our findings.

		Shale gas methane emissions versus those generated by conventional gas drilling	
2010	Depth	None*	Maximum**
	1,000 meters	+ 30 %	+ 38 %
	2,500 meters	+ 176 %	+ 183 %

		Shale gas methane emissions versus those generated by conventional gas drilling	
2030	Depth	None*	Maximum**
	1,000 meters	+ 1 %	+ 8 %
	2,500 meters	+ 35 %	+ 43 %

25 Larger greenhouse-gas footprint resulting from shale gas relative to the gas currently used in Germany.

"None" means that no diffuse methane emissions occurred.

*** "Maximum" represents the highest value obtained under unfavorable conditions.*

Our simulations revealed that the greenhouse-gas footprint of shale gas is anywhere from 30 to 183 percent greater than that of classic natural gas. This performance could potentially be improved by using renewable electricity rather than diesel to run hydrofracking pumps. If this were done, the carbon footprint of shale gas would be only 43 percent greater. If realistic data concerning the methane emissions from the shale stratum were available, it would be possible to measure the greenhouse-gas footprint of hydrofracking related methane emissions.

Water Use and Wastewater Disposal

Hydrofracking entails the use of 20,000 cubic meters of water per well that is drawn from the public drinking water supply or from the gas company's own drinking water wells and to which hydrofracking proppants and chemicals are added.

On completion of a hydrofracking cycle, as much hydrofracking fluid as possible is "suctioned" back to the surface, although the tests conducted to date reveal that only around 20 % of this fluid is actually recovered. This in turn means that the resulting wastewater also contains a high proportion of deep groundwater, depending on the geological conditions at the site in question.

The graphic on the right shows a truck containing hydrofracking fluid at a water treatment plant in Williamsport, Pennsylvania.

After being treated, the wastewater is transported to a disposal site in tank trucks or pipelines, and in Germany is injected into rock strata that lie anywhere from 350 to 4,000 meters below the surface in the environs of Sulingen and Cloppenburg.

In the US, operators are required to transport hydrofracking wastewater to sites with no dead wells for recycling. After being filtered, the wastewater is used for the next hydrofracking cycle and the residues are taken to specialized waste dumps.

26 The table displays the substances contained in flowback water (Buchhorst T 12, 27 July 2011), which in deep groundwater can comprise salts, heavy metals such as mercury, and radioactive substances, depending on the prevailing geological formations. In the presence of natural gas, hydrocarbons such as benzene are also found.

Parameter	Unit	02.08.	04.08.	08.08.
Strontium	mg/l	70	64	46
Barium	mg/l	1.0	1.0	0.0
Manganese	mg/l	2.0	1.0	1.0
Zinc	mg/l	1.0	3.0	2.0
Lithium	mg/l	18	15	11
Acetate	mg/l	420	480	350
Formate	mg/l	190	160	150

Stakeholder question

Which additional possibly natural substances will presumably be dissolved underground and pumped out of the ground with the water during gas production and hydrofracking?

Classic natural gas production generates large amounts of deep groundwater, which is transported to dead wells by pipelines or tank trucks. Various accidents have occurred recently that resulted in the release of benzene (which is carcinogenic) and other chemicals. Although the exact cause of these events remains unclear, it is thought that benzene leaked through the walls of plastic hoses, most likely owing to a tear in a hose that may have been caused by a bulldozer. If such leakage goes unnoticed over a lengthy period, the benzene has to be removed from the contaminated soil. Benzene can potentially be a health hazard for local residents.

In the view of mining officials and gas companies, deep-injection disposal poses no problem – providing of course that no accidents occur during the transport process, which basically involves returning deep groundwater to its original source.

Outsiders have difficulty understanding why this is done, particularly since such wastewater contains hydrofracking chemicals. There is also scientific evidence that deep-injection disposal can provoke earthquakes (also see p. 48). The standard alternative water treatment methods in the context of deep-injection disposal are in some cases unsuitable for the specific wastewater components that come into play, particularly when it comes to the high salt content, which renders wastewater treatment problematic. Partial treatment of wastewater for recycling purposes may potentially reduce the amount of water used and the volume of wastewater that needs to be disposed of.

See above (pp. 32–34) for a discussion of the possibility that contaminants may be released into the atmosphere during the wastewater transport process, during deep-injection disposal, or in deep underground areas.

In our view, deep-injection disposal is an acceptable method provided that a master concept for wastewater disposal is elaborated, including optimization of the state of the art through the development of improved wastewater treatment and recycling methods, as well an across the board substance flow analysis. This in turn would involve the development of failsafe pipelines, which in any case need to be monitored round the clock and inspected at regular intervals.

The available data concerning flowback water properties are insufficient, and in particular shed far too little light on the possible breakdown products of hydrofracking chemicals. Comprehensive hydrofracking substance flow analyses need to be carried that take account of (a) all possible treatment methods, including wastewater recycling; and (b) the relevant environmental risks.

The (possible) shape of things in 2030

Drilling 300 wells and carrying out 4,000 shale gas hydrofracking operations will consume around six million cubic meters of water, which represents the total annual water consumption of a city the size of Osnabrück (population 165,000). By 2030 these operations will also generate 1.2 million cubic meters of wastewater, which if not reused will have to be disposed of. To do this, additional disposal wells will be needed.

A large gas field containing numerous production sites will presumably involve converting pipelines into wastewater treatment plants – around one per ten production sites. Around 70 kilometers of new pipeline will be laid for the 200 square kilometer area, and leakage can be expected to occur at five year intervals. Tank trucks ferry non-reclaimable wastewater from the treatment plant to the deep-injection disposal wells. With 22 production sites, this could potentially amount to some 2,000 trips over a 15 year period and the consequent accident risk.

As the wastewater leakage scenarios are basically the same as those discussed previously, a 30 ton diesel tanker truck can be applied to the accident involving a ruptured wastewater pipe, even though a smaller amount is involved. This event would also result in soil contamination that would involve a cleanup and disposal process.

Seismic Events

Stakeholder question

Is it absolutely certain that hydrofracking does not provoke earthquakes? How did it happen that in 2004 Lower Saxony was struck by a 4.5 magnitude earthquake that was caused by gas production? Did this earthquake result from a hydrofracking operation? If not, what caused it? Could such an event recur in Lower Saxony? What are the differences relative to the specific location in Lower Saxony?

If the lowlands of northern Germany are far from being a typical earthquake area, the tectonic plates in Northern Germany are nonetheless subject to tectonic stress that has caused severe earthquakes in the past such as those in Wittenburg (east of Hamburg) and Bremerhaven in 2000 and 2005 respectively. These earthquakes are extremely difficult to predict due to the fact that they are isolated incidents.
In addition to hydrofracking, conventional natural gas production can provoke earthquakes if large amounts of gas are produced. The immediate cause of such earthquakes – which occur in the immediate environs of gas fields and exhibit clear upward or downward distortion – is a significant pressure drop in the gas reservoir a number of years following gas production start-up. A prime example of such incidents can be found in Dutch gas fields, where around 15 years after production start-up, minor induced earthquakes occurred in shallow source depths, solely in close proximity to the gas strata sandstone formations. These earthquakes caused fine cracks to form in building walls and tiles to fall from roofs.
The magnitude of the earthquakes in Soltau (1977) and Rotenburg (2004), Lower Saxony, was up to one order of magnitude higher than that of the highest levels registered in The Netherlands. These earthquakes occurred near charted tectonic faults, and in the case of Soltau coincided with conventional gas production start-up. It is difficult to differentiate such events from natural earthquakes, and this difference is still being studied by scientists.
Earthquakes are provoked by fracturing processes in the earth's crust, which also occur during hydrofracking. However, the lengths of hydrofracking fractures, which amount to only a few meters, translate into a magnitude of energy that is at least 1,000 times below the point at which an earthquake is perceptible. Hydrofracking can provoke a tectonic event only in the presence of a highly unusual confluence of rare events. For example, during fracking in a Blackpool, England shale gas field in 2012 an accidentally drilled weak zone was placed under pressure by virtue of a massive amount of hydrofracking fluid having been injected into this zone. However, microseismic monitoring can detect such extreme situations in their incipient state, and their effects can be mitigated by modifying the hydrofracking process.
Seismic events can also be provoked by formation water disposal, a process which, unlike discrete hydrofracking operations, involves long term injection of large amounts of fluid into partly emptied reservoirs. This process is widely used by gas companies worldwide and provokes earthquakes in exceptional cases only, one example being the series of earthquakes that occurred in Youngstown, Ohio in 2011. In the northern German lowlands, no earthquake has occurred at the five injection sites and deep injection disposal sites used by ExxonMobil for volumes of wastewater ranging from 300,000 to 3 million cubic meters in a radius we amply defined as 10 kilometers and for injection periods ranging from 10 to 30 years.

