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The Role of Hydraulic Fracturing for the Supply of Subsurface Energy

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1 Introduction

Until a decade ago gas liquefaction plants were built in several regions of the world to supply the U.S. market with liquefied natural gas. The boom was sourced by the prediction of an increasing gap between the demand and the supply of natural gas, resulting from a predicted steady decline in domestic production. Things have changed. In 2015 the U.S.A. will start to export natural gas. An oversupply of natural gas has caused prices to fall, leading increasingly to a re-industrialization of the country and can even be recognized in the CO_2 emission of the country, which has significantly decreased in the last years.

Key to this development is the technology of hydraulic stimulation, also known as fracking or hydraulic fracturing. The technology is in use since the 40s of the last century. In the combination of horizontal drilling and multi-fracking the technology has evolved into a tool allowing the development of even shale gas deposits, in rocks so tight, that the concrete pavements of the highways look like kitchen sieves. In the combination of horizontal drilling and multiple fracking the technology is applicable in principle also for the development of geothermal resources in the deep subsurface, the potential of which is many times larger than the potential of the unconventional oil and gas deposits, at least theoretically.

2 Hydraulic Fracturing

Hydraulic fracturing refers to the process of the generation and propagation of fractures in a rock formation by pumping a liquid under high pressure into this formation. The high pressure liquid enters the formation through holes perforated into the cemented steel pipes, which protect and seal the wellbore, at the level of this formation. Pressure medium (frac-fluid) is in general water. Depending on the application, the water is mixed with proppants to keep the generated fractures open, for example quartz sand, as well as other substances as additives (Emmermann 2014, Reinicke 2012).

In conventional sandstone reservoirs, the treatment usually results in the formation of a two-wing vertical fracture. The entity, which looks much like a butterfly, has a half-length of less than 100 to approximately 300 m in modern applications (Reinicke 2012). As a result of the layering of the geologic subsurface, the fractures are typically longer than higher, because individual sedi-

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mentary layers, like for example clay layers, act as «barrier formations», which impede the growth of fissures in the vertical direction (Fig. 1).

The growth of the fractures is influenced by the geo-mechanical and hydro-mechanical properties of the geologic layers, the stresses acting in these layers, the injected fluid volume, the fluid properties and the pressure at which the fluid is injected. Within these dependencies the extension of the fractures is predictable, in particular their orientation, their geometry and their effect on well productivity, if the properties of the subsurface and the treatment parameters are known (Economides & Martin 2007).

The objective of a hydraulic treatment is the generation of highly conductive flow paths for the transport of fluids (liquids and/or gases) in an otherwise low permeable rock. To have this effect, the generated fractures must remain open. To prevent them from closing and healing, when the pumps stop and the fractures start to close under the influence of the acting rock stresses, proppants are introduced into the fractures, for example sand.

Pure water is not able to carry sand and transport it into the created fractures. To achieve carrying capacity, the water is thickened or gelled by adding viscosifiers (Fig. 2). To clean the created channels, the gels have to be broken subsequent to the treatment, which is why breakers are added. Other additives serve to reduce frictional losses when pumping the viscosified fluid, to avoid the introduction of biological substances into the subsurface, to prevent corrosion, and to stabilize the target formation by, for example, clay stabilizers, etc.

In total, today all additives make up approx. 1% (0.2–3%) of the frac-fluid volume (Fig. 2). The rest is water and proppants. Today's recipes result in mixtures, classified as weakly water contaminating, which means they are in the same category as liquid manure. The classification according to the German *Gefahrstoffverordnung* (hazardous substances ordinance) is not toxic and not hazardous to the environment. Work is under way to further reduce the environmental impact, for example by UV irradiation instead of using biocides (Kassner 2014).

