An IENE Research Note

INSTITUTE OF ENERGY FOR SOUTH-EAST EUROPE

A REVIEW OF HYDRAULIC FRACTURING

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1. Fracking

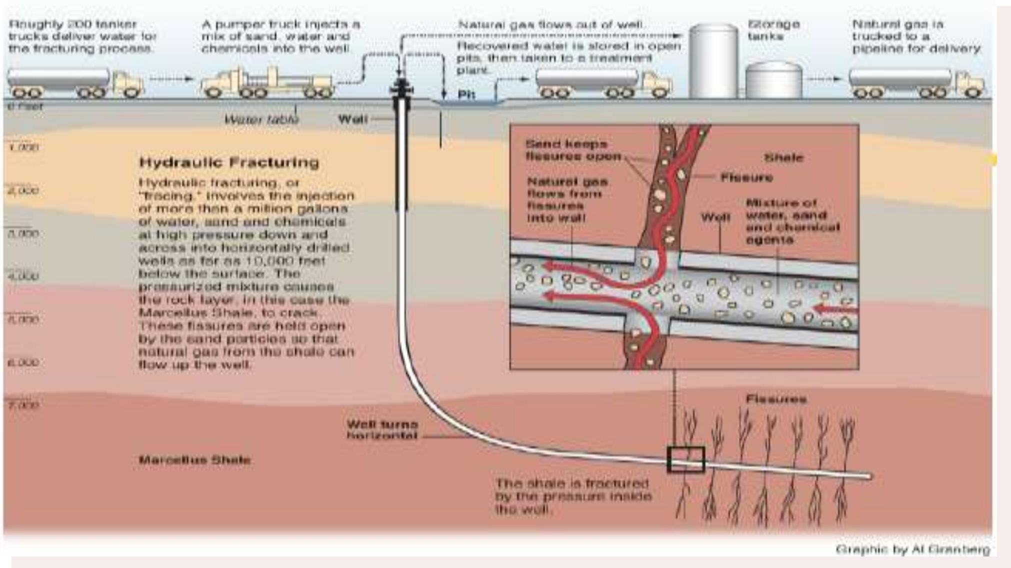
Hydraulic fracturing or ‘fracking’ or ‘fracing’, is a well-stimulation process used to maximize the extraction of underground resources -- including oil, natural gas, geothermal energy, and even water. The oil and gas industry is recently using hydraulic fracturing to enhance subsurface fracture systems so that oil or natural gas move more freely from the rock pores to production wells that bring the oil or gas to the surface. Over the last few years shale gas has become a viable energy source thanks to hydraulic fracturing technology which is used to extract it.

Fracturing can be traced to the 1860s, when liquid [and later, solidified] nitroglycerin [NG] was used to stimulate shallow, hard rock wells in Pennsylvania, New York, Kentucky, and West Virginia. Although extremely hazardous, and often used illegally, NG was spectacularly successful for oil well “shooting.” The object of shooting a well was to break up, or rubblize, the oil-bearing formation to increase both initial flow and ultimate recovery of oil. This same fracturing principle was soon applied with equal effectiveness to water and gas wells.

The first experimental treatment to “Hydrafrac” a well for stimulation was performed in the Hugoton gas field in Grant County, Kansas, in 1947 by Stanolind Oil. George Mitchell then developed the formula for fracking with water and sand twenty years ago. The modern fracking technique that made the extraction of shale gas economical was first used in 1997 in the Barnett Shale in Texas, thanks also to horizontal drilling, a further revolutionary step developed by Devon, the company that had bought out George Mitchell.

The entire process of hydraulic fracturing is shown in the below diagram and begins with building the necessary site infrastructure including well construction. Production wells may be drilled in the vertical direction only or paired with horizontal or directional sections. Vertical well sections may be drilled hundreds to thousands of feet below the land surface and lateral sections may extend 1000 to 6000 feet away from the well.

Hydraulic Fracturing Schematics. *Source: IEA*



Once wells are connected to processing facilities, the main production phase can begin. During production, wells will produce hydrocarbons and waste streams, which have to be managed. But the well site itself is now less visible: a ‘Christmas tree’ of valves, typically one metre high, is placed on top of the well, with production being piped to processing facilities that usually serve several wells; the rest of the well site can be reclaimed. In some cases, the operator may decide to repeat the hydraulic fracturing procedure at later times in the life of the producing well, a procedure called re-fracturing.

Fluids, commonly made up of water and chemical additives, are pumped into a geologic formation at high pressure during hydraulic fracturing. When the pressure exceeds the rock strength, the fluids open or enlarge fractures that can extend several hundred feet away from the well. After the fractures are created, a propping agent is pumped into the fractures to keep them from closing when the pumping pressure is released. After fracturing is completed, the internal pressure of the geologic formation cause the injected fracturing fluids to rise to the surface where they may be stored in tanks or pits prior to disposal or recycling. Recovered fracturing fluids are referred to as flowback. Disposal options for flowback include discharge into surface water or underground injection.

In some cases, it may also be necessary to use hydraulic fracturing to increase the permeability of the coal seam in order to stimulate the release of water and gas. This is normally practised only in deeper wells, typically at several hundred metres below the ground. The decision to proceed with hydraulic fracturing needs to be made before drilling begins, as the well and surface facilities need to be designed accordingly. The approach is similar to that described above, but in contrast to current practice with shale gas and tight gas wells, fracturing for coalbed methane production is frequently a single-stage process, *i.e.* one fracturing job per well, rather than multi-stage. Since wells are often drilled in batches, the water required for hydraulic fracturing can be sourced from neighbouring wells that are being de-watered. The flow-back fluids recovered from the well are pumped to lined containment pits or tanks for treatment or offsite disposal.