Well piping or cementing (see p. 33) is unlikely to be damaged by an earthquake, but this is nonetheless a real possibility. A seismic event with the force of the Rotenburg earthquake will presumably result in mean tectonic displacement of 1.6 centimeters along the fault line, which is around eight square kilometers in size and more than five kilometers below the surface. Moreover, in order for the piping to incur damage the earthquake's displacement would have to pass right through the well, which would cause the piping to tear or rupture, depending on the angle to the drilling axis.

Seismic events provoked by hydrofracking and by deep-injection disposal are a very real possibility. Careful site selection and process monitoring can reduce the likelihood of perceptible seismic events in Germany to the existing level of seismic risk from natural earthquakes.

Hydrofracking Risk Management: What are the Options?
Monitoring

Stakeholder question

Who verifies that only the mandated chemicals and that only the mandated amounts of such chemicals are added to hydrofracking water? Who's in charge of monitoring this? At which intervals do they do so? Who bears the expense of this monitoring process?

If operational monitoring by both regulatory authorities and the operators themselves is crucially important, there are also good reasons to incorporate scientists and the population at large into the monitoring process and publicize the findings in an understandable fashion. As the example of lignite mining shows, such an approach helps to build trust among the relevant actors and to optimize existing concepts and develop new ones.

What Kind of Monitoring is Needed?

1. Seismic monitoring, which helps to ensure that hydrofracking doesn't provoke earthquakes.
2. Groundwater monitoring, which allows for the immediate detection of major leakage, but probably not minor leakage. The effectiveness of groundwater monitoring can be heightened by installing measurement gauges around the well that are linked to a chemical and toxicological monitoring device. Moreover, monitoring measures need to be supported by an emergency plan so that the appropriate response can be instituted quickly.
3. Gas monitoring, which allows for assessment of the greenhouse-gas footprint of shale gas and is based on methane emissions data.
4. Building-status monitoring, which allows for determination as to whether any defects that appear predate a seismic event or were provoked by hydrofracking.
5. Leakage monitoring at the well and in pipelines, via pressure and other measurements.
6. Monitoring of the hydrofracking process, including the use of chemicals, a task which by law falls to government officials. However, in some cases it may be useful to allow representatives of water companies or citizen representatives to access production sites and participate in the monitoring process.

Is Monitoring Meant to be an Alarm System or an Observation Process?

The answer is: both. Some processes move faster than others. Thus for example concerns that polluted deep groundwater has been flowing toward thermal baths for decades can only be validated through long term monitoring. On the other hand, rapid action is needed in cases where, for example, contaminants are percolating out of a well or a leaky pipeline. The exact procedures in such cases should be hammered out through dialogue with the various groups concerned.

Which Types of Monitoring are Prescribed by Law?

The EU Water Framework Directive calls for groundwater and surface waterbody monitoring, with the goal of allowing for the following: timely detection of adverse changes in water properties; determining the causes of pollution; developing strategic remediation and/or avoidance measures; and assessing the effectiveness of the measures that are implemented. Germany has a network of around 6,500 chemical-status monitoring sites with which the measurement stations that are to be installed at hydrofracking sites can be integrated.
Water companies keep watch over the quality of their drinking water through regular contaminant and bacteria testing, as prescribed by law, and key drinking-water treatment operating parameters are monitored online continuously. Some larger waterworks supplement these measures with continuous biological testing.

Safety Management

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Stakeholder question

In view of the problems that have arisen in the past in Lower Saxony, why should I suddenly put my trust in ExxonMobil?

Apart from the technical integrity of the relevant installations, the manner in which safety and emergency measures are managed is of major importance. Industry actors became aware of this and began implementing the attendant measures in the early 1990s in the wake of a series of major accidents. At this time, further optimization of technical safety translated into only a marginal improvement in overall safety, and marked the birth of safety management systems that have since become standard in all industries whose operations are subject to risk and today constitute legal requirements in some cases, e.g. for mining authorization procedures. At the same time, certain elements of safety management systems have also been incorporated into the monitoring practices of government agencies. Audits allow for assessment of the following: local integration of businesses and the latter's relationship with their environment; and internal company processes and structures aimed at ensuring that all statutory requirements and company policies are adhered to. Improvements in safety management practices have resulted in the advent of highly developed cultures of safety that address the specific concerns of specific companies and promote integration of companies into the social fabric of the communities in which they operate. The main characteristics of a culture of safety is that the focus of the relevant personnel is on assuring installation safety by cooperating closely with each other. What's more, operational safety needs to be proactively organized through the following measures, among others: establishment and integration into company operations of a safety management system; providing employees with safety training; and ensuring that the personnel of outside companies apply equally exacting safety standards; setting aside sufficient time and financial resources; defining safety performance indicators; learning lessons from operational experience and accidents; conducting regular audits and management reviews of installation safety.

Emergency management, which is an integral part of a company's safety management system, ensures that suitable measures will be taken in the event of an incident. A multi-level response system needs to be put in place to handle escalating situations, and in particular requires excellent teamwork between company safety officers and government safety officials. It is likewise crucial to formulate precautionary measures aimed at managing the specific hazards arising from hazardous substances – including providing the general public with useful and accurate information in advance.

In order for a company to exercise social responsibility, its installations and the environments in which they operate must be described in full. ExxonMobil has at its disposal internally the information necessary for this, whereby the company's operational plans disclose only a portion of the available information. ExxonMobil has also made a host of additional key information available to regulatory authorities, and such information can come in handy in the context of cooperative efforts between operators and officials. All such information should be made available to the local residents concerned and should be made public as well, as this can help to strengthen government and company monitoring activities by involving all concerned in the process – namely experts, neighbors, citizens' action groups, and nature and environmental protection organizations.

For all of its operations worldwide, ExxonMobil uses an Operation Integrity Management System (OIMS), which is an extensive and logically structured instrument that allows for the management of safety, health and environmental risk. This system, which ExxonMobil regards as a work in progress, was last updated in 2010. ExxonMobil's OIMS reflects the current state of the art for good corporate governance and extensively addresses all relevant areas of concern. ExxonMobil has also taken on board additional elements of a good safety culture, insofar as it is possible for the company to do so. The system has been checked by us based on random sampling concerning the relevant substantiation and procedures, and no problems were found.

Criteria for Chemical Selection

Stakeholder question

Which of the drilling mud additives and chemicals would it still be acceptable to use from an environmental standpoint, and which of these elements should no longer be used?

In our view, some of the hydrofracking chemicals that are currently in use should be replaced, for environmental reasons.

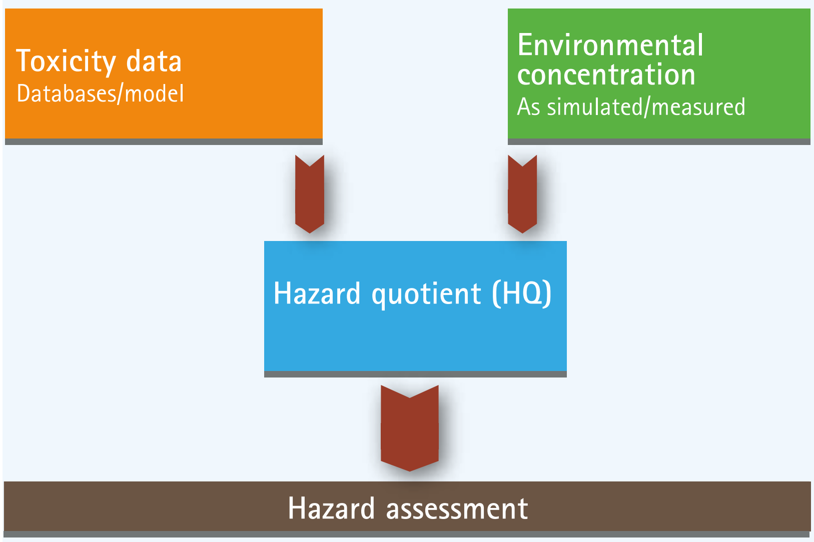
Three systems of assessment were proposed as "signposts": If one of the three systems identified a substance as hazardous, its further usage should be re-considered:

1. The European Union´s Regulation on Classification, Labelling and Packaging of Substances and Mixtures (CLP), which mainly centers around work safety and consumer protection, and classifies substances according to human-toxicological hazardousness characteristics such as the following: highly toxic; toxic; health hazard; nontoxic, as well as other categories such as corrosive and carcinogenic.
2. Germany's Drinking Water Regulation (Trinkwasserverordnung), whose requirements include that water be virtually free of organic biocides (limit value less than 0.1 µg/l).
3. The hazard quotient (HQ) method, which was developed with the goal of identifying possible ecosystem hazards, allows for identification of the hazards arising from a particular substance or substance mixture. The US Environmental Protection Agency defines the hazard quotient as follows: "An HQ comprises the ratio of the potential exposure to the substance and the level at which no adverse effects are expected. If the HQ is calculated to be equal to or less than 1, then no adverse health effects are expected as a result of exposure. If the HQ is greater than 1, then adverse health effects are possible. The HQ cannot be translated to a probability that adverse health effects will occur and it is unlikely to be proportional to risk. It is especially important to note that an HQ exceeding 1 does not necessarily mean that adverse effects will occur." The HQs of various substances are aggregated in the hazard index, thus allowing for the assessment of hazards arising from hydrofracking fluids (i.e. mixtures).