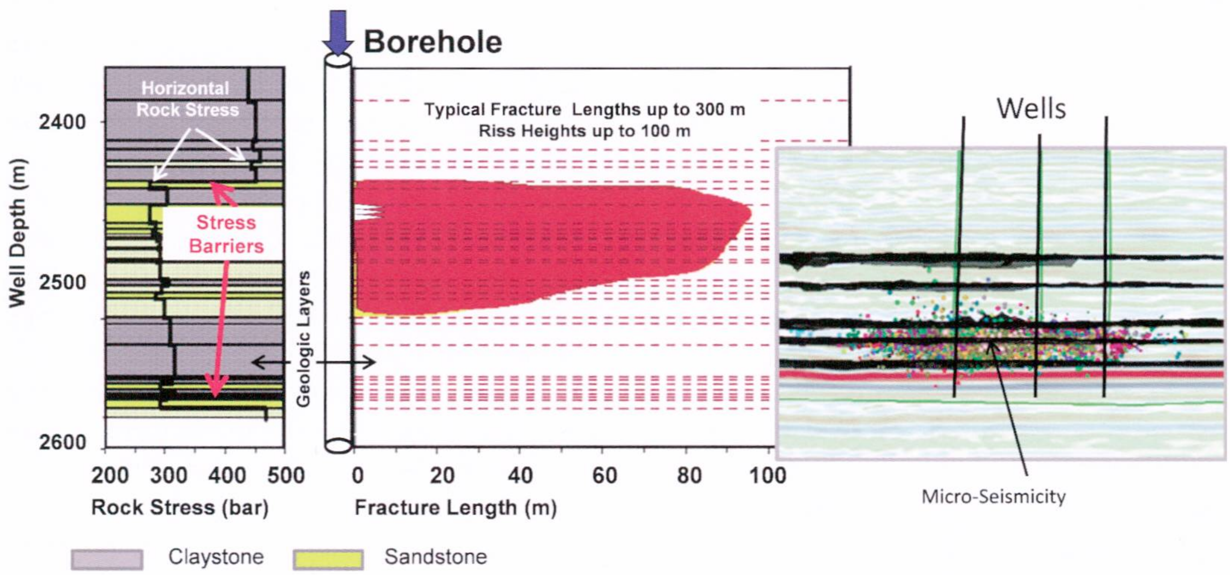

Fig. 1: Fracture propagation in a reservoir: left prognosis, right measurement. The prognosis of fracture propagation is made with recognized methods and commercially available simulators based on the knowledge of the geo- and hydro-mechanical properties of the subsurface and its stress distribution. The measurement is made by monitoring the micro-seismicity associated with the fracture extension (right).

In unconventional (shale and coal bed) reservoirs and geothermal (hot dry rock) reservoirs the process of fracture generation is usually more complex. The reservoir rock often contains natural fissures and fractures. Often the rock is subject to shear stresses like the basement rock in the Upper Rhine valley for example. Both have an influence on the fracture system.

If the reservoir rock contains fissures and fractures, the fracture treatment does usually not result in a two wing fracture system, but in more complex tree-like structures, which follow the zones of weakness in the rock, i.e. the naturally occurring fissures. Under these conditions the injected frac-fluid is distributed over more fractures, which reduces the dimensions of the fracture system. If shear stresses are present und if they are sufficiently high, lateral displacements along the rough fracture surfaces may result. If the rock is sufficiently hard, flow channels remain after fracture closure even without the introduction of proppants, because the fracture faces do no longer fit perfectly into each other. These so-called water fracs are the treatment of choice for petro-thermal energy recovery. The treatments cost less and they are of lower environmental impact, because the frac-fluids require less additives or none at all.

3 Fracking Targets

The targets of hydraulic treatments are at great depths, far below the geologic horizons, which are used or may be used for the withdrawal of drinking water. The water quality does generally not improve with depth. In Northern Germany it is brackish already at depths below 50–400 m. The water contained in the rocks at large depths is heavily loaded with salts and may in addition – albeit at low concentrations – contain heavy metals and naturally occurring radioactive materials. In Northern Germany salt loading of the deep brines is mostly up to saturation. With 200–300 g/l the salt concentration is far above that of our noodle water with 1 tea spoon/l or 8–10 g/l and it is almost a factor of 10 higher than the salt concentration of sea water (35 g/l) (Burri & Häring 2014).

For the only treated well in an unconventional shale reservoir in Germany, treatment depths were lager than 1.200 m. The potable water horizons at the location of the well reached down to approx. 40 m with thick barrier formations from clay between the potable water horizons and the frac horizon. The depth range typically assumed for the exploitable unconventional hydrocarbon deposits in Germany starts at approx. 1.000 m. Shale gas developments shallower than 1.000 m are unlikely, because commercial rates require

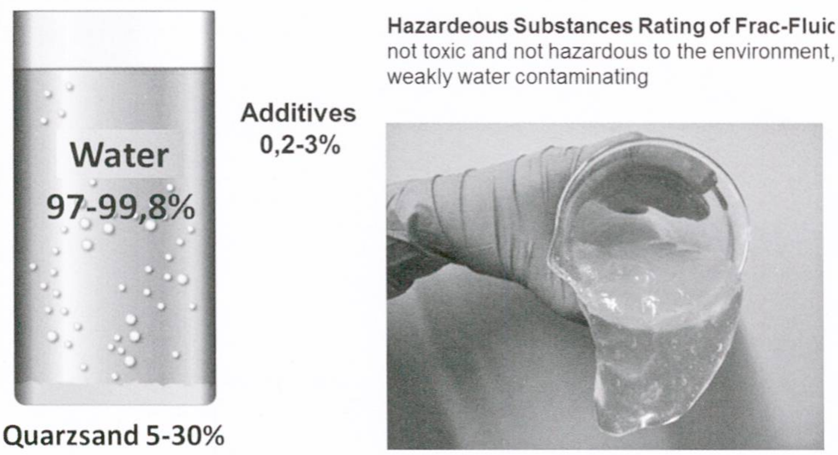

Fig. 2: Frac-fluids.

high reservoir pressures which are not found at the shallower depths, which is also the experience in the U.S.A.

The targets in conventional reservoirs are typically found at depths greater than 3.000 m. Geothermal targets are even deeper, because the desired water temperature of 150 °C or more requires depths of approx. 4.000–5.000 m under average central European conditions. The fracking targets in these reservoirs are overlain not only by clay layers but usually also by several impermeable salt layers, which may reach thicknesses of several 100 m.

4 Fracture Height Growth

According to the myth distributed by the fracking opponents in the internet, the fractures reach from great depths up to the drinking water horizons and create wide flow paths for gas and frac-fluids (Fig. 3, left). For the above described depth ranges and the usual frac-fluid volumes this is physically impossible. The physical balance laws, according to which generated fracture volume can at best be as large as the fluid volume used for its generation, are also valid in the geologic subsurface. In general, the volume will be even smaller, because fluid leaks into the formation as it is fractured and is no longer available for the creation of fracture volume.