Natural Gas Liquids [NGLs] are the raw, associated gases and liquids that come up along with oil and natural gas from the well. NGLs are very important-vital even-now for regular, dry gas [methane] producers, as they are separated and sold as more expensive products like ethane, propane, butane and condensate.

Water use: In the case of a shale gas or tight gas development, though some water is required during the drilling phase, the largest volumes of water are used during the hydraulic fracturing process: each well might need anything between a few thousand and 20 000 cubic metres [between 1 million and 5 million gallons]. Efficient use of water during fracturing is essential and the industry stands to benefit from a cost/benefit analysis and a Water Life Cycle analysis of such operations.

2. Proppants. Frac sands

As was already explained above, the fracking process requires a mixture of water, chemicals and a 'proppant' [usually sand] to be pumped into a well at extremely high pressures to fracture rock and allow natural gas to escape. In the early 1990s Mitchell Energy used fracking [water only] to 'link' the pore spaces to ease flow. The problem was that, when pumps stopped, new pore spaces closed up. The solution envisaged was to add sand to fracking fluid, with the sand to be carried into the fractures. This way, the water pressure drops, but sand particles prop open fractures; this technique was perfected by 1999 and the term '*proppants*' is now used for these small compression-resistant particles.

These are natural eg. silica sand, or synthetic or 'ceramic' eg. sintered bauxite, kaolin, alumina, or resin-coated.

The major frac sand property is conductivity of 'proppant pack' that has a direct effect on deliverability of fluids to the wellbore. The American Petroleum Institute [API] sets frac sand specifications. The primary considerations are the physical aspects of the sand. The API recommends specifications on size, sphericity, roundness, crush resistance and mineralogy. Solubility and turbidity are also required, but a high silica sand is generally insoluble. High silica content sand, sphericity, roundness and crush resistance are the key factors in seeking a good frac sand.

3. Techniques in hydraulic fracturing

Guar gum: Guar is a plant grown mainly in northern India, where its seeds are harvested and then developed into a gummy substance that long has been an ingredient in a host of foods, cosmetics, drugs, explosives, fire retardant and paper. The big bump in demand now, however, stems from guar gum's role in the shale boom. It is a key component in the mix of sand, water and chemicals used in hydraulic fracturing. Halliburton, the world's largest provider of hydraulic fracturing services, says prices for some varieties of guar gum have surged more than 800 percent since January 2011.

Slickwater fracking: Many fracking programmes are now pursuing 'slickwater' treatments that forego guar gum, and use a much thinner liquid to transport the proppant. However, in using low-viscosity slickwater fluids, these typically require small-diameter, low-density proppants, the technique now known for being so cheap, yet so controversial. Slickwater fracks involve adding chemicals known as "friction reducers" to water to allow for more efficient gas extraction. According to Halliburton and Forest Oil Corp, slickwater fracks allow fluid to be pumped down the well-bore as fast as 100 barrels per minute. Without using slickwater the top speed of pumping is around 60 bbl/min. It also enables extraction in highly pressurized, deeper shales.

PermStimSM fracturing service: To meet the needs created by an increase in North America fracturing and the emerging international market, Halliburton has developed a new fracturing fluid system that simply out-performs guar-based systems. PermStimSM fracturing service has been developed to replace guar-based fracturing fluid systems by providing a cleaner, more robust system that will result in more cost-effective treatments and improved well performance. PermStim™ fluid is based on a derivatized natural polymer that does not contain insoluble residue. The PermStim fluid technology is applicable across a wide temperature range of 100°F (38°C) to 275°F (135°C). It can be used at higher temperatures when cool down effects are considered. The fluid system is said to provide important benefits: improved well cleanup, enhanced proppant pack permeability, controllable viscosity, excellent proppant transport, salt tolerance, instant and delayed cross-linking systems.

Ceramic Proppants: Ceramic proppant manufacturers, such as Carbo Ceramics, are reminding the market that lightweight ceramics have similar or lower densities than sand. This eases placement in the fracture but provides significantly higher flow capacity than similar sizes of sand, including resin-coated grades. Certainly, ceramic proppants are widely acknowledged to have greater strength and thermal stability, to have more uniform size and shape, and to yield higher conductivity than frac sand. No doubt this trend is being picked up by Chinese ceramic proppant suppliers which are already penetrating the US fracking market with calcined bauxite grades. Carbo Ceramics has taken the decision to stop construction of the resin-coated frac sand section of its Marshfield plant until market conditions improve because they claim that the market is oversupplied with resin-coating of all forms and fashions, it's oversupplied on sand and there's an oversupply of Chinese IDC [Intermediate Density Ceramic proppant. Sand prices declined over the quarter, Carbo said, due to pressure from low natural gas prices, oil price volatility as well as the Chinese IDC.

LPG: LPG is a waterless, propane-based form of fracking**.** LPG uses a mixture of propane [and occasionally some butane] that's pressurized to the consistency of a gel. Then, like water-based fracking, it's injected through pipes at high pressure underground to release oil and gas by cracking open rocks using sand [or another proppant]. Unlike water, though, LPG naturally mixes with petroleum, so it returns to the surface with the oil or gas being extracted. And since LPG is electrically neutral and lacks much friction, it doesn't dissolve any salts, heavy metals or radioactive compounds — compared to water, in which these things return to the surface and make a typically toxic mixture even more so. LPG fracking eliminates an entire wastestream — the copious amounts of toxic 'flowback' water that has to be reused, treated and discharged into waterways, or disposed of in deep injection wells, which have been linked to earthquakes.