Under EU law a chemical may only be used if its use in hydrofracking fluid is taken into account when the chemical is registered or if the relevant users have conducted their own risk assessment and have implemented their own risk management measures. Adequate data concerning the toxicological impact of the relevant substances are also necessary for this registration.

If the requisite data were available and if the aforementioned three signposts were applied, the new hydrofracking substances would in fact have a less severe environmental impact. If the sole criterion taken into account were the hazardousness of the relevant substance, a company would then be able to implement measures such as using a higher concentration of a less toxic substance.

27 Ecotoxicological assessment method for hydrofracking fluids.



Liability and Accountability

Stakeholder question

The worst-case scenario would be that an accident would result in deep groundwater being contaminated by hydrofracking fluid and that formation water would contaminate the Münsterland region's drinking water reservoir. Has an emergency action plan been drawn up for this eventuality and is this risk insured?

By law, a corporate polluter whose mining activities cause damage to buildings, waterbodies or the soil can be required to pay financial compensation regardless of whether the incident is the company's fault. In such cases, liability for damages applies that need not arise from negligence.

However, pursuant to the principle of causality, the injured party is required to prove that the company (to the exclusion of any other party) actually caused the damage; as a rule this is extremely difficult to do. Causality is easier to establish if the status of the possibly affected buildings and/or groundwater areas are investigated ahead of time through monitoring measures. Germany's Federal Mining Act (Bundesberggesetz) somewhat lightens the burden of proof concerning mining damage (section 120); but legal experts disagree as to whether this provision also applies to gas exploration and production. An arbitration panel such as the one that was used in the Rheinisches Revier mining case, can help to avoid lengthy litigation and enables the injured parties to have their claim reviewed without incurring any risk.

A special fund has been set up in Germany to indemnify injured parties in cases where the company responsible for mining damage goes bankrupt and is unable to pay.

Corporations take out liability insurance to cover the risk entailed by such scenarios. Such insurance provides blanket cover for both personal injury and property damage. However, mining damages are normally not covered by such policies, which means that a company needs to take out separate environmental liability insurance to cover groundwater damages. Consideration should be given to the possibility of providing such coverage by instituting financial guarantees.

Legal Considerations

Stakeholder question

How can it be ensured that environmental safety will be established in a timely manner for the entirety of a given gas field as well as for individual hydrofracking operations, and that the public will be involved in this process?

Although Germany does not currently have a hydrofracking law on the books, the country's mining, water resource and immission control laws contain provisions that also apply to hydrofracking and that protect groundwater, drinking water, the environment and public health.

And while some of these requirements are extremely general in nature and allow for wiggle room, there are some deep underground drilling regulations on the books that also apply to hydrofracking. But these regulations are wide of the mark when it comes to (a) the possible events discussed in this report; and (b) the requisite precautionary measures aimed at preventing, managing and/or mitigating the effects of such events. Hence we recommend that the incidents and leakage events discussed here be regarded as plausible incident scenarios for which legal restrictions and regulations should be imposed, and that operators be legally required to have the capacity to handle such events and keep them under control.

To do this, it would be necessary to implement numerous safeguards that are consistent with the state of the art and that reach the mandated protective objective. That entail short and long term measures aimed at limiting the amount of damage caused by incidents, and of course preventing them from occurring in the first place – particularly when it comes to natural-gas wells. This would also necessitate the assessment of damage to geological systems, whereby the covering strata need to comprise sufficiently robust and nonporous protective barriers for groundwater. The risk of groundwater damage is practically nil (a) in cases where artesian groundwater is not under pressure; and (b) in the presence of porous fault zones.

It works to the detriment of risk assessments that an Environmental Impact Assessment (Umweltverträglichkeitsprüfung) is not carried out, and that the public is not involved in the assessment process. And while companies are required to conduct an Environmental Impact Assessment for sites where 500,000 cubic meters of gas are extracted daily, this threshold will probably never be reached for gas production from unconventional reservoirs. Owing to the various phases entailed by the relevant decision making processes, key risks are oftentimes not assessed until after a number of investments and positive decisions have been made.

A large scale gas field comprising hundreds of drilling sites and the attendant infrastructure consisting of wastewater treatment facilities, gas and wastewater pipelines, and roadways will have a significant impact on the relevant economic and residential structure, the landscape, and nature conservation. Any official landscape, nature, or water conservation protection areas are inherently protected against such uses, which are permitted in exceptional cases only. Breaching the safeguards for protected areas should be allowed in exceptional cases only. Moreover, in order to safeguard outdoor areas against the deleterious effects of poorly coordinated large scale projects, or at least limit the damage caused by such projects, such areas should be designated for specific competing uses based on clearly defined policy priorities, through timely planning at the various planning levels. In cases where unconventional gas drilling that will have a land use impact is planned for a given area, state, regional and construction master plans should clearly identify areas where gas exploration is permitted and those where it is not. To this end, planning should be carried out at the state level.

Members of the panel in conversation with fellow experts who provided feedback on the study: Martin Sauter and Alan Krupnick (above), Fritz Frimmel and Hermann Dieter (center) and Ruth Hammerbacher, Alexander Roßnagel and Michael Reinhard.

Recommendations

These recommendations are predicated on the assumption that the exploitation of unconventional gas reservoirs is an altogether viable option in Germany. The issue as to whether this option is also politically viable and/or supported by our political leaders was not addressed here, as this was not part of our brief. Our recommendations are essentially conditional (if-then) propositions. In other words our recommendations are based on the following chain of logic: If unconventional natural gas reservoirs are exploited and if this is done using hydrofracking, then we recommend that the criteria and procedures described below be applied. Also, our recommendations are based on and take account of the extensive laws and regulations that are already on the books but that are not expressly mentioned here as they are givens. We also make reference to the detailed recommendations in the various reports comprising this study.

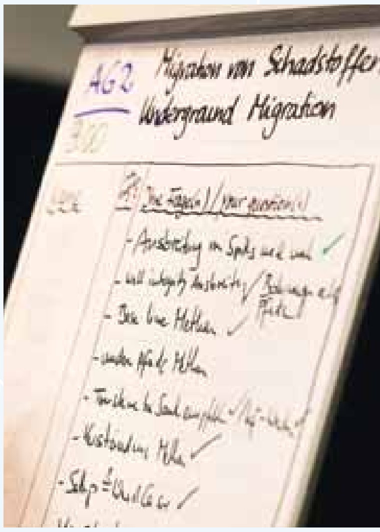
Recommendations

A new Risk Dimension

In many respects the risks associated with exploitation of unconventional natural gas reservoirs are comparable with those entailed by conventional gas exploitation – a domain where, as we see it, there is also room for improvement that would render exploration for and exploitation of both conventional and unconventional gas reservoirs safer for both the public and the environment from both a technological and management standpoint. Our recommendations apply to both shale gas and coal-bed methane reservoirs. We also looked at tight-gas reservoirs, which are a cross between conventional and unconventional reservoirs.

Hydrofracking entails the following new risk dimension that does not arise in connection with conventional gas production in Germany:

1. Relative to conventional gas reservoirs, most of Germany's unconventional gas reservoirs are located closer to the surface, closer to usable groundwater, and closer to ecosystems that depend for their survival on groundwater.
2. Exploiting unconventional gas reservoirs (a) entails the realization of numerous wells and hydrofracking operations; and (b) involves the following additional elements and risks relative to conventional gas production:
   - A greater amount of land is needed in any given region for production sites and technical infrastructure elements, which in turn means that more people and in particular agriculture, tourism, and nature conservation are directly affected in a given region.
   - Hydrofracking also requires the use of more trucks and pipelines, as well as greater numbers of chemical, wastewater and natural gas filling, cleaning and storage cycles; and this of course translates into a greater risk of accidents.
   - In Germany, we have no experience whatsoever with underground operations in gas fields entailing a large number of hydrofracking cycles in tight spaces.
   - A considerably greater amount of water is used owing to the high number of hydrofracking operations that need to be carried out.
   - The higher number of drilling operations entails greater energy use, and this of course enlarges the greenhouse-gas footprint of natural gas production.