The limits to vertical growth are supported by the mapping of real fracture growth data in thousands of fracturing treatments in the U.S.A. by monitoring the micro-seismicity associated with the propagation of fractures in shale gas deposits. Result is, that vertical growth of created fractures is in the order of hundreds of meters at the most with more than 1.000 m of sediments separating the top of the fractures from the drinking water horizons (Fisher & Warpinski 2012) (Fig. 3, right).

5 Methane Emissions

Also, the often implied significant emissions of methane into the atmosphere by natural gas wells and facilities do not represent reality, at least not where best practice is applied like in Europe. According to the German *Umweltbundesamt* (Federal Environmental Agency) and the *Wirtschaftsverband Erdgas und Erdölgewinnung* (Oil and Gas Producers Association), 53% of the total methane emission in 2012 originated from agricultural sources (UBA 2014a). Only approx. 3% came from energy industry sources with a contribution of the natural gas production of less than 0.1% (WEG 2012). If high standards are applied for the construction and maintenance of natural gas facilities – which can be assumed for the gas

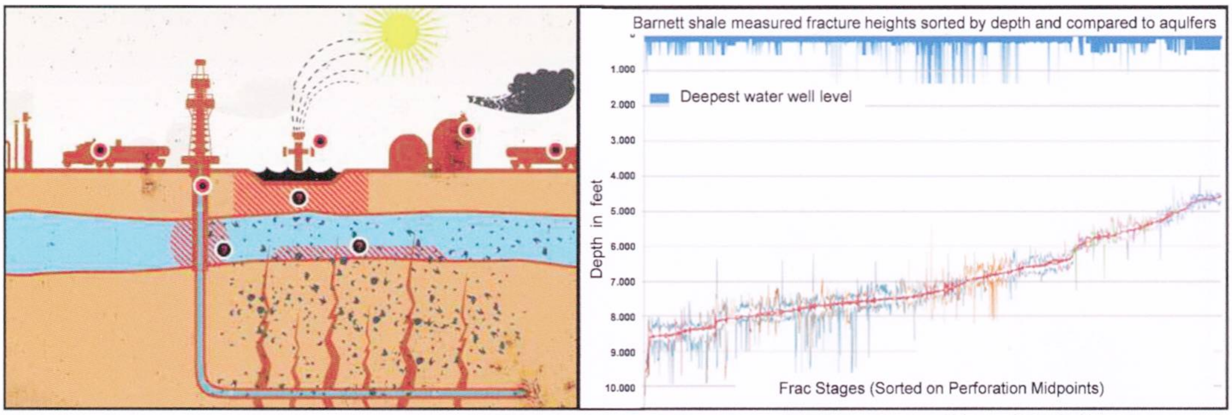

Fig. 3: Fracture vertical growth: Myth and Reality.

operations in Western Europa – methane emissions are not an issue. Climate improvements and avoidance of air pollutions like those for example in China require the substitution of e.g. coal by natural gas.

6 Effect of Hydraulic Treatments

Regardless of the type of fracture system, which is generated in the course of a fracture treatment, it will change the flow pattern in the rock. The reservoir content no longer flows radially to the well bore, to squeeze into a bore of approx. 20 cm diameter, but more or less linear to the significantly larger fracture system, to then flow within this system to the wellbore. For a two-wing system this system has an extension which is mostly a thousand times wider than the wellbore. In a way, the effect resembles that of a highway across a city during the rush hour traffic. It attracts traffic and enables a significantly faster influx and efflux to the central business area(s).

The influence of a hydraulic treatment on the productivity of a well is significant. It is not unusual, that the initial production rate increases by a factor of 5-10 and more to stabilize after an initial strong decline at a significantly higher level than the original flow rate. In the example of a North German gas well, the initial rate could be increased after two hydraulic treatments by a factor of seven (Reinicke et al. 1983) (Fig. 4).
The well shown is still producing today after more than 35 years. The example illustrates not only the influence of hydraulic fracturing treatments on the productivity of a well and its development, it documents also that hydraulic fracturing treatments are nothing new even in Central-Europe. The sample well was fracked in 1977 and is part of a major campaign, during which a significant number of gas wells were subjected to major fracturing treatments, so-called MHF treatment, during the end of the 70s/beginning of the 80s. To now suggest, that the technology is something new is not correct. It is in use since the end of the forties and has in the