4. Shale gas/Shale oil

As discussed, the main application of fracking is in shale oil and shale gas. Shale is a fine-grained sedimentary rock that forms from the compaction of silt and clay-size mineral particles that we commonly call 'mud'. This composition places shale in a category of sedimentary rocks known as 'mudstones'. Shale is distinguished from other mudstones because it is fissile and laminated. 'Laminated' means that the rock is made up of many thin layers. 'Fissile' means that the rock readily splits into thin pieces along the laminations.

Shale is a rock composed mainly of clay-size mineral grains. These tiny grains are usually clay minerals such as illite, kaolinite and smectite. Shale usually contain other clay-size mineral particles such as quartz, chert and feldspar. Other constituents might include organic particles, carbonate minerals, iron oxide minerals, sulfide minerals and heavy mineral grains. These ‘other constituents’ in the rock are often determined by the shale's environment of deposition and often determine the color of the rock.

On shale oil

Shale oil consists of hydrocarbons being trapped in the pores of the source rock. The oil itself is still in a premature status, called kerogen. To transform kerogen into oil it needs to be heated up to 450 °C. Therefore, the production of shale oil rather compares to conventional mining of shales, followed by the heat treatment. Its early uses trace back more than 100 years.

Shale oil is oil that was generated naturally in source rocks but never migrated out of them. It should not be confused with ‘oil shale’, a source rock in which oil has not yet been generated, but that is capable of generating oil if artificially heated.

On shale gas

Shale gas is a natural gas produced from shale. It belongs to unconventional sources of natural gas, beside other unconventional sources including coalbed methane, tight sandstones, and methane hydrates. Shale gas is extracted from rock formations that act as both the source and the reservoir for the natural gas itself.

5. Developments in Central and South-Eastern Europe

The USA has been the theater of almost all of the development in fracking for shale oil and shale gas. The EU is lagging behind, for a number of reasons such as problems of land access, higher production costs than in the North American market, as well as mining rights regimes and heightened environmental concerns.

At the same time, however, most Central, South and Eastern European countries are highly dependent on the importation of natural gas, while in addition, they rely heavily upon a single, large supplier – namely **Russia**. As a result, the development of unconventional energy resources, such as shale gas, has increasingly been viewed as a potential solution for the region.

Geologically, the chances of finding shale gas in Europe are every bit as good as in America. France, **Poland**, Britain and **Ukraine** look promising, and decent quantities may yet be found in other countries. America’s EIA puts Europe’s recoverable reserves on a par with America’s.

For the purposes of this paper, the South-eastern European region is defined as consisting of the following countries: Albania, Austria, Bosnia-Herzegovina, Bulgaria, Croatia, FYROM, Greece, Hungary, Italy, Kosovo, Lithuania, Moldova, Poland, Romania, Serbia, Slovakia, Slovenia, Ukraine.

In collaboration with experienced North American companies that have the necessary technology, know-how, and capital, Central and Eastern European countries have begun to look for ways to access their shale gas resources, while at the same time sharing the costs and risks of exploration.

With strong governmental and public support for shale gas development, and significant proven shale gas reserves, Poland is considered to be the most favorable market in the Central and Eastern European region for shale gas production, which –as in **Romania** and **Lithuania** – will essentially be driven by the economics of development. Other countries, such as Ukraine**,** have also demonstrated their support for the development of unconventional gas, although their current regulatory and legal environments continue to have elevated risk in the eyes of potential investors. Most of the remaining countries in the region have yet to explore for any potentially extractable resources, while in some cases, limited domestic experience with upstream oil and gas production means that such countries may need to rely more heavily on the technology and expertise of foreign investors.

There are a number of other promising opportunities in Europe, where no [or only a few] reliable resource assessments have been conducted. Some of these include the entire Baltic basin, where only Polish territories have been partially explored and the Lublin basin in Poland, a country which is likely to continue to pursue development of their geological structures which are believed to contain substantial natural gas and oil reserves, to reduce its dependence on Russian fuel. Exxon has left the field but a consortium of four state-owned companies are moving in and Poland's top refiner PKN Orlen plans to spend 300 million zlotys ($87 million) on shale gas exploration in 2012.

Unconventional resources, such as shale gas and tight gas, are also available in Romania in the Carpathian-Balkanian Basin, and in the Pannonian-Transylvanian Basin in **Hungary** and Romania, as well as the Carpathian-Balkanian basin of Romania and **Bulgaria.** However, initial exploration efforts suggest that the cost to recover the gas may be quite high. The exact amount of shale gas resources is still uncertain, although there are various studies discussing the unconventional gas potential of Romania, with the most promising exploration area being the Carpathian-Balkanian Basin in the eastern, southern, and southeastern parts of the country. According to the US Energy Information Administration, the joint reserves for Romanian, Bulgarian, and Hungarian shale gas in this basin is around 538 Bcm. The most promising exploration area is considered to be the Makó basin, which is located in the southern part of Hungary.

Due to its dependency on imported gas, shale gas is considered to be a potential source of diversification for Bulgaria's energy supplies. Part of Bulgaria's territory is located in the Carpathian-Balkanian Basin, which is considered to be a prospective area for shale gas development by the EIA. The potential of the Carpathian-Balkanian Basin was first realized by Direct Petroleum Exploration, which estimated the amount of shale gas reserves to be around 300 Bcm. Others, including Chevron and BKN Petroleum, estimate the amount of shale gas reserves to be between 300 Bcm and1 Tcm at the Novi Pazar area.

Shale gas reserves in Ukraine have been estimated to be 5.5 Tcm, of which 1.18 Tcm may be recoverable. There are two main shale gas bearing basins, namely the Ukrainian Lublin Basin, which contains an estimated 840 Bcm, and the Dnieper-Donets Basin with 336 Bcm of technically recoverable shale gas. In February 2011, Ukraine joined the Global Shale Gas Initiative, through which it has agreed to cooperate with the assessment of unconventional gas resources, the preparation of feasibility studies, and the coordination of regulatory issues and investment promotion.