Exclusion Hydrofracking in Selected Areas

Hydrofracking can entail considerable environmental risk, particularly when it comes to water resource conservation, which we strongly feel absolutely must take precedence over energy production. To this end, we strongly recommend that hydrofracking, as well as deep-injection disposal, be banned in the following types of areas:

> Areas characterized by critical underground tectonic stress or by severe tectonic upheavals.

> Areas that exhibit both pressurized artesian/confined deep groundwater and continuous transparent pathways (continuous and porous faults or hydrogeological features that have been severely affected by coal mining or the like).

> Zone I and II drinking water protection areas, as well as thermal spring conservation areas.

Take it Slowly and Tread Carefully

We see no objective reason why hydrofracking should be banned, for hydrofracking will constitute a manageable risk if the recommendations and procedures described in this report are followed. That said, in view of the new risk dimension entailed by hydrofracking we feel that it is best to proceed cautiously, one step at a time, so as to allow for careful testing and ensure that hydrofracking is not pursued in haste.

In order for hydrofracking to be used over broad areas, the following elements are necessary: a defined state of the art; a legal framework that addresses the new risk dimension entailed by hydrofracking; and additional scientific knowledge, particularly when it comes to methane emissions from underground which can greatly increase the greenhouse-gas footprint of unconventional gas reservoirs. Hence for the time being, all that should be made possible is exploration of gas fields and realization of single model projects, for which extensive safety precautions should be taken and the scope of investigations and testing should be expanded. Such undertakings should aim to (a) define and optimize the state of the art; (b) gain a greater understanding of the impact of hydrofracking on both surface and subsurface areas; and (c) set and test out a widely applicable and exemplary good-practice precedent in terms of involving the relevant stakeholders in the process and providing information concerning the risks entailed by hydrofracking. Such undertakings should unfold in tandem with (a) an extensive and in-depth dialogue with the German people, social groups, government officials, subject experts and policymakers; and (b) efforts to align statutory and planning instruments and application thereof with the new risk dimension entailed by fracking.

At the same time, scientists should set in motion far reaching and long term basic research aimed at gaining greater insight into the procedures and processes entailed by the use of unconventional energy resources.

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Model Projects: Demonstration and Exploration

1.
Two large scale model projects should be carried out, one for shale gas and the other for coal-bed methane, via a production site containing the number of wells that would be necessary for extensive hydrofracking. These projects would enable scientists to study in greater depth the potential impact of widespread use of hydrofracking, in light of the surface and sub-surface conditions at the relevant sites. As these projects will need to meet an extremely high environmental safety standard, it would not be possible to conduct above-ground activities in zone III drinking water protection areas. In these projects, the distance between the surface and the target gas reservoirs should exceed 1,000 meters, while the distance between the deep groundwater stratum and such reservoirs should exceed 600 meters. The most advanced technology available should be used in terms of chemicals, well design, well appurtenances, safety management (i.e. risk identification and assessment, emergency management) and wastewater disposal. The substance and toxicity data, as well as the underground transformation behavior of all chemicals used, are known. These model projects should be carried out in tandem with an extensive monitoring program that centers around the following:

> Monitoring the concentrations of specific substances in groundwater

> Geomechanics (hydrofracking crack propagation)

> The physical, chemical and biological conversion and transport processes that occur underground

> Material flow analyses concerning the following: methane emission levels; wastewater composition and volume; chemical and radioactive substance concentrations in deep groundwater; hydrofracking fluid concentrations; hydrofracking chemical degradation products

> Ensuring well and pipeline integrity.

2.
In the run-up to realization of these model projects, it is vital that extensive exploration be carried out, in particular so as to ensure that no high-risk areas are being used and that the requisite safety distances are maintained.

3.
In addition to these large-scale model production sites, specific existing or newly established model locations could be used to research specific types of operations and issues.

> Hence research should be carried out at a minimum of one model deep-injection disposal site.

> In addition, the nature of the drinking water risks entailed by hydrofracking should be studied in detail at existing production sites. This would also allow for the investigation of monitoring related issues, such as the following: What is the optimal tracer? How reliably and quickly can leaks be detected? What impact do remediation measures have on drinking water?

4.
In tandem with these measures, both of the large production sites should be used to study and assess the regional land-use impact of hydrofracking in light of various economic development scenarios.

5.
A site specific risk assessment should be carried out for the various model-project wells. This assessment should also address the issue of the minimum distance between hydrofracking sites and populated areas and other vulnerable entities, as this distance can range up to 1,000 meters depending on the types of hazards involved.

Social Dialogue with Stakeholder Groups; Regional Management

When demonstration and exploration activities are carried out, the relevant local groups and political figures should be invited to participate in the process in the interest of transparency and to ensure that concerned citizens' desire to keep the noise, traffic, bright lights and vibrations associated with hydrofracking to a minimum be addressed.

Moreover, the exploration and demonstration process realized at the model projects should be accompanied by regional discussion forums (e.g. one each for shale gas and coal-bed methane), that concern themselves with the following: avoiding uncontrolled spatial industrial development; the regional impact of hydrofracking on the economy, water use, wastewater disposal, and the protection of groundwater, thermal springs, and mineral water resources.

It is incumbent upon the model-project companies as well as the competent regulatory authorities to ensure that key information is provided during all participatory processes.

In addition, the monitoring process for the model projects should be designed, defined, accompanied and evaluated via a social dialogue on the following aspects of hydrofracking: seismic events; groundwater quality; methane emissions; flowback water; hydrofracking fluids; water resource management; chemical pathway analyses; gas well and gas pipeline integrity; and the structural integrity of buildings located in the environs of hydrofracking sites. The monitoring process should take account of both short term impacts and long term management.

In terms of the latter, gas companies, government authorities, and the relevant stakeholder groups should establish an arbitration panel modeled on the type used in Germany's coal mining industry that would be empowered to rule on disputes concerning environmental damage, property damage and other untoward effects of hydrofracking.

Further Development of the State of the Art

The entire body of technical regulations concerning handling substances that are hazardous to water; groundwater protection; hydrofracking chemical use; wastewater treatments and disposal; pipeline standards; well integrity standards; monitoring; and quality assurance should be strengthened and improved in consultation with the relevant actors so as to ensure that an advanced state of the art is defined for hydrofracking. This should include the following aspects:

- In view of the new risk dimension entailed by hydrofracking, existing safety management practices should be expanded, and insofar as necessary upgraded in such a way that an across the board culture of safety is established.
- The number of chemicals used for hydrofracking should be scaled back as far as possible, the chemicals currently in use should be replaced by substances less hazardous for the environment, and environmental hazard assessments should be strengthened by comprehensive knowledge on potential exotoxicological effects. Such studies should also take into account the environmental mechanisms of these substances in relation to specific exposure scenarios associated with wastewater and waste disposal.
- Advanced technological solutions that place greater emphasis on reuse and on treatment methods should be developed for flowback water management.
- New drilling methods should be introduced with the goal of reducing noise and land use (e.g. electrical generators; lower drilling sites and towers; housings; dismantling and renaturing drilling sites as soon as possible after the production phase ends; installing drilling site in bunker-like underground structures).
- Optimized pipe installation, cementing, and monitoring methods could potentially reduce the risk of well leakage and in particular improve safety over the long haul.

Strengthening and Improving Hydrofracking Regulations

1.
Strict adherence to the applicable regulations

> As already partially common in practice, hydrofracking and deep injection disposal should always be subject to the approval of water resource authorities.

> Before widespread use of hydrofracking is officially approved, areas where hydrofracking is allowed and those where it is not should be clearly designated based on a strategic Environmental Assessment, so as to allow the various approval procedures to unfold within this statutory land-use framework.

2.
Clarification of a key legal issue

> It should be determined whether section 120 of Germany's Federal Mining Act (Bundesberggesetz), which lightens the burden of proof for mining damage caused by subsidence by defining the specific circumstances under which such damage is deemed to have occurred, also applies to gas exploration and production.