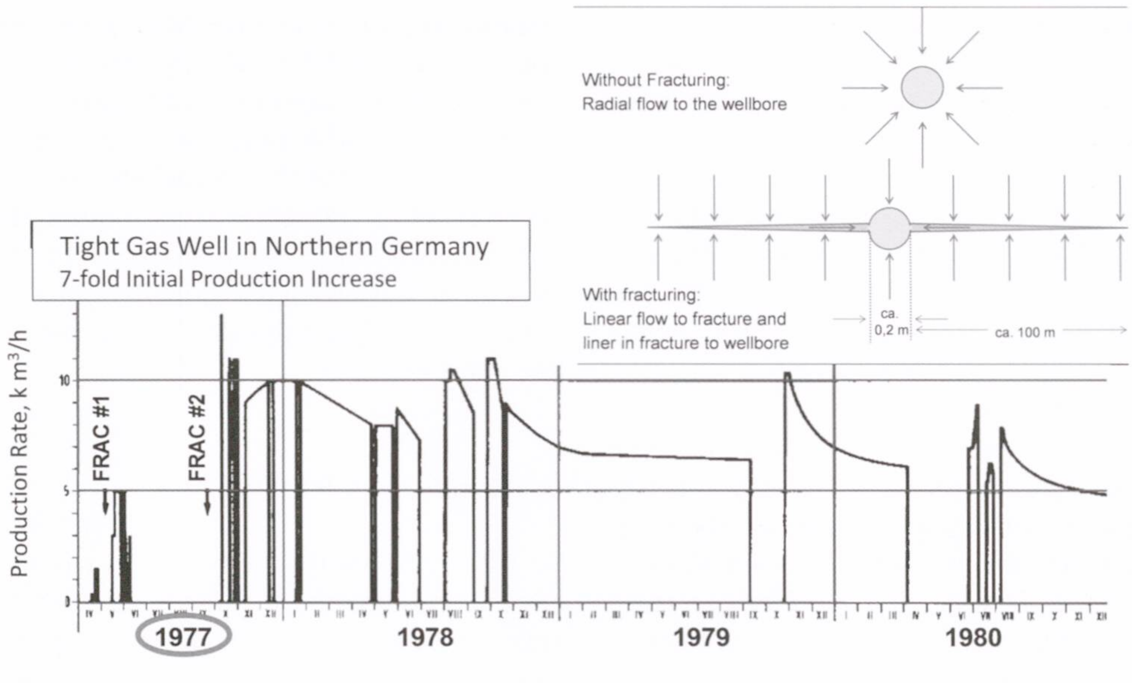

Fig. 4: Effect of a hydraulic fracturing treatment on flow pattern and well productivity (in 1.000 m³/h).

meantime been used worldwide approx. 3 Million times. In Germany approx. 400 fracturing treatments have been carried out since the 60s without any measurable impairment of the environment ever reported.

7 Hydraulic Fracturing and Energy Supply

The influence, which fracking can have on a national economy is represented using the U.S.A. as an example. The U.S.A. has had its peak natural gas production from conventional deposits in the early 70s. The development of tight gas resources with the aid of fracking, starting in the 70s, has reduced the decline of domestic natural gas production to reverse the trend in the 90s. With the development of the shale gas deposits since the second half of the last decade, the U.S.A. have seen a rapid increase in production to a level, which is today already higher than the peak production in the 70s. From a dependent importer, the technology of hydraulic fracturing has enabled the U.S.A. to become an exporter of natural gas. Liquefied natural gas originally developed for the U.S.A in the Middle East and West Africa is now shipped to the Far East and Europe.

The development in Germany is completely different. Here domestic production has decreased since 2003 from more than 20 Billion m^3 (10^9 m^3) to less than half in 2013. The trend will continue, if the government maintains its «no» to the development of the German shale gas resources. The consequence is the increasing burning of coal.

In North-America the natural gas surplus has led to a significant reduction in the price of natural gas. Prices have declined from 6 to more than 10 \$/Mscf (thousand standard cubic feet [gas]) to actually 3-4 \$/Mscf or approx. 0.9 Euro-cents/kWh. This is a third to a half of the price in Europe and a forth to a fifth of the price in the Far East.

The supply of secure and low-priced hydrocarbons fuels an industrial job machine. Investments in the U.S.A. are rising. In the chemical industry for example the additional investments up to 2014 are estimated to amount to more than \$ 100 Billion and this in particular by companies headquartered outside the U.S.A. The additional industry production expected from this investment is estimated to be more than \$ 80 Billion, the jobs created exceed 600.000.

Because of the low gas prices, recent developments focus increasingly on wet gas and light oil in the unconventional deposits with impacts for the oil production similar to those for natural gas. The trend of decreasing oil production has been halted. Since 2007, domestic oil production in the U.S.A. is increasing again and was 50% higher in 2013 than in 2007. Production matches for the first time for a long time again the oil imports. In the first half of 2014, the U.S.A were even the largest oil producer worldwide.

The effect of the American shale gas revolution can also be recognized in the development of CO_2 emissions of the country. Since 2005, CO_2 emissions of the U.S.A. have decreased by approx. 600-700 million tons, mainly through substitution of coal in power generation by gas. The decrease represents approx. 70% of the total CO_2 emissions in Germany, which are increasing again since three years – also because of the use of coal – and it is 15 times the annual emissions of Switzerland. It should be kept in mind, that the emission of CO_2 is only one part of the environmental problems. Equally important are pollutants like sulphur, CO, and particulate matters.