Unconventional resources, such as shale gas, are under exploration in Lithuania. Shale gas exploration is included in the National Energy (Independence) Strategy as one of the five strategic initiatives. Minijos Nafta plans to launch exploration and test drilling for shale resources in 2012, in the western part of the country. The exact amount of Lithuanian shale gas resources is still uncertain, but the US Energy Information Administration estimated in April 2011 that Lithuania may hold approximately 120 Bcm of shale gas reserves in the southwestern part of the country, not far from the Polish border. Earlier estimates have even put potential amounts of reserves at 480 Bcm, but, these were only theoretical and not based on geological data.

In the **Slovak** Republic, the country's storage and E&P company, NAFTA, entered into a cooperation agreement with the Austrian company OMV at the end of 2007 for two exploration licenses in the Slovak part of the Vienna Basin, for the exploration of hydrocarbons (including shale gas reserves), covering an area of about 1,400km^2. In 2010, the cooperation executed drilling in the Húšky area, near the Slovak-Austrian-**Czech** border triangle, which did not result in proving the existence of hydrocarbons. Drilling was subsequently carried out in the Závod area. While NAFTA continues to focus its shale exploration activities in this area, any development potential may be limited due to possible concerns over its impact on water tables in the Eastern Slovakian Lowlands, near Bratislava, or on the Danube.

Although no identified shale formations have been confirmed in **Croatia**, there is an estimated 18 to 30 Bcm of unconventional gas in the Drava Depression. Both tight gas and deep shale formations, ranging from 3,400 to 4,400 meters, are expected to hold large quantities of gas. Croatia's national oil and gas company, INA, believes that there is even more unconventional gas available, however further exploration still has to take place in order to gain more knowledge and understanding of potential source areas.

Serbia's domestic shale prospects may be expected to advance as its regulatory approach to unconventional resources progresses. In this regard, the country has so far been primarily focused on its shale oil basins. However, NIS invited bids last year for the exploration of unconventional gas in the northern part of the country, at the southern edge of the Pannonian Basin. Drilling was proposed to extend to a maximum depth of 4,500m and extend over five phases, the last of which was expected to terminate in early 2012, over a total area of 532km^2 over two fields. Regardless of these results, the cost-competitiveness of Serbian shale gas development will be weighed against existing gas supply from Russia and related pipeline projects.

In **Slovenia**, Ascent Resources completed a fracture stimulation in November 2011 of a well at Petišovci, where tight gas was found. As of February 2012, tight gas reserves have been estimated to amount to 14.3 Bcm at the Petišovci Project, which would significantly change the state of the Slovenian gas market and render it less dependent on imports.

In **Turkey**, according to analysis released by the U.S. government in early 2011, the country has 15 trillion cubic feet of technically recoverable shale gas, reserves that Exxon could help TPAO tap. TPAO signed an accord in November for Europe's largest energy company Shell (RDSa.L) to look for oil and gas in the Mediterranean and southeastern

Turkey and said other major international firms were interested in exploring nearby. Shale gas reserves have been found in 32 countries and 48 regions around the world. Turkey is known to have, along with Poland, the world's largest shale gas reserves.

TransAtlantic and Valeura have been the first companies that entered the Turkish market via M&A deals and collaboration with TPAO for the exploration of the country's shale resource potential. The companies cite seismic studies indicating the presence of "world-class" reserves in northwestern and southeastern regions, as well as other regions with lesser potential around the country. The discovered potential has apparently sufficed to entice global giants to assume a part in shale gas production in Turkey.

There are the two shale gas basins in Turkey assessed: the Thrace Basin in western Turkey and the Southeast Anatolia Basin along the border with Iraq and Syria. Turkey may also have shale gas potential in the interior Blacklake and Taurus basins, as well as the onshore portion of the Black Sea Basin. The state-run Turkish Petroleum Corporation (TPAO) has recently announced that there are shale gas basins in the regions of Diyarbakır, Erzurum and Thrace with 20 trillion cubic meters of natural gas and 500 billion barrels in reserves.

As for **Greece**, an event entitled "Greek Petroleum and Natural Gas: Fact or myth", was organized in Thessaloniki on June 27, 2011 by Greece's Technical Chamber / Department of Central Macedonia [TCG / SCM]. There, the director of Hydrocarbon Exploration and Production group of Greek Petroleum, John Gregoriou, said 'Greece has many unexplored areas…there are potential oil targets at depths of over 4,000 meters, which have not been investigated so far, and in water depths of over 500 meters, while there has been no search at all for natural gas and shale gas [clay shale gas]'. According to information, there may be structures of shale gas in Western Thrace and elsewhere.

The Greek Ministry for the Environment, Energy and Climate Change awarded a preparatory research project to the Greek state-owned Institute for Geology and Mineral Exploration [IGME] and major universities, so as to explore potential shale gas reserves in the territory, 'based on similar initiatives by other European countries'. Moreover, the ministry asked for an examination of best practices in other countries, especially Poland, France and Bulgaria, while it was made known that Greece may join the Shale Gas Resource initiative.

Lastly, a seminar took place in Patras on April 26, 2012 concerning 'Shale gas perspectives', with Dr Jurga Lazauskiene as speaker in cooperation with the European Association of Geoscientists and Engineers [EAGE].