3.
Introduction of new legal instruments

> A site specific risk assessment of above and below ground risks for a given project should be conducted for each approval procedure. This assessment should determine (a) whether the safety regulations for the model projects can be updated in light of (i) technological advances such as the advent of new chemicals; or (ii) local geological conditions such as continuous and fault-free salt or clay strata; and (b) whether such safety regulations need tightening in response to untoward circumstances that have come to light. A site specific Environmental Impact Assessment can be included in such risk assessments in cases where environmental data are needed that were not provided by the strategic Environmental Assessment.

> When the approval process gets underway, such site specific risk assessments should go hand in hand with the introduction of instruments that allow for preliminary positive overall assessments.

Research and Development

In the interest of furthering the aforementioned model gas exploration and production projects, further research should be conducted on the following issues:

> How can gas production be optimized in such a way that the extent of crack formation can also be reliably limited?

> How exactly do temperature and pressure interact with gas reservoir geochemical and biochemical processes when hydrofracking is carried out?

> Which microbiological and chemical conversion processes unfold during hydrofracking and which risks are entailed by such processes?

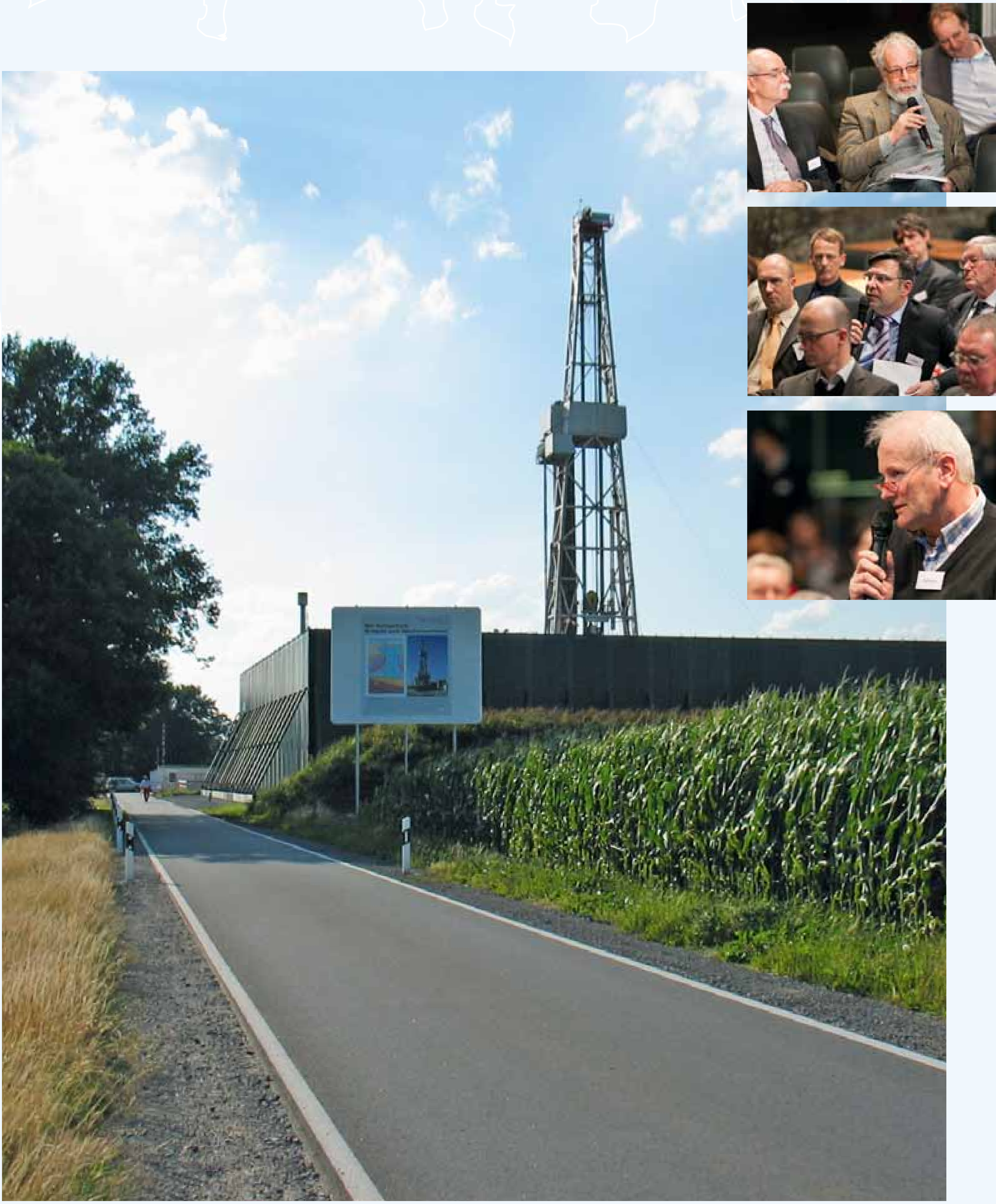
> What is the nature of the diffuse methane emissions induced by hydrofracking and how can they be measured and if necessary reduced?

Although we began the process of determining the greenhouse-gas footprint of hydrofracking, there are significant gaps in the data and thus this determination will need to be taken further using an optimized data pool so as to allow for the following:

> Elaboration of comprehensive regional above-ground and below-ground substance flow analyses concerning water use, chemical use and wastewater generation.

> Realization of a comprehensive analysis of the greenhouse-gas and energy footprints of unconventional gas reservoirs, so as to allow for a comparison with similar energy sources.

The recommendations above were elaborated by the following panel members: Dietrich Borchardt, Ulrich Ewers, Fritz Frimmel, Rainer Helmig, Alexander Roßnagel, Martin Sauter, Mechthild Schmitt-Jansen, Hans-Joachim Uth.



Executive Summaries of the Reports Issued by the Panel's various Working Groups

Risks in Geological Systems Working Group

Prof. Dr. Martin Sauter

Professor of Applied Geology, University of Göttingen

Prof. Dr. Rainer Helmig

Professor of Hydromechanics and Hydrosystem Modeling, University of Stuttgart

Estimated impact of hydrofracking on near-surface groundwater

This study investigated the possible hydrofracking-induced propagation of hydrofracking fluids and methane in deep underground areas resulting from cracks created artificially in gas strata by injecting fluid into them under high pressure, which in turn heightens system permeability and causes methane to escape. In cases where hydrofracking cracks extend beyond the gas strata and reach fault zones or groundwater aquifers, methane and hydrofracking fluid may be released into the atmosphere. Hence the scope of this transport process hinges on the operant geological properties.

For the study, the field data and measurement results from the Niedersächsisches Becken and Münsterländer Becken regions were evaluated, and from these data and results estimated effective hydraulic parameters for the various strata and fault zones were compiled. This was then used as a basis for defining seven different settings whose characteristics have a decisive impact on contaminant transport.

The fluid and methane transport calculations were based on a constellation of unfavorable conditions concerning the following:

> Propagation dynamics (advective transport processes only, to the exclusion of potential retention effects such as adsorption, matrix diffusion and substance breakdown).

> Leaky hydrofracking wells resulting from anomalies such as faulty joints between the cement and surrounding rock.

> The fact that it is common in some parts of the US to use ponds as wastewater storage facilities, whose wastewater can release the methane contained in it.

> Pipeline leaks and leaks that occur during the gas purification process that can provoke methane emissions.

> Underground fault zones that allow underground methane to rise to the surface.

It was anticipated that while the simulation results would be plausible from a physical and mechanical standpoint, they would constitute extremely unlikely outcomes and would indicate the most unfavorable upper and lower limits of the range of the possible results..

The following three contaminant transport scenarios were modeled.

1.
Contaminants being transported via fault zones toward usable aquifers, whereby the driving force here would be the pressure that is generated to allow for injection of the hydrofracking fluid into the rock. The gas reservoirs in the seven settings selected were incorporated into the simulation as limiting conditions. Various elevated pressures that were generated by the hydrofracking process at the boundary between the gas deposit and the rock above it (overlying rock) were used as limiting conditions during the hydrofracking phase; whereby "elevated pressure" here means pressure that is generated above and beyond the hydrostatic pressure and that ranged from 50 to 700 bar above the hydrostatic pressure depending on deposit depth. In the simulations, this pressure either acted directly on a fault zone or on the environs of the intact overlying rock. The assumption to the effect that the high pressure generated during the hydrofracking phase is located square on the boundary between the gas deposit and the overlying rock is extremely conservative, as it means that the cracks induced by hydrofracking will extend to the overlying rock. In addi-

tion, no pressure drop between the well and overlying rock (where the maximum pressure prevails) was posited, despite the fact that in reality such a pressure drop would be likely to occur. It was assumed that the maximum pressure would remain constant for two hours, although this would likewise be unlikely to occur. If hydrofracking fluid entered a fault zone, the pressure would drop in this zone and hydrofracking operations would come to a halt owing to the hydrofracking pressure drop provoked by the downward flow.