8 Is Fracking Needed?

To meet the energy demand provides an increasing challenge. During the last ten years the demand of primary energy has increased by 28%. Key drivers of this development are the ever increasing world population, the increasing prosperity in particu-

lar in the developing countries, and economic growth (Reinicke et al. 2014). As long as there is no change in these drivers, energy demand will further increase. To meet it requires a broad mix in energy. The further development of renewables should be encouraged and supported under all circumstances. But even if this is continued successfully, the world will remain dependent on fossil energy sources for many decades, possibly the whole century, in particular if nuclear energy is no longer an option.
A closer look at the development of the contribution of the individual energy sources shows, that renewables have grown by more than 300% (without hydraulic power) in the last 10 years (BP 2014). This growth nevertheless covers only 7.5% of the total growth in energy demand during this period and contributes today only 2.2% of the worldwide primary energy consumption. Including hydraulic power, the renewables contribute almost 9% to the total consumption. Approx. 86% of the primary energy consumption is still covered by fossil sources with a strongly increasing share of coal. Despite the increase in the contribution from renewable sources, the relative contribution of the fossil energies has remained almost constant compared to 10 years ago, when fossil contribution was 87%. In absolute volumes, the yearly consumption of fossil energies is significantly higher today than it was 10 years ago.
The renewable energies should be encouraged, in particular geothermal energy, but despite the rapid growth of wind, solar energy, etc. the world is far from covering even the global growth in energy consumption, let alone to substitute fossil energies by renewables. If large quantities of fossil energies are needed also in the future, consideration should be given to using the cleanest of these energy forms.

9 Chances and Potential of Fracking

The resources of the subsurface, which can be developed through wells are crude oil and natural gas in conventional and unconventional reservoirs as well as hydro-thermal and petro-thermal energy.
In this context the term conventional reservoir denotes a deposit in a storage rock. In this rock the hydrocarbons are captured by buoyancy forces below an impermeable barrier formation. For the capture, the barrier formation must form a trap, for example a bulge similar to a cheese dome. The trapped hydrocarbons have not been generated in the storage rock, they have migrated to it from a source rock. The permeabilities of storage rocks are usually high enough to allow a development and exploitation by use of classical drilling and production techniques. Under favorable conditions up to 90% and more of the gas in place is recoverable. If the permeabilities are low, as in the case of Tight Gas reservoirs for example, hydraulic fracturing may be used to improve the productivity of the wells, which is done since the middle of the last century.
Unconventional reservoirs are defined as deposits in source rock with oil and gas, which has not yet left the place where it was generated. Pre-requisite for the existence of a deposit is solely a mature source rock, for example a shale, with a sufficiently high content of organic matter, which has been transformed under the influence of pressure and temperature into oil and gas. Because of the low permeabilities of source rocks, which are of similar magnitude as those of barrier formations, a significant amount of the hydrocarbons stays behind in the source rock. It was only in the last ten years, that geologists have discovered that this is often the bigger portion of the generated oil and gas.
To be able to economically utilize unconventional deposits in source rocks with pore throats in the order of nano-meters (1 nm = 1/1.000.000 mm) the use of elaborate hori-

zontal drilling and multi-frac technology is an absolute necessity. By using these technologies it is possible to recover gas volumes in the one digit percentage range up to approx. 20% of the in-place volumes in the subsurface. Despite this low fraction, the incentive for a development of these deposits is large, because other than the «discrete» accumulations of conventional reservoirs, unconventional deposits occur basin-wide with in-place volumes which are enormous.

According to estimates of the U.S. Energy Administration Agency (EIA 2011) and the *Bundesanstalt für Geowissenschaften und Rohstoffe* (BGR 2012) (Fig. 5), the economically recoverable shale gas resources in Europe amount to 10.000–15.000 Billion m^3. This is 40 times the current production and 30 times the current consumption in Europe and not much less than that what is estimated for the U.S.A. (15.500 Billion m^3). The U.S.A. is no geologic exception. There are significant unconventional resources worldwide.

The world is neither at the end of the oil or the gas age – as predicted by the Club of Rome – nor is there a steep decline of oil and gas production imminent, as propagated by the Peak Oil organization. For both prognoses, previous knowledge of the past has been extrapolated. Over longer time spans, this has never been reliable.

The geologic subsurface does not only contain hydrocarbons, it also contains geothermal energy. To use it economically for the generation of electric power high temperatures (> 150 °C) and high volume production (several 10 to > 100 l/s) are required. High temperatures require great depths. In great depths, however, rocks are highly compacted and thus have low permeabilities. The solution is to create permeabilities artificially by hydraulic fracturing.

The theoretical supply potential of hydro- and petro-thermal energy is large and would be able to make a significant contribution to cover the demand, even then when only a fraction of it would be developed. According to estimates published in Ganz et al. (2013),