Kosovo's primary energy source is coal [lignite], serving 55% of the total energy consumption, and any gas consumption is only limited to bottled LPG, as is also the case in **Montenegro**. There is no gas production or gas storage in **FYROM**, and at present there are no plans to build any. Imported gas is only used in the industrial and power generation sector, such as the TE-TO Skopje power plant, the Zelezarnica steel plant, and the Cementarnica cement plant, and in Skopje's district heating. Shale gas potential in **Albania**, **Bosnia-Herzegovina,** and FYROM is currently out of scope for most energy companies, as conventional gas exploration is to be executed first.

6. Environmental issues

Dense hydrocarbon containing geological formations have in common their low permeability. For that reason, the production methods for the extraction of shale gas, tight gas and even coalbed methane are quite similar. Nonetheless, they differ on the quantitative level. Since shale gas formations are by far the most impermeable structures, the effort required to get access to the gas pores is the highest. This results in the highest risk for environmental impacts from the development of these formations. However, there is a continuous transition from the permeable conventional gas containing structures, over tight gas to the almost impermeable gas shales. The common characteristic is that the contact between the drilled wells and the pores must be enhanced artificially, done by hydraulic fracturing.

These are:

- 'Consumption' of landscape as the rig pads need space for technical equipment, fluid storage and road access for their delivery.
- Air and noise pollution as the machinery is operated by combustion engines, the fluids [also waste water] might allow harmful substances to evaporate into the air, the trucks with frequent transport activity might emit volatile organic compounds, other air pollutants and noise.
- The water might be contaminated with chemicals from the fracturing process, but also with waste water from the deposit that contains heavy metals [e.g. arsenic or mercury] or radioactive particles. Possible migration paths to ground and surface waters could be accidents by truck transport, leaks of gathering lines, waste water ponds, compressors etc., spills from accidents [e.g. blow out with a fountain of fracturing fluid or waste water], damages to the cementation and casing or simply uncontrolled subsurface flows through artificial or natural cracks of formations.
- Earthquakes induced by the hydraulic fracturing process or waste water injection.
- The mobilization of radioactive particles from the underground.

There are many naturally occurring substances in the shale formation, and the process of hydraulic fracturing can affect their 'mobility', which means their ability to move around and potentially enter a water source. These substances can include: naturally occurring 'formation' fluid [such as brine] found in the shale rock; gases, such as the target natural gas [mostly methane], carbon dioxide, hydrogen sulphide, nitrogen and helium; trace elements of substances such as mercury, arsenic and lead; naturally occurring radioactive material [radium, thorium, uranium]; and 'volatile organic compounds' [VOCs] that easily vaporise into the air, such as benzene.

Impacts on landscape

The well pads are connected with roads for truck transport, which further increases land consumption. After extraction, the gas must be transported to the distribution grids. As most wells have a small production rate with a steep decline profile, very often the gas is stored at the well pad and periodically loaded on trucks. If the well density is high enough gathering networks with compressor stations are built. Which storage or transport mode is chosen and whether the lines are built above or below ground depends on the specific parameters of the projects and on the applicable regulations.

Air pollutant emissions and soil contamination

The emissions potentially originate from the following sources: from trucks and drilling equipment [noise, particulates, SO2, NOx, NMVOC and CO]; from natural gas processing and transportation [noise, particulates, SO2, NOx, NMVOC and CO]; evaporation of chemicals from waste water ponds; spills and well blow outs [dispersion of drilling or fracturing fluids combined with particulates from the deposit]

Water contamination

Often, the detailed composition of the chemical additives is confidential and therefore not published. One of the substances is tetra-methyl-ammonium-chloride which is toxic and harmful for drinking water already if small amounts are released. According to [Bode 2011], toxic substances such as such as 2-butoxy ethanol, 5-Chloro-2-methyl-4-isothiazolin-3-one, and 2-Methylisothiazol-3[2H]-one have been used as chemical additives for hydraulic fracturing in Lower Saxony, Germany.

Chemical, physical, and toxicological properties can be used to aid identification of potential exposure pathways and chemicals of concern related to hydraulic fracturing wastewaters. Possible water contaminations might be induced by:

- Spills of drilling mud, flowback and brine, from tailings or storage tanks causing water contamination and salinization.
- Leaks or accidents from surface activities, e.g. leaking fluid or waste water pipes or ponds, unprofessional handling or old equipment.
- Leaks from inadequate cementing of the wells.
- Leaks through geological structures, either through natural or through artificial cracks or pathways.

Radioactivity

Naturally occurring radioactive materials [N.O.R.M.] are part of any geological formation, though with a very small share in the ppm to ppb range. Through the hydraulic fracturing process, these naturally occurring radioactive materials such as uranium, thorium and radium bound in the rock are transported to the surface with the flow-back fluid. Sometimes, radioactive particles are injected with the fluids for special purposes [e.g. as tracer]. N.O.R.M. can also move through the cracks in the rock into the ground and surface water. Usually, N.O.R.M. accumulates in pipes, tanks and pits. Because the radioactive materials become concentrated on oil and gas-field equipment, the highest risk of exposure to oil and gas N.O.R.M. is to workers employed to cut and ream oilfield pipe, remove solids from tanks and pits, and refurbish gas processing equipment. [Sumi 2008].

GHG emissions [methane etc]

Fugitive methane emissions from hydraulic fracturing processes can have a very large impact on the greenhouse gas balance. Existing assessments give a range of 18 to 23 g CO_2^- equivalent per MJ from the development and production of unconventional natural gas. The emissions due to methane intrusion of aquifers are not yet assessed. However, project specific emissions might vary up to a factor of ten, depending on the methane production of the well. Depending on several factors, greenhouse gas emissions of shale gas relative to its energy content are as low as those of conventional gas transported over long distances or as high as those of hard coal over the entire life cycle from extraction to combustion.

Shale gas and tight gas have higher production-related greenhouse-gas emissions than conventional gas. This stems from two effects:

- More wells and more hydraulic fracturing are needed per cubic metre of gas produced. These operations use energy, typically coming from diesel motors, leading to higher CO_2 emissions per unit of useful energy produced.
- More venting or flaring during well completion. The flow-back phase after hydraulic fracturing represents a larger percentage of the total recovery per well [because of more hydraulic fracturing, the flow-back takes longer and the total recovery per well is typically smaller due to the low permeability of the rock].

Similar concerns about emissions attach to coalbed methane production, where significant volumes of methane can be vented into the atmosphere during the transition phase from dewatering to gas production and, where hydraulic fracturing is applied, during the well completion phase

Seismic risks

It is known that hydraulic fracturing can induce small earthquakes in the order of 1 – 3 at the Richter scale. It has been suggested that drilling and/or hydraulically fracturing shale gas wells might cause low-magnitude earthquakes. Public concern about this possibility has emerged due to several incidences where weak earthquakes have occurred in several locations with recent increases in drilling, although no conclusive link between hydraulic fracturing and these earthquakes has been found.

7. Public Policies

As with many other natural resources, public policies and legislation in this case are concerned with the following issues: environmental and licencing; protection of public health and safety in general; enhancing & protecting natural resources; price volatility; investment uncertainty; and tax policy.

Furthermore, in the specific field of energy and especially unconventional oil and gas extraction through hydraulic fracturing, two other important issues are at play: Securing energy independence; and the cartelization of gas markets.

EU policies

A number of factors are driving the development of shale gas. Among these are region-specific concerns, particularly with regard to energy security, and a desire to reduce dependency on foreign sources of primary fuels. However, there are also a number of inhibitors preventing shale gas from gaining traction in various countries, including in the EU: issues related to land access, higher production costs than in the North American market, as well as heightened environmental concerns. These drivers and inhibitors have implications for the future of shale gas development [including] in the Central and Eastern European region, as well as the energy security of those countries.

Coordinating the interests of EU member states, the member states of the ‘Energy Community’, and other market players is a complex process.

Perhaps the most important difference between the EU and **the US** is in property rights. In America individuals generally own the minerals under their property. Since a gas strike will benefit them directly, they will generally be enthusiastic about extracting. In Europe mineral rights mostly belong to the state.

Another big difference is that in America most of the shale gas occurs in easily accessible fields far from houses and schools. Europe is far more densely populated, and the more people that live near shale-gas operations, the more objections there will be to tankers carrying the quantities of sand and water needed for fracking. A single shale well could require between 890 and 1,340 truck journeys from drilling to completion.

But sensible rules can go a long way to mitigating the effect. In the Marcellus there are agreements that traffic will be suspended at weekends and on holidays, or even when the school bus is running. Moreover, operators are obliged to upgrade potholed roads and rickety bridges that otherwise might wait years for repair. And if necessary, water could be piped in at additional cost to cut down on the traffic. Traffic, in any case, is a concomitant of modern life. As the European Parliament notes [see below], a pad with eight wells may need 4,000-6,000 lorry journeys over six months to get the well up and running; but a typical shopping centre will require 15,000-25,000 lorry journeys year in, year out.

EU legislature

The exploration and exploitation of unconventional hydrocarbon have to comply with the requirements of the EU legislation. A comprehensive legislative framework on environmental protection and non-discriminatory access to hydrocarbon resources is already in place and applies to all hydrocarbons, conventional and unconventional, from planning to aftercare of sites following exploitation. Within this framework Member States have to ensure appropriate licensing and permitting regimes. The letter sent on 12/12/2011 by the Commission services refers to the EU environmental legislation applicable to unconventional hydrocarbon projects using advanced technologies such as hydraulic fracturing and horizontal drilling. The present note provides further guidance on the applicability of Council Directive 85/337/EEC to the above projects.

Council Directive 85/337/EEC, as amended, on the assessment of the effects of certain public and private projects on the environment [known as the Environmental Impact Assessment or the EIA Directive] is an essential part of the permitting process. In fact, the EIA Directive plays a central role, as it ensures that the environmental implications of projects are taken into account in the permitting process, before the final decisions are made, and it involves the public in the decision-making process making it more transparent.

Regarding shale gas in particular, neither the EU nor the Energy Community has passed any trans-national legislation on it, nor is there any draft legislation planned, as of the day of writing the present paper. The EU’s *Energy Roadmap 2050* only mentions shale gas as a potential energy resource to be researched further. Some individual countries, such as Poland, have argued against any EU-wide legislation on shale gas, citing each member state's sovereignty over its own natural resource developments.

European Parliament Industry, Research and Energy [ITRE] Committee rapporteur, Niki Tzavela [EFD, Greece] released her draft report on 'Industrial, Energy and Other Aspects of Shale Gas and Oil' on April 3, 2012. Highlighting the potential of European shale gas production to improve European economies, energy independence, and ability to reach the Energy Roadmap 2050 targets, the ITRE report can be considered a positive institutional response towards unconventional gas. While acknowledging that the regulatory framework in the EU for early exploration is adequate, the draft report emphasizes the need for high standards of safety during the extraction process - with ongoing monitoring. Furthermore, the report calls upon industry to engage in an open and transparent dialogue with civil society and consult with local communities at every step of the shale gas extraction process. One proposal for improved transparency put forward in Tsavela's report is the public disclosure of chemicals used in the hydraulic fracturing process. Following the consultation process the final report has to go for a vote in the European Parliament's ITRE committee.

At national level

Unconventional gas exploration bans have been recently instituted by governments in France, followed by Bulgaria.

For comparison, the **UK** exploration was halted after an earthquake which was possibly a result of hydraulic drilling operations in Lancashire's Bowland Basin. The Cuadrilla Company has discovered there a particularly rich and thick 'play' [geological formation] that could make the UK, like the U.S., self-sufficient in natural gas. After the government-ordered pause in the operations, the Cameron Government has given the go-ahead to proceed [but cautiously] with hydraulic fracturing activities in the area. The UK is concerned about the relatively swift decline in North Sea oil and gas output. It is also moving more rapidly than others at evaluating the prospects of off-shore fracking operations that could restore production and tax revenues.

8. Geopolitics

A number of important geopolitical issues are at play as a result of unconventional oil and gas extraction.

First, the US is already gaining a tremendous advantage by obtaining new, low-cost, reserves of oil and gas. Characteristically, some LNG import terminals in the US are re-designed to handle gas **exports**. European fracking bans / opposition has slowed the development of natural gas in Europe, creating export opportunities for U.S. producers hurt by low prices and a glut of gas at home. In addition, US manufacturing is benefiting from a very low price of natural gas used either as fuel for energy-intensive industries or as raw material for petrochemicals.

Second, and conversely to the above, countries like Russia and Qatar are loosing their competitive advantage as suppliers of [non-conventional] oil and gas to the US and to every other country that is not benefiting, directly or indirectly, from the fracking revolution. Also, Gazprom is expected to reduce the price of its gas to compete with the shale gas.

Third, in the EU, bans and moratoria could delay by at least a decade the replacement of much of the high priced Russian and North African gas with cheaper domestic production. Ironically, the EU could benefit from cheap imports from the US, as mentioned above. Could an analogy be drawn with Europeans' benefiting from the US military might without committing forces themselves?

Fourth, one of the most important incentives behind shale gas development is its potential to reduce each country's dependency on imported gas, thereby increasing domestic energy security. However, as a result of possible EU bans and moratoria, and imports from the US notwithstanding, Russia and Gazprom will remain the key supplier for much of Central and South Eastern Europe, with all the geopolitical dangers associated.

Fifth, oil and gas affects current account deficits as well as prices/inflation in oil and gas importing countries. For example, amidst increasing concerns over Turkey's vast current account deficit [CAD], fuelled by foreign dependence to cater for the energy requirements of a rapidly developing economy and further exacerbated by soaring global oil prices, a news story signals a game changer. While the price of 1,000 cubic meters of shale gas is around $90 in the US, it costs $400 in Europe and Turkey. The price of the gas depends on the price of oil.

Sixth, the international nuclear energy industry is expected to be heavily affected by lower-priced non-conventional oil and gas. Gas, and thus fracking, gained in importance after Fukushima. Japan turned off all 50 of its surviving nuclear reactors and the country faces a growing debate over the future role that nuclear power should play in its energy supply. Lacking domestic fossil fuel sources, Japan has been forced to rely more heavily on expensive imports of oil and liquefied natural gas to fuel conventional power plants. This has made the nation more vulnerable to supply shocks, which has prompted the trading companies to secure resources by investing more aggressively in upstream energy assets. In July '12, Sumitomo Corp confirmed it would invest about $2bn in Texas shale oilfields by buying large stakes in assets from Devon Energy, the Oklahoma-based operator.

In more detail

As the role model for European shale gas development, **the US** has been a net importer of natural gas, with Canadian piped [90%] and North African LNG [10%] imports covering approximately 16% of domestic consumption. After American shale gas production increased 12-fold during the last decade, it now accounts for about 23% of domestic production, thereby significantly decreasing the amount of imported gas. As a result, the US is expected to become a net exporter of LNG by 2016, and could become an overall net exporter by 2021.

Higher prices for natural gas in the last decade [especially after hurricanes Katrina and Rita] and the advances in horizontal drilling and hydraulic fracturing [i.e. chemistry in action] changed the dynamics for economic shale gas extraction. The latter technologies allowed extraction of shale gas at about $7.00 per thousand cubic feet, which was well below prices of natural gas during the time just after the hurricanes. With new economic viability, natural gas producers responded by drilling, setting off a ‘shale gas rush’, and as learning curve effects took hold, the cost to extract shale gas [including return on capital] fell, making even more supply [and demand] available at lower cost.

In the EU, should the production of shale gas reach a significant percentage of domestic consumption, domestic and import prices are expected to decrease because of increased competition from new supply sources. Future price development will depend upon the liberalization of national markets, and on the potential to export excess capacities.

While the shale gas boom in the US has been on-going for a number of years, natural gas spot prices have decreased since 2009, and have since decoupled from the price of crude. The suppliers of imported piped gas and LNG have adapted to oversupply by decreasing prices. Gas prices in the US are therefore expected to be less than half of what they otherwise would have been without shale gas development. US natural gas prices, as measured at the Henry Hub in Louisiana, peaked at $14 per thousand cubic feet in 2005. Earlier this year the price slumped to a lowly $1.80 after a warm US winter, but has since recovered to about $3.

For the last two years, many natural gas producers have been acquiring and drilling gas plays with high liquids content. NGLs are typically valued as a percentage of crude oil prices, and are worth 2-10 times what dry gas is worth.

9. Public reactions in Central and South-Eastern Europe

2011 and 2012 have seen significant anti-fracking activities in Europe. In an upsurge of citizen-led pressure, civil liberty groups, activists and residents as well as some European governments and state legislatures, have expressed themselves against the hydraulic fracturing industry.

Grassroots organisations have staged marches, legal challenges, public meetings and many direct actions in response to this perceived threat, and this remarkable collective action has scored a series of victories – including bans, moratoriums and revoked licenses.