2.
Lateral transport of liquid contaminants to deep groundwater aquifers over a lengthy period, a process that would be driven by a possible hydraulic groundwater-aquifer gradient. Hydrofracking per se (pressure pulse) would come to an end. The simulation region was based on the hydrological catchment area of the Münsterländer Becken region, which is around 100 kilometers long and 2 kilometers deep and exhibits the Cenoman-Turon aquifer, which is transected by a thin mudstone stratum from the Upper Carboniferous. This scenario is predicated on the assumption that a minor amount of hydrofracking fluid had penetrated the Cenoman-Turon aquifer before the simulation began and was being mobilized horizontally by this aquifer. Its rate of flow is extremely low owing to the horizontal gradient exhibited by the Münsterländer Becken region, which contains little in the way of topographical features. Using selected fault zones located in the rock unit between the deposit and near-surface aquifer, we investigated the extent to which and under which conditions hydrofracking fluid can rise to the surface.

3.
Methane rises to the surface via fault zones by virtue of (a) the force resulting from the fact that gas is lighter than water; and (b) capillary force resulting from the differing hydraulic properties of the various strata in the overlying rock, causing the methane to propagate laterally. The parameters that determine the extent of this propagation include residual saturation, geological structures, and vertical pathways formed by clefts and faults in the overlying rock. The simulation, which was based on that used for the shale gas and tight gas sites in Lower Saxony, was run for a period of 100 years. Studies that investigate the relevant transport processes in this regard are few and far between and little in the way of data is available. In view of the substantial scientific uncertainty that prevails when it comes to defining the operant limiting conditions and the hydraulic properties of the various geological strata, the results of this simulation should be regarded solely as qualitative data that shed light on whether and under which conditions methane can migrate upward.

The findings of the present report allow for estimation of the minimum distances that come into play here. The minimum distance between horizontal hydrofracked wells and the aboveground surface was set at 1,000 meters, based on the following assumptions:

> Maximum vertical extension of hydrofracking cracks: 500 meters.

> Vertical substance transport will extend a maximum of 50 meters into the fault zone. Even in the absence of this assumption, to be on the safe side it was presumed that a hydrofracking crack will undergo two or more events such as nearby drilling that lengthen it and that no crack will be more than 200 meters long.

> Near-surface aquifers will be around 100 meters from the surface.

> An additional safety gap amounting to 200 meters.

Toxicology and Groundwater Working Group

Prof. Dr. Ulrich Ewers

Department of Environmental Medicine and Toxicology, Ruhr District Institute of Hygiene

Prof. Dr. Fritz Frimmel

Professor of Water Chemistry, Karlsruhe Institute of Technology (KIT)

Dr. Birgit Gordalla

German Technical and Scientific Association for Gas and Water (DVGW)

Assessment of hydrofracking fluid additives with respect to groundwater and drinking water from a human toxicology standpoint

This assessment was based on the fracking fluid formulas published by ExxonMobil, as well as on information that was made available to us concerning the composition of flowback water and formation water.

Virtually all hydrofracking chemicals are substances that are widely used in industrial, commercial and domestic domains; and to manufacture food and body care products. In their pure form, many of these chemicals are classified as hazardous substances under EU chemical law (Regulation (EC) No 1272/2008), but are so highly diluted in the hydrofracking fluids that they do not in fact qualify as hazardous substances under EU regulations. Most hydrofracking substances that have been classified fall into water hazard class 1 (slightly hazardous to water).

In order to estimate concentrations of hydrofracking chemicals in groundwater in the event of a borehole, pipeline or surface leak, it would be necessary to elaborate a model based on the actual circumstances that prevail on site. As these factors cannot all be predicted, it is sensible to work with generally applicable, non-site specific, assessments in this regard. Thus substance concentrations were evaluated that would occur in 1:1,000; 1:10,000 and 1:100,000 part dilutions in hydrofracking fluid. Our human toxicology assessment of the various hydrofracking fluids with respect to the groundwater was based – as far as possible – on the parametric values stipulated by Germany's Drinking Water Regulation (Trinkwasserverordnung), the WHO drinking water guideline values, and human toxicological guideline values. For substances that are not amenable to toxicological assessment, a health related indication value of 0.3 µg/l was used as an assessment yardstick, in accordance with the recommendations of the Federal Environmental Agency of Germany (Umweltbundesamt) and the German Drinking Water Commission (Trinkwasserkommission).

For most hydrofracking fluid additives, a dilution of 1:10,000 would yield a concentration that is lower than the aforementioned health-based limit and guideline values. For certain substances such as bromate and the biocide known as Kathon, dilutions of around 1:100,000 would be necessary. This also applies to benzene and mercury in formation water. The salt content of hydrofracking fluids amounting to an around 1:1,000 dilution is already at the level found in drinking water. The health related indication value for substances for which the relevant toxicological data are not available is so low that it is not exceeded in hydrofracking fluids with 1:100,000 dilutions.

Recent changes in hydrofracking fluid formulas indicate a tendency toward reduced numbers and quantities of the hydrofracking chemicals, as well as the use of substances with low toxicity to humans.

The composition of formation water is more problematic than that of hydrofracking fluid from the standpoint of both human toxicology and groundwater protection.

Toxicology and Groundwater Working Group

Dr. Mechthild Schmitt-Jansen

together with
PD Dr. Rolf Altenburger,
Department of Bioanalytical Ecotoxicology,
Helmholtz Centre for Environmental Research – UFZ

Ecotoxicological Impact of Hydrofracking Chemicals and Fluids

The aim of this study was to assess potential environmental hazards of chemical mixtures used during the fracking process. A tiered assessment strategy was applied based on available ecotoxicological knowledge for individual compounds composing selected fracking fluids.

In a first step, a database was created containing available ecotoxicological knowledge on the fracking fluid chemicals used in the past. In total 149 substances were considered in this database, derived from 18 hydrofracking fluids provided by ExxonMobil. After a critical revision of substance identity of the chemical components effect, concentrations for three biological models (fish, algae and Daphnia) were summarised in a database for 118 substances. Data were retrieved from the US EPA Ecotox database and the ESIS database. Obvious data gaps were amended by modelling the minimum toxicity (narcosis) using the ECOSAR software of the US EPA.

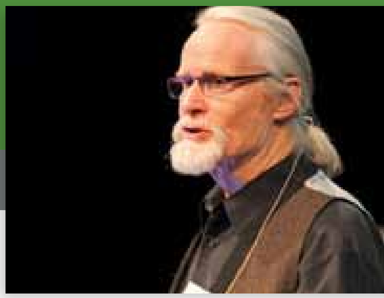
In a second step hazard quotients (HQ) were calculated for individual compounds. The HQ is defined as the ratio of an exposure estimate of a chemical in relation to an effect concentration. Environmental hazards are assumed to be most likely for HQs > 1. Initial concentrations of chemicals composing the fracking fluids were used as a "worst-case" exposure estimate, as no exposure scenarios were available. Effect concentrations retrieved in the above mentioned database were used for calculation of compound-specific HQ values. For 38 of the 118 chemical compounds a HQ > 1 was calculated. Especially 2-butoxyethanol (CAS no. 111-76-2), isopropanol (CAS no. 67-63-0) and methanol (CAS no. 67-56-1) frequently showed high hazard quotients.

In a third step a hazard index (HI) was calculated for each fracking fluid to consider compound mixtures. It is based on the assumption of concentration additive effects of chemical mixtures. The HI is the summation of all HQs of compounds composing a fracking fluid. All HI values for the 18 fracking fluids were above one, indicating substantial potential hazards deriving from the original hydrofracturing fluids. Therefore, a specific risk management for these fluids seem necessary.

Obvious data gaps became evident with regard to an unambiguous identity of the chemicals in use, the availability of effect data suitable for the assessment as well as suitable exposure estimates.

In conclusion the compound-based assessment strategy applied in this study seems to be suitable to identify potentially hazardous substances contained in hydrofracturing fluids by considering the intrinsic toxicity of individual compounds as well as the concentration in which they are used. A highly variable range of HI values, calculated for the different fluids, indicate substantial potential hazards of the fluids to the environment but also offers the perspective to optimize the hydraulic fracturing process according to environmental concerns.

Risks in Technical Systems Working Group



Incident Scenarios, Risk Management, and the State of the Art

Dr. Hans-Joachim Uth

Facility safety expert, former employee of the German EPA

This arm of the study assessed the risks that arise from the following in cases where (a) proper operational procedures are followed; or (b) such procedures are not followed and/or an accident occurs: the presence and use of above-ground technical equipment at drilling sites; transport of dangerous goods on road and in pipelines; gas-well design engineering.