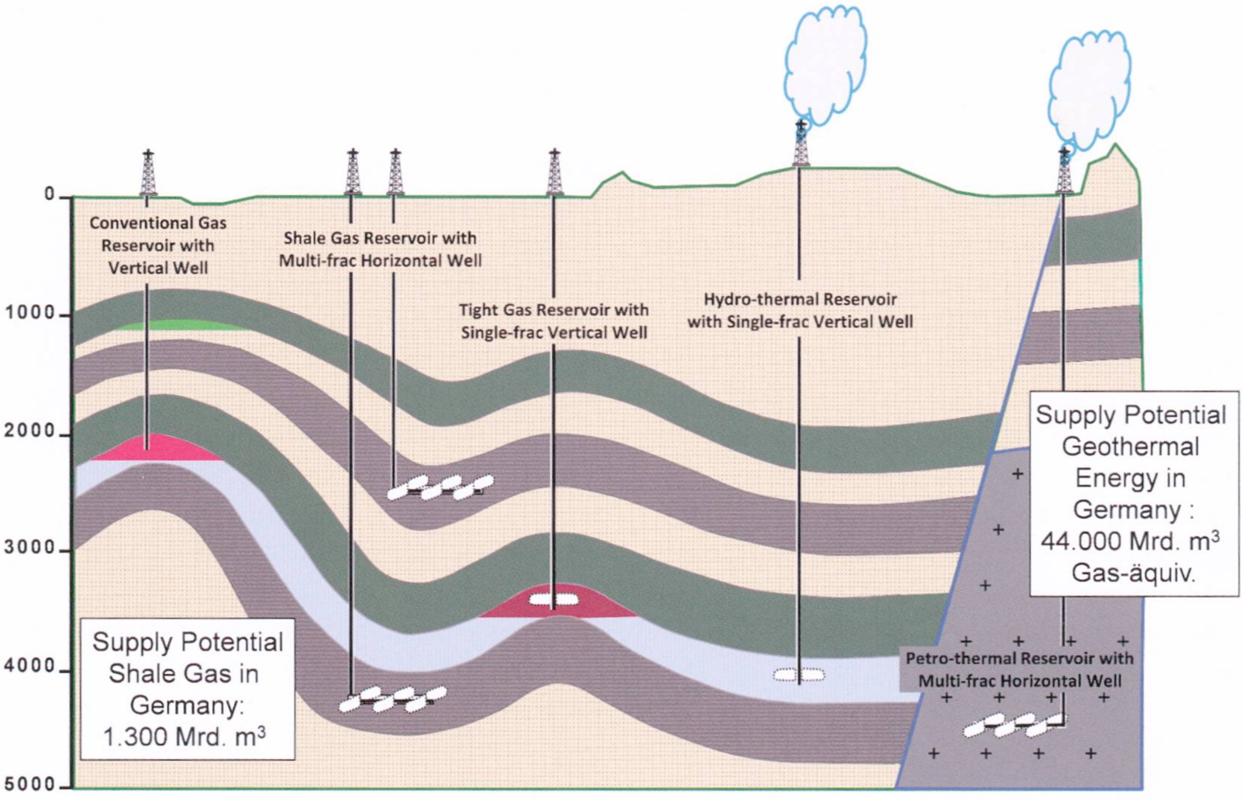

Fig. 5: Potential for energy recovery through wells according to BGR (2012) and Ganz et al. (2013).

the geothermal supply potential for Germany alone amounts to 1.700 EJ or expressed in natural gas equivalents approx. 44.000 Billion m^3 (Fig. 5), in comparison to a shale gas potential for all of Western Europe of approx. 10.000–15.000 Billion m^3. The question is not, is this potential there? The question is, how much of it can be realized technically and in particular economically?

According to the quoted reference, the largest potential is that in crystalline rock, which amounts to 1.150 EJ of so-called petro-thermal energy, i.e. energy which is stored in the rock itself. To develop this potential in the «hot dry rocks» requires the use of the fracking technology. Aside from a few conductive fault zones there is no chance for an economic development without this technology. The deep underground is tight. Its conductivity must at first be generated.

For the generation of this conductivity one can use high-volume fracs as in Basel, Soultz, or Hannover, which is not without seismic risks in tectonically stressed regions. One can also start with proven oil field technology and adapt it for use in geothermal applications, for example the multilateral horizontal drilling technology coupled with the multi-frac technology – already applied to develop shale gas – to construct an Enhanced Geothermal System (EGS) with many small heat exchangers in the hot dry rock (Fig. 6). With such a system, the seismic risk could be greatly reduced, such that tremors of a magnitude as observed in Basel could be avoided. It was one of the essential findings of the frac in Basel, that the magnitude of possible seismic events increases with the volume of the injected fluid and hence with the size of the fracture surface, which has been created. The injected volume in Basel was 11.500 m^3. In a system of several much smaller multi-fracs the injection volumes would be in the order of 1.000 m^3 per frac or less, which would be injected without proppants and therefore also largely without chemical additives.

It is worthy of note that the noticeable seismicity observed so far in the context of hydraulic treatments was limited to injections of high volumes of fluids in deep horizons in or close to the basement, where they led to the release of existing shear stresses (in Basel for sure, likely also in St. Gallen and in Landau, also for the water disposal-