The anti-fracking movement is spread continent-wide – from the Atlantic to the Black Sea sea. And with no wells in production and only a handful under exploration, big Oil and Gas is finding it increasingly difficult to root fracking into the European pscyhe.

Bulgaria –Romania: In January 2011 thousands of people took to the streets of Sophia and other major cities to demand the government ban hydraulic fracturing. The opposition – largely organised on Facebook – forced Bulgarian MPs to vote overwhelmingly for a ban. In February 2012 Bulgarian and Romanian activists along with members of Frack Off staged a demonstration near the Romanian embassy in Kensington, London. With chemical suits, chants and street performers they protested against the proposed use of controversial 'fracking' to extract shale gas in Romania.

Poland: Poland perhaps represents the most aggressive environment for shale-gas development as the government aims to reduce its reliance on Russian gas exports. Prime Minister Donald Tusk has indicated that commercial production could begin as early as 2014, and expects that Poland may be self-sufficient in natural gas by 2035. The industry is not unopposed, however. In the autumn activists occupied a Shale industry conference, and are increasingly vocal.

In the United Kingdom, activists have increasingly joined forces with local residents, and the mood in the UK's ruling party is said to be swinging against the industry. Welsh Green party took planning application to court.

Gathered in Marseilles on Friday March 16 during the Alternative World Water forum [FAME], activists and campaigners against shale gas in Bulgaria, Poland, Ireland, Germany, Spain, United States, France, etc. affirmed their 'determination and categorical opposition against all extraction of shale gas and every use of hydraulic fracturing'.

The WWF position

On May 23, 2011 the WWF posted 'WWF Shale Gas is a Dangerous Distraction', expressing unease that MPs on the Energy and Climate Change Committee had dismissed concerns around the environmental impacts of shale gas. In November 23, 2011, the WWF website hosted some questions and answers on shale gas and the climate. More specifically they focused on: '*The worrying news that drilling for shale gas probably did cause earthquakes near Blackpool is only part of our problem with 'fracking'. The other big environmental elephant in the room is that shale gas is simply another greenhouse gas-pumping fossil fuel, and far from the 'wonder gas' it's hyped as'.*

On April 17, 2012, the WWF website hosted some questions and answers on shale gas and climate change: *'We're calling for a moratorium on shale gas extraction until all the environmental concerns are properly studied and understood - and for attention and investment to be focused where they should be, on renewables. We're not convinced that the recent report into shale gas by MPs on the Energy and Climate Change Committee gave enough weight to the dangers of water contamination during the hydraulic fracturing ['fracking'] process - not to mention excessive use of precious water resources - as well as the potential levels of greenhouse gas leakage.'*

The Greenpeace position

On May 10, 2011 Greenpeace posted 'Daily News: Renewables Could Supply 80 percent of World's Energy within 40 Years, While Methane from Shale Gas Is Contaminating tap Water' and on June 1, 2011 Greenpeace posted 'Daily News: Arctic Protest Shakes Oil Investors Confidence and Toxic Toys Threaten China's Children'.

10. Concluding remarks

Shale gas has the potential to revolutionize the world’s energy industry. It is abundant and cheap. It burns cleaner than fossil fuels. And it is being found almost everywhere. But for shale gas to become the game-changer that some analysts predict, the industry has to surmount large reputational and regulatory hurdles. And there are no guarantees that natural gas prices will ever rise high enough to make the high costs, financial risk, and extended development periods worth the returns. Even still, with the prospects of substantial profits and stable, secure supplies, players at the national and industry levels are placing their bets.

Many countries stand to benefit from the shale oil/gas revolution, directly [as producers] or indirectly [as importers], in terms of local development, healthier balance of payments and reduced dependence from a single source.

On the other hand, an excess in the supply of natural gas can lead to ‘collateral damages’. Three of Britain's biggest companies wrote down $6.2bn [£4bn] of assets in July 2012, while on August 3, 2012, BHP Billiton slashed the value of its US shale gas business by $2.84bn. BHP Billiton only bought the assets last year – spending $4.75bn buying Fayetteville from Chesapeake Energy. Shale gas prices have plunged by about 50pct since the purchase.

The problem can turn into one of an excess of supply. Large companies including Exxon and Chevron bought a series of shale assets from independent companies, with a view to using their superior financial firepower to develop the assets quickly. The majors delivered on their promises, resulting in a glut of gas that has kept prices low. In effect, shale gas producers have been a victim of their own success and the country does not have the infrastructure in place to export the gas to Asian markets in the form of liquified natural gas [LNG]. That will be several years in the making.

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Vasili has graduated from the National Technical University, Athens, and from Stanford University, U.S.A. with a M.Sc. in Engineering - Economic Systems. After working in consulting in California, he returned to Greece for a technical and managerial career with Grecian Magnesite SA and Magnesitas Navarras in Spain and Premier Magnesia in the US. He has also served as CEO of ERGOSE SA, a large Greek state-controlled company.

Mr Nicoletopoulos has been a member of the Executive Committee of Eurometaux in Brussels, a Commissioner of the Hellenic Competition Commission, as well as a member of the board of the Athens Chamber of Commerce and Industry, the Center for Renewable Energy, the Center for Public Enterprises and a number of private companies. Other positions held include those of General Secretary of the Greek Mining Enterprises Association and member of the General Council of the Association of Greek Industries.

Vasili has authored two books [Electric Power Economics, Corporate Governance] and several articles in journals and financial newspapers worldwide. He is the author of numerous studies, most recently on rare earths and hydraulic fracturing in shale deposits. Vasili has lectured on mining, energy, public policy in many countries and has organized and/or presided numerous international conferences. He speaks Greek, English, French and Spanish.