This assessment was based on a worst-case scenario approach that allows for definition of the measures necessary to avoid accidents and limit their consequences, in accordance with the state of the art. The measures thus defined were then compared with realistic technical and organizational preventive measures for a typical installation, and the completeness and suitability of these measures were evaluated. The investigations were based on information and documentation that were provided by ExxonMobil Production Deutschland GmbH, as well as on the literature.

We began with emissions, explosions and fires involving the whole inventory of above-ground hazardous substances that are found at a drilling site, and then used this as a basis for developing scenarios entailing the use of increasingly lower amounts of hazardous substances based on the graded effectiveness of the technical and organizational measures that would normally be deployed. While the scenario elaboration process excluded any attempt to analyze the causes of the events under consideration, a central role was played by the measures aimed at forestalling these causal factors, such as traffic, environmental and installation related hazards, as well as actions by unauthorized persons. Simulations were run for eight main scenarios and 29 subsidiary scenarios, whose effects and probability of occurrence were then evaluated. The events that have the greatest impact on the population and environment are natural-gas (sour gas) blowouts, the entire stock of the diesel fuel stored at the drilling site catching fire, and emissions during the transport process of substantial amounts of substances that are hazardous to water. The state of the art and good management practice were defined for measures aimed at preventing drilling site incidents and limiting their effects, and were then compared with and assessed in light of standard practices. The lessons learned to date in the natural-gas industry were supplemented by an accident analysis. The said comparison then formed the basis for the formulation of recommendations aimed at improving protection of the population and environment.

While the realization of complex multi-layer well sealing systems can potentially give rise to irregularities and defects, they can be reliably detected by logging mechanisms and are readily amenable to repair. The industry's eight decades of experience with the long-term stability of cement shows that gas well cementing does not remain leak-proof indefinitely. This also means that abandoned and sealed wells need to be monitored so as to detect any gas or contaminant emissions early enough to take the necessary countermeasures.

Our main recommendation is that hydrofracking operations should be conducted in accordance with prevailing chemical industry standards, even if adherence to these requirements is not prescribed by law. This pertains to requirements concerning the following: the manner in which substances that are hazardous to water are handled; pipeline requirements for natural gas, backflow water and formation water transport; and instituting modern cultures of safety, including providing information concerning risks and the elaboration of risk management action plans. Recommendations were also made as regards well integrity testing, in view of the mission critical nature of this matter.

Risks in Technical Systems Working Group

Prof. Dr. Alexander Roßnagel

Institute of Commercial Law, University of Kassel

Role and Assessment of Environmental Regulations

This report addresses the issue as to what exactly government agencies do with and in response to risk assessment findings, and which actions lawmakers could potentially take in light of the various concerns and problems addressed here.

The goal here is not merely to manage the risks entailed by individual natural gas wells, but also to protect vulnerable areas and bring order to situations where a myriad of production sites are installed in a given area.

Under German law, groundwater at all depths is considered to be a protected resource except insofar as it can be established that groundwater will not commingle with managed water resources under realistic circumstances. In cases where this cannot be excluded, a water-use permit must be obtained for both hydrofracking and formation-water injection operations. The law states as follows concerning the latter: "In cases where liquids that were already underground are to be injected downward to the exclusion of any other liquids," wastewater may be discharged into groundwater "provided that the relevant conditions are defined." In the reverse case (e.g. after groundwater has been mixed with hydrofracking fluid) by law it must be ensured that the groundwater does not undergo any deleterious change. Water-use permits are issued by mining authorities, subject to the approval of water resource authorities.

According to German immission control law, the provisions of the Hazardous Incident Regulation (Störfallverordnung) do not apply as long as the relevant maximum values are not exceeded. Nonetheless, in the interest of preventing avoidable environmental damage using state of the art measures and minimizing unavoidable environmental damage, it may be necessary to apply certain safety related provisions of the said law. The principle of deterministic safety holds that safe conditions are deemed to have been achieved insofar as adequate safeguards can be instituted concerning specifically defined accidents (incident management), whose definition is based on plausibility considerations concerning possible events that constitute realistic incident scenarios. In other words, all protective measures must be taken that are necessary for incident management purposes.
It works to the detriment of risk assessments that an Environmental Impact Assessment is not carried out, and that the public is not involved in the assessment process. Owing to the various phases entailed by the relevant decision making processes, key risks are oftentimes not assessed until after a number of investments and positive decisions have been made.

A large gas field containing numerous production sites and the infrastructure needed for such sites will have a major impact on the relevant economic and residential structure, the landscape, and on nature conservation. Breaching the safeguards for protected areas should be allowed in exceptional cases only. Moreover, in the interest of safeguarding outdoor areas against the deleterious effects of uncoordinated large scale projects, or at least limiting the damage caused by such projects, areas where unconventional gas exploration is permitted or banned should be identified in state, regional and construction master plans.

Additional Reports

State of the Art of and Advanced Approaches to Flowback Water Disposal

Prof. Dr. K.-H. Rosenwinkel

Institute for Urban Water Management and Waste Technology, University of Hanover

This report discusses the environmental load arising from storage, transport, and disposal of wastewater and waste generated by drilling deep natural gas wells for unconventional reservoirs, including hydrofracking. In a first step, the relevant characterizations and calculations were carried out concerning the hydrofracking fluids used and the wastewater generated by hydrofracking. These findings then formed the basis for recommendations concerning water resource management, handling, recycling, and disposal.

The substance flow simulations that form the basis for this report were conducted for three representative drilling sites in northern Germany. In addition, data from the literature and other observations, mainly from US studies, were evaluated. These elements are only applicable to Germany in settings characterized by similar types of rock, reservoirs, and hydrofracking solutions, and insofar as German standards are met in such settings.

Inasmuch as it emerged from this preliminary phase of the study that no detailed and viable substance flow analyses or differentiated chemical analyses are available for flowback water during and shortly after hydrofracking operations, it is difficult to identify formation water and hydrofracking fluid in flowback water and to clearly classify all flowback water residues.

The substances comprising flowback water and formation water fall into the following categories: hydrocarbons; metals and salts; dissolved and undissolved substances; and highly volatile substances. We recommend that the relevant regional chemical analyses be described and documented in detail in a manner that takes account of land-use and timeline factors and that focuses in particular on the relevance of salt load, as well as the characteristics over the long term of all substance flows in the area under study.

While neither a generally applicable standard nor state of the art methods have yet been established for flowback water management, methods have been defined for certain domains, requirements and measures such as rainwater management and hazardous substance transport and storage. In this report, we describe the minimum general requirements for operations such as wastewater discharge into municipal sewers, as well as for the various relevant procedures. However, we were only able to supply specific information concerning flowback water use for a limited number of settings.

While deep injection of wastewater, which is subject to government approval, is the standard disposal method in Germany, other wastewater management methods are available that are determined by flowback water salt content and geological conditions, as well as by local conditions such as the water balance and the extent to which waterways are available. The practicality, feasibility and economic viability of the existing methods, as well those described in this report, need further study, and can only be reliably assessed if more precise analyses and investigations are carried out. This also applies to the management of radioactive formation water, which should only be deep-injected using suitable methods and in a manner that allows for possible recycling and regional substance management that takes account of the relevant risks and environmental factors – which are particularly important when it comes to protecting water and soil resources.

A master concept needs to be developed for the exploitation of unconventional natural gas reservoirs. This concept should in particular take into account the land use and timeline aspects of all gas fields on a region by region basis, so as to allow for elaboration of state of the art wastewater treatment, recycling, disposal, and deep injection methods. In our view, the implementation phase for all such methods should go hand in hand with across the board documentation of all substance flows, as well as robust monitoring.

Additional Reports

Dipl.-Ing. Helmut Schneble

Umweltplanung Bullermann Schneble GmbH, Darmstadt

Landscape, Land Use and Noise Pollution

This study investigated the above-ground impact of hydrofracking on the landscape and protected landscape elements.

This study mainly focused on the following cause and effect relationships concerning protected elements, and in particular on drilling sites with a relatively high number of wells (10 to 20).