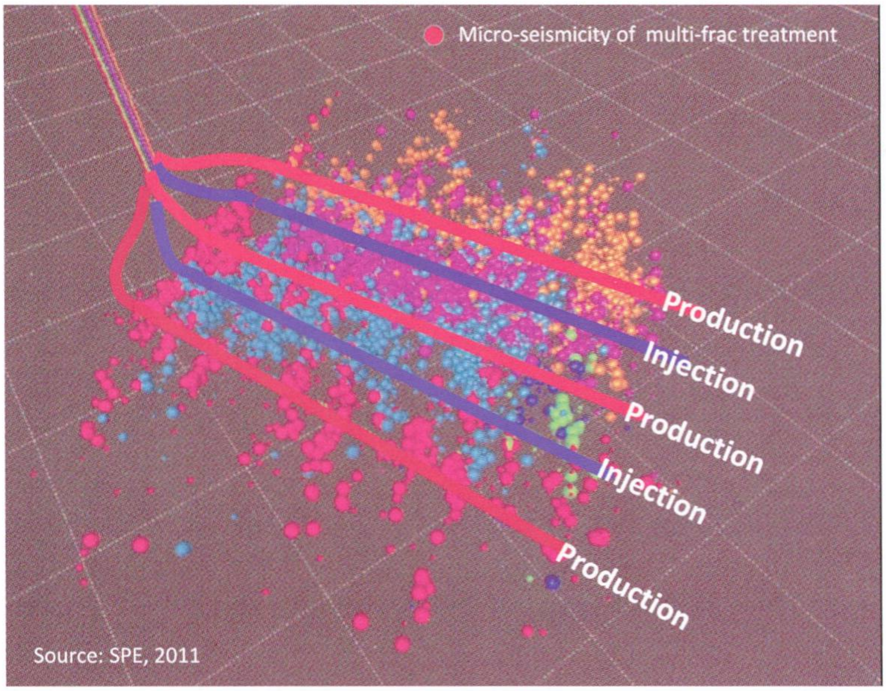

Fig. 6: Possible multi-frac heat exchanger system for the recovery of petro-thermal energy using a shale gas well with five horizontal laterals, fracked 10 times each.

induced tremors in Oklahoma). Contrary to this, no damaging tremors have so far been reported for fracturing treatments in sediments. Noticeable seismicity (up to a magnitude of 2.5) induced by fracturing treatments in shale formations was recorded near Blackpool (2012), which, however, stayed significantly below damage levels (Emmermann 2014).

Granted, it is still a long way until a functioning multi-heat-exchanger system based on multi-fracturing technology can be implemented on a large scale, let alone optimizations thereof. The target horizons are deeper and harder, the necessary wells are more expensive, and the operation of heat exchanger systems is significantly more difficult than draining a hydrocarbon bearing reservoir. But the potential is large and offers a lot of incentives.

In summary, the potential for the recovery of geothermal energy is large and offers chances for implementing a secure and low emission energy supply. However, it requires the use of horizontal drilling and multi-fracturing technology. An economic implementation will likely be possible only when larger numbers of geothermal wells are drilled in a «factory style» process to feed sizeable geothermal power plants. As a first step on the way to this, it is necessary to prove viable technical concepts for a petrothermal recovery in pilot projects now.

10 Fracking Risks and Possibilities of Risk Management

Like everything in life also the fracking technology is not free of risks. It is the subject of very controversial discussions, which one can read about almost daily. The discussions are dominated by gut feelings and gut reactions. This is true not only for Germany, this is the case internationally. In discussions facts are in most cases of only minor or no importance. The results of reputable investigations, the efforts of industry, and the evident progress in best practice to manage risks and make the technology environmentally compatible have hardly found their way into the public debate until recently.

With due respect for the concerns raised in the context of the use of the fracking technology, they are often based on images, not representative for the real operations and they do not take into account the measures already implemented to manage risks. The burning water tap in the movie *Gasland* has nothing to do with the production of natural gas and nothing at all with fracking. Also the term «poison cocktail» regularly used to denote frac-fluids, does not represent reality (see also Fig. 2).

The following definitions of the terms risk and environment are the basis of the subsequent elaborations regarding risks and measures to manage risks. Risk is defined as the product of probability that an adverse event occurs multiplied by the severity if the event happens. Environment is defined as the totality of the resources humans-animals-plants, soil, (potable) water, landscape, climate, and cultural assets as well as all interactions.

Of largest concern is quite rightly the preservation of the potable water resources. It is therefore in the focus of the subsequent elaborations. Potential pathways for pollutants to potable water horizons are: substance input from the surface, substance ascent along wells, substance ascent and dispersal through the overburden. Decisive for the severity of a possible event is the damage potential of the contaminants, in particular those contained in the frac-fluids (Fig. 7).

Against this background, there are the following approaches to reduce the probability of an event from occurring and their severity if it occurs. The probability of a water damaging event can be reduced by (1) operations sites and practices on these sites, which prevent inputs from the surface, (2) wells, proven to be tight, (3) a geologic subsurface, proven to contain barrier forma-

tions, and (4) a fracture propagation which does not impair the effectiveness of the overlaying barrier formation. To reduce the severity of a possible damage it is necessary (a) to reduce the damage potential of the substances used (not hazardous to water – no risk), (b) to be able to detect incidents and react immediately, and (c) to provide for unplanned events (Reinicke 2014).

For improved risk management the companies organized in the *Wirtschaftsverband Erdöl- und Erdgasgewinnung* (oil and gas producers association) in Hannover have identified, analyzed, and evaluated the risks associated with hydraulic fracturing and jointly developed «best operational practices» (WEG 2014), and commissioned frac-fluids of improved environmental compatibility. The practices are a voluntary commitment of the industry in addition to the statutory and official requirements, documented in Germany in the *Bundes-Berggesetz* (federal mining law), the *Tiefbohrverordnungen* (deep drilling ordinance) of the *States of Germany* as well as the relevant specialist legal requirement like for example the Water Resources Act. With these practices and requirements there are clear rules in place for the execution of hydraulic fracturing treatments, which ensure, that existing risks are accounted for.

The execution of a wellbore treatment, for example, requires a mining authorization, which can be granted by the mining authorities only to organizations, which have the required technical qualification and the financial resources. The execution of activities requires authorization within the framework of the *Betriebsplanverfahren* (mining operations plan procedure). The admission of the operations plans requires evidence that no damaging effects can be expected, in particular whether the requirements of the Water Resources Act are fulfilled and whether relevant public interests like emmission prevention, soil protection, regional planning, and nature conservation according to the relevant specialist legal requirements have been accounted for.

