Project no. 723678

□The next Generation of Carbon for the Process Industry□

Coordination and Support Action

Theme [SPIRE 5] □ Potential use of CO_2 and non-conventional fossil natural resources in Europe as feedstock for the process industry

Deliverable *1.2*: *Map and potential impact analysis of all relevant shale gas sources*

Due date of deliverable: June 2017

Actual submission date: 30 June 2017

Start date of project: 1 September 2016 — Duration: 24 months

Organisation name of lead contractor for this deliverable: TRINOMICS

Table of Contents

1. Executive Summary

This report presents an overview of the potential of shale gas in Europe. This is achieved by mapping the resources and comparing this to global resources, describing the current situation across Europe (especially in Poland and the UK where there has been greatest interest) and describing the technologies used. There is a brief review of the investment requirements and key challenges, followed by a look at the potential of shale gas extraction to provide new sources of carbon dioxide and natural gas liquids.

It is concluded that, compared to North America and Asia-Pacific, the technically recoverable resources of shale gas in Europe are limited. The production of shale gas has several challenges, not least the environmental risks. Some countries have imposed a moratorium on shale gas production until they can better assess the risks and in other countries there is significant public/social concern about the impacts. It is not yet clear how shale gas will develop in Europe, but large scale deployment as seen in the United States appears unlikely to occur. Outside of the UK, where it is possible that it could have an impact on domestic industry if deployment proceeds as planned, we do not foresee that shale gas will have an impact on Europe's processing industry. It is therefore proposed that it be disregarded from further research.

2. Introduction

2.1 The objective of this deliverable

Shale gas is probably the most well-known and broadly debated unconventional carbon resource. The huge impact on US industry and drop in energy prices caused by the strong increase in shale gas production in the US logically translates into the question if shale gas holds the same promises for Europe.

The present report (deliverable 1.2) presents an overview of the potential of shale gas in Europe. It exists in conjunction with the deliverables 1.1 Map of relevant CO_2/CO containing gases and 1.3 Map and potential of other non-conventional natural carbon sources like tar sands, coal bed methane and gas to liquid; as well as alternative technologies as coal to liquid technologies. The objective is to show a map of all non-conventional carbon resources in Europe in order to estimate the potential impact of these resources on the European process industries. The three deliverables provide the results of WP1.

In order to analyse the potential of shale gas in Europe we have to break down the discussion into three elements:

1. The impact of production in Europe of shale gas (methane form shale layers) on Europe's industry and energy prices;
2. The potential for using CO_2 streams linked with shale production (both process CO_2 as well as 'associated' CO_2 (contained in the mined gas, that has to be washed out);
3. The potential impact of shale by-products, so called Non-Gaseous Liquids, for the chemical industry. This refers to higher hydrocarbons like Ethane, Propane and Butane that can be directly used by the chemical industry.

2.2 Methods

The results presented in this report are based on existing literature from the IEA, JRC, EIA, and various news sources. The EIA and IEA have published estimations of shale gas resources, which are described and compared. News sources are also used, to provide an overview of the current state of play.

3. The potential of shale gas production

There are several definitions of shale gas. The difference between shale gas and conventional gas is mainly that shale gas is trapped in a fine-grained sedimentary - shale - rock. The gas has very little connectivity, which makes it more difficult to extract than gas from conventional reservoirs. The rocks need to be hydro-fractured and a channel needs to be drilled so that the gas can flow from the source through the rocks to the well. For shale gas typically many more drilling/production installations are required compared to traditional gas winning. The types of reservoir are similar to that of tight gas, which is located in low-permeable sandstone reservoirs, and also requires hydro-fracturing and horizontal wellbores (see Figure 3-1). This is why shale gas is sometimes considered as a sub-category of tight gas.

Definition 1: *“Natural gas contained in organic-rich strata dominated by shale. Because of the types of reservoir, it is sometimes considered a sub-category of tight gas.”*[1]

Definition 2: *“Natural gas trapped in fine-grained sedimentary rock called shale that has a characteristic ‘flaky’ quality.”*[2]

Both definitions define shale gas by its characteristic of being located in shale rock, which makes it more difficult to extract than conventional gas (see Figure 3-1). The first definition by the IEA will be used throughout this report.

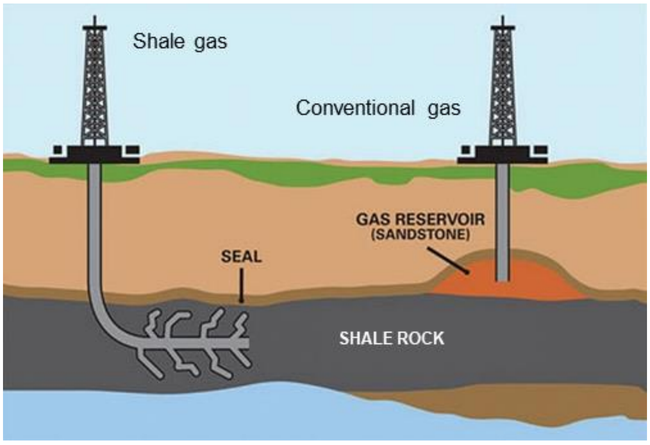

Figure 3-1. Difference between shale gas and conventional gas production

Based on: https://www.croftsystems.net/oil-gas-blog/conventional-vs.-unconventional

3.1 Mapping resources

The US Energy Information Administration (EIA) has made estimations of shale gas resources, which are most commonly used in research reports (e.g. WEC 2016; JRC 2016). The largest concentrations of technically recoverable shale gas resources are in China, Argentina, Algeria, the United States and Canada. EU Member States have much smaller concentrations, with notable resources in Poland, France and Romania (bordering Ukraine and Bulgaria in the east and south).

Table 3-1. Technically recoverable shale gas resources (Tcm)

No	Country	Technically Recoverable Shale Gas Resources (Tcm)	*Proven* Natural Gas Reserves 2017 (Tcm)	Comment on national policy regarding shale gas production
Top 10				
1	China	31.6	5.19	
2	Argentina	22.7	0.32	
3	Algeria	20.0	4.50	
4	United States	17.6[(1)]	8.71[(2)]	
5	Canada	16.2	2.18	
6	Mexico	15.4	0.36	
7	Australia	12.2	1.99	Moratorium on hydraulic fracturing in the Northern Territory since 2016,[3] Tasmania since 2015,[4] Victoria since 2012,[5] New South Wales since 2011.
8	South Africa	11.0	0.02[(3)]	Lifted moratorium in 2012.
9	Russia	8.1	47.81	
10	Brazil	6.9	0.43	
Europe (EU Member States)				
12	Poland	4.1	0.08	
13	France	3.9	0.01	Moratorium on hydraulic fracturing for shale gas since 2011.
19	Ukraine/Romania	2.3	0.1 (Romania)	
25	Romania/Bulgaria	1.0	0.006 (Bulgaria)	Bulgaria: Moratorium since 2012. Romania: Moratorium has been lifted.
26	Denmark	0.9	0.02	
28	Netherlands	0.7	0.79	Moratorium on hydraulic fracturing for shale gas 2015-2020.[6]
29	UK	0.7	0.21	Temporary moratorium in Scotland since 2015, opposition to fracking by Welsh government.
34	Germany	0.5	0.04	Ban on hydraulic fracturing since 2016.[7]
35	Sweden	0.3	-	
36	Spain	0.2	0.003	
43	Lithuania/Kaliningrad	0.1	-	
	Total Europe (EU)	16.9[(4)]	1.38	
	Total outside Europe	197.6	185.62	

Source: EIA 2015 World Shale Resources, Attachment A. (Data from May 2013); EIA International Energy Statistics Proved Reserves of Natural Gas
(1) The value for the US was recovered from the EIA website, and was updated in April 2015
(2) Value from 2016
(3) Value from 2012
(4) Including Ukraine/Romania, as no separate figure for Romania is available

[3] https://frackinginquiry.nt.gov.au/
[4] http://www.premier.tas.gov.au/releases/fracking
[5] http://www.farmonline.com.au/story/3602774/fracking-moratorium-for-victoria/
[6] http://www.shalegas.international/2015/07/13/dutch-government-bans-shale-till-2020/
[7] https://www.theguardian.com/environment/2016/jun/24/germany-bans-fracking-after-years-of-dispute; http://www.reuters.com/article/us-germany-fracking-idUSKCN0Z71YY

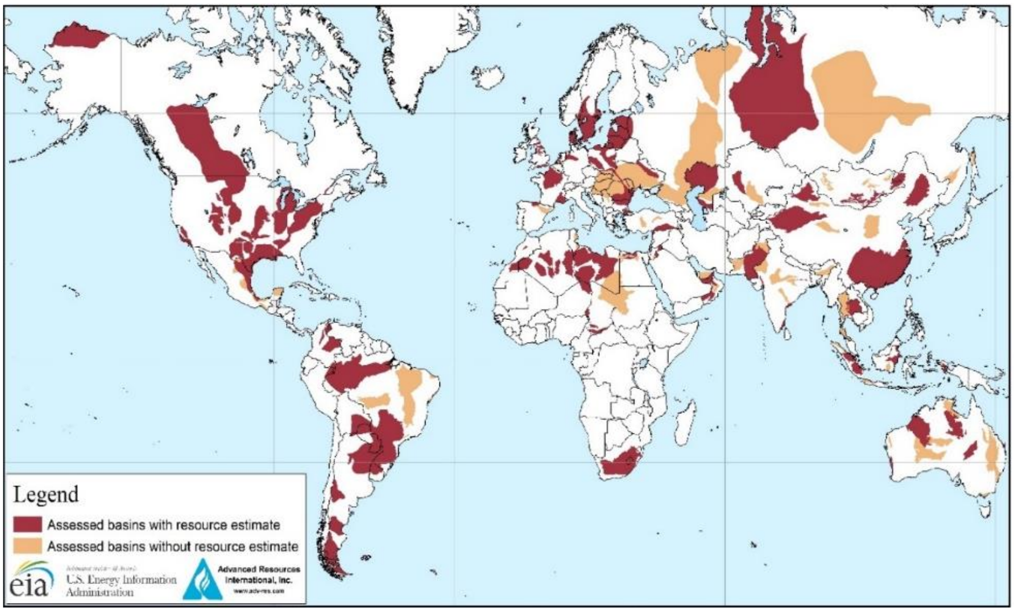

Figure 3-2. Assessed shale gas basins with and without resource estimates

Source: EIA World Shale Resource Assessments (last updated Sept 2015)
http://www.eia.gov/analysis/studies/worldshalegas/

The IEA has also made estimations per region, which amount to 210 Tcm ultimately recoverable resources, of which 17 Tcm in OECD Europe. The IEA estimations are more conservative than the EIA's.

Table 3-2. Estimated ultimately recoverable resources per world region (Tcm)

No	Region	Ultimately Recoverable Shale Gas Resources	Other Recoverable Unconventional Gas Resources	Ultimately Recoverable Conventional Gas Resources
1	OECD Americas	57	26	81
2	Asia Pacific	57	36	44
3	Latin America (non-OECD)	34	15	27
4	Africa	30	8	41
5	OECD Europe	17	6	35
6	Eastern Europe and Eurasia	12	30	160
7	Middle East	7	8	132

Source: IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future"

As can be seen in Table 3-1 and Table 3-2, the geographic distribution of shale gas resources is very different from that of conventional gas. Whereas the Middle East and Eastern Europe / Eurasia have large quantities of conventional gas and relatively little shale gas resources, Latin America and Asia Pacific have larger shale gas resources than conventional gas resources. Europe falls in between these two extremes, with the ultimately recoverable shale gas resources estimated at half the size of recoverable conventional gas resources. If these estimations prove correct and the reserves are not only technically but also economically recoverable, shale gas could play a big role in the European gas market.

3.2 Current state of play

The United States has the fourth largest technically recoverable shale gas resource and it is currently the largest producer of shale gas. Shale gas made up 34 % of its total natural gas production in 2011 and the IEA estimates it will rise to 49 % by 2035. Together with tight gas and coal bed methane

(CBM), unconventional gas provided 58 % of the US natural gas supply in 2010, which makes it questionable whether the term "unconventional" is still valid for these resources. Canada was the second-largest producer with almost 60 bcm unconventional gas production in 2008.[8]

Apart from North America, countries are still in an experimental or exploratory phase. In Europe, EU regulations on chemicals and mining, coupled with national environmental laws, planning restrictions, a higher population density and different arrangements for mineral ownership set a different playing field for shale gas than in the United States. Nonetheless, as the shale gas extraction in the United States has cut gas prices and imports to the US, several companies are investigating shale gas prospects in Europe.

Resources in Poland were estimated by EIA at 5.3 tcm in 2011 and many petrochemical companies entered the market. The initial high expectations were dimmed somewhat in 2012, when the Polish national geological institute PGI gave a much lower estimate of 0.35 – 0.77 tcm[9], which would still be enough to become independent from Russia's gas and other gas exporters.[10] The EIA lowered its estimation to 4.1 tcm in 2013. After disappointing test well