Protected elements	Sources of impact; possible damage (for specific locations)
People	Noise emissions (traffic; drilling and hydrofracking operations; exhaust emissions; light emissions), impact on recreational areas
Soil	Land use/paving (drilling sites and accesses thereto); loss of natural soil mechanisms; impact on recreational and agricultural areas (agricultural and forestry use)
Water	Storage and disposal of surface water from paved areas
Air and climate quality	Exhaust emissions from diesel generators
Landscape	In particular: landscape appearance; loss of landscape diversity, uniqueness and beauty owing to the erection of drilling rigs
Animal and plant biodiversity	Land use; biotope loss; indirect effects such as the effects of segmentation, noise, light, and movement
Cultural assets	Possible damage to cultural assets and archaeological monuments owing to land use

The report discusses conflict avoidance and minimization measures, as well as compensatory nature-conservation measures, and points out the lack of knowledge in this domain. The animations and 3D models that were elaborated to exhibit the possible cause and effect relationships and damage that come into play here focus in particular on interventions in the landscape.

The report's land use analysis describes ExxonMobil's current gas exploration areas and estimates the total amount of land use that the build-out concept would involve. The report describes and discusses the land use criteria that should be particularly taken into account for gas production site selection; these criteria were also characterized and studied in connection with two selected exploration areas.
The study shows that the above-ground impact of one or more sites on the protected landscape elements and the like would be environmentally sustainable if suitable sites are selected, suitable methods are used, and suitable minimization measures are carried out.
As extensive gas production in an exploration area comprising more than 100 square kilometers would require numerous production sites, the effects on the landscape and on landscape related environmental factors would not revolve around individual production sites, but would instead involve the overall territorial and time related context entailed by gas production in a large exploration area. In view of the overlapping protection and usage exigencies that come into play here, we recommend that a structured land-use related development plan be elaborated for unconventional gas exploration and production.

Additional Reports

Uwe Fritsche

Department of Energy and Climate Protection, Institute for Applied Ecology (until 03.2012), International Institute for Sustainability Analysis and Strategy (IINAS)

Energy Balance and Global Warming Footprint of Unconventional Natural Gas Relative to other Energy Sources

This report addresses the issue as to how gas production at unconventional reservoirs of the type planned by ExxonMobil in North Rhine-Westphalia and Lower Saxony stacks up against other energy sources in terms of its energy, global warming and air pollution footprint and the pollution pathways as a whole.

Using the data gathered concerning typical hydrofracking situations as a basis, a range of post-production shale gas scenarios was elaborated in terms of drilling depth and diffuse methane emissions, whereby the latter were modeled for a 100 year period and were determined in light of the amount of gas obtained from hydrofracking and the amount of electricity generated using this gas.

Range	Lower Limit	Upper Limit
Drilling depth	1,000 meters	2,500 meters
Post-drilling methane emissions	0 %	23 %

The relevant process chains and the various exploratory, operational, and disposal phases were then extrapolated from these findings and were differentiated on a year by year basis for the 2010–2030 period.

The energy and greenhouse gas footprints were then determined for the gas production process, as well as for gas provisioning, including processing, and conveyance to the gas grid, and the amount of gas needed for electricity generation in a new gas fired CCGT power plant was determined.

The core data for gas production from German and Russian gas reserves in 2010 and 2030 were then determined in order to provide a point of comparison.

As with unconventional natural gas, these GEMIS-based calculations also factored in the energy and greenhouse gas footprint of gas provisioning, including processing, and conveyance to and within the gas grid, and the amount of gas needed for electricity generation in a new gas fired CCGT power plant was determined.

Carbon dioxide and methane (carbon equivalent) were the main factors used for the greenhouse gas analysis, which revealed that the difference between conventional and unconventional gas is mainly attributable to the energy used for drilling, particularly at depths of 2,500 meters. This disadvantage will be reduced when the industry switches to drills that run on renewable electricity. The author factored our simulation findings into his calculations of post-production methane emissions – although it should be noted that our figures are of a provisional nature.
Liquefied natural gas (LNG) from Algeria and renewable gas (from biomass and wind turbines) were also included for the run-up to 2030. Calculations were realized for following additional environmental elements:

> Acidifying air pollutants (SO2 equivalents, SO2, NOx)

> Non-renewable primary energy consumption

> Land use

In addition, the study data were reviewed by outside experts.

The Reports at a Glance

Risks in Geological Systems Working Group

> **Hydrogeological settings and substance transport**

> *Prof. Dr. Martin Sauter*, University of Göttingen (with Karolin Brosig, Torsten Lange and Wiebke Jahnke)

> **Modeling underground mining processes**

> *Prof. Dr. Rainer Helmig*, University of Stuttgart (with Alexander Kissinger and Anozie Ebigbo)

Toxicology and Groundwater Working Group

> **Assessment of hydrofracking fluid additives with respect to groundwater and drinking water from a human toxicology standpoint**

> *Prof. Dr. Ulrich Ewers*, Ruhr District Institute of Hygiene
Prof. Dr. Fritz Frimmel, Karlsruhe Institute of Technology – KIT (with Dr. Birgit Gordalla)

> **Assessment of the ecotoxicity of hydrofracking fluid components**

> *Dr. Mechthild Schmitt-Jansen and PD Dr. Rolf Altenburger*, Helmholtz Centre for Environmental Research – UFZ (with Stefan Scholz)

Risks in Technical Systems Working Group

> **Incident scenarios, risk management and the state of the art**

> *Dr. Hans-Joachim Uth*, facility safety expert

> **Role and assessment of environmental regulations**

> *Prof. Dr. Alexander Roßnagel*, University of Kassel (with Dr. Anja Hentschel and Andreas Polzer)

Additional Reports

> **State of the art and advanced approaches to flowback water disposal**

> *Prof. Dr. Karl-Heinz Rosenwinkel*, University of Hanover (with Dr. Dirk Weichgrebe and Oliver Olsson)

> Landscape, land use and noise pollution

> *Helmut Schneble*, Umweltplanung Bullermann Schneble GmbH (with Katja Weinem)

> **Energy balance and global warming footprint**

> *Uwe Fritsche*, Institute for Applied Ecology (with Dr. Werner Zittel and Dr. Nils Jungbluth)

> **Preliminary study on the regional economic impact of hydrofracking**

> *Prof. Dr. Kilian Bizer*, University of Göttingen (with Christoph Boßmeyer)

Outside Experts

> **Geological records concerning the Münsterländer Becken and Niedersächsisches Becken regions; monitoring; environmental cleanup**
>
> > *Ingenieurbüro Heitfeld-Schetelig* (with Dr. Michael Heitfeld, Dr. Johannes Klünker and Prof. Dr. Schetelig)

> **Seismic hazards associated with gas drilling in northern Germany**
>
> > *Prof. Dr. Manfred Joswig*, University of Stuttgart

> **Well casing and cementing**
>
> > *Prof. Dr. Frank Schilling*, KIT Karlsruhe (with Dr. Birgit Müller)

> **Substance related regulatory aspects of hydrofracking**
>
> > *Prof. Dr. Martin Führ*, Darmstadt University of Applied Sciences (with Stefanie Merenyi)

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> *Prof. Dr. Michael Reinhardt*, Institute of German and European Water Management Law, University of Trier

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Photo credits:

Diameter of the first steel pipe
that is rammed into the ground: 50.8 cm

Cement layer no. 1

Owing to the many issues that have been raised in Germany concerning the safety and environmental impact of hydrofracking, in early 2011 ExxonMobil decided to launch an unusual project whereby the company provided a team of outside experts with the resources necessary to conduct a study of the risks entailed by hydrofracking.

The results of this study show that fears that toxic substances will flow upwards into usable groundwater are unjustified, provided that specific underground related requirements are adhered to. However, leaks and accidents in wells and during the transport and storage of fluids containing hazardous substances are a very real possibility, and fears of such events are justified in view of the number of wells that are routinely drilled for hydrofracking operations.

If hydrofracking is carried out despite these various risks, the bar needs to be set very high in terms of the following: safety technology and instituting a culture of safety; monitoring hydrofracking operations; and emergency cleanup measures in the event of an accident.

Hydrofracking poses a serious problem not only to groundwater resources, but also in other areas. For if harmful components of natural gas that is mobilized underground make it past the well and rise to the surface, this will deepen the greenhouse-gas footprint of natural gas. Moreover, the many drilling sites entailed by hydrofracking should be subject to an overarching planning process and master plan aimed at preventing the landscape from being turned into an industrial zone.

We see no particular reason to ban hydrofracking. In view of the fact that knowledge gaps are endemic in this domain, we recommend that a small number of hydrofracking projects be approved on a case by case basis and that they be scrupulously monitored by rigorous application of the scientific method.

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Second steel pipe

Cement layer no. 2

Third steel pipe

Cement layer no. 3

Fourth steel pipe (11.4 cm in diameter)

Informations- & Dialogprozess

der ExxonMobil über die Sicherheit und Umweltverträglichkeit der Fracking-Technologie für die Erdgasgewinnung