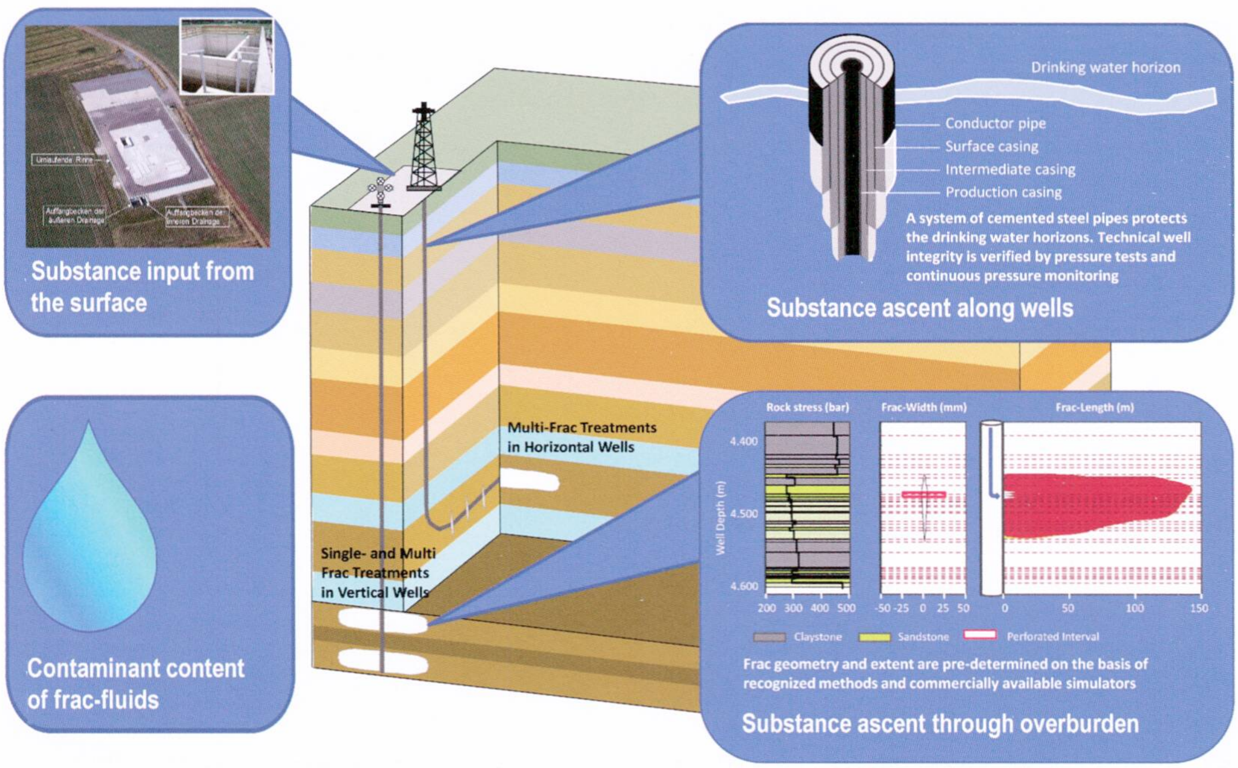

Fig. 7: Potential pathways to potable water horizons and risk management.

Whether the existing rules and regulation require modification to even better account for the risks associated with hydraulic fracturing is currently being debated in Germany. In this context an environmental impact assessment for hydraulic treatments is under discussion, addressing in particular the subsurface risks of fracturing in a structured and transparent evaluation process. An environmental impact assessment, which will break new grounds, will come. Its content, procedures, and evaluation criteria are currently being agreed with all stakeholders.

Even now there are no scientific reasons to ban hydraulic fracturing as documented in German and Europe-wide expertises (Emmermann 2014, UBA 2014b, Neutraler Expertenkreis 2012, NRW 2012, UBA 2012). The way forward should therefore be to create the preconditions for scientifically supported demonstration projects executed under special requirements for the recovery of unconventional hydrocarbons and geothermal energy. Such projects would allow proving the technical and environmentally compatible viability of hydraulic fracturing in shale and hot dry rock, improving the technology, further developing standards, rules, and regulations, and earning trust by transparent information of the public. This applies both to the recovery of shale gas and to deep geothermal energy as well.

11 Summary

The development of unconventional natural gas and deep geothermal energy is only possible by employing the technologies of hydraulic fracturing and horizontal drilling. Experience over many decades has shown that the risks associated with hydraulic fracturing can be managed. For the thousands of frac-jobs carried out in Northwest Europe no environmental damages have been reported, in particular in Germany, The Netherlands, the United Kingdom and Norway.

The companies organized in the German *Wirtschaftsverband Erdöl- und Erdgasgewinnung* (oil and gas producers association) in Hannover have identified, analyzed, and evaluated the risks associated with hydraulic fracturing and have defined additional measures like frac-fluids that are environmentally compatible. The agreed best operational practices represent the minimum standard of the German oil and gas industry for carrying out hydraulic fracturing treatments.

An environmentally compatible use of the technology on the basis of these practices and in compliance with existing laws and regulations is already possible today. The technology is therefore of no greater risk than any other industrial activity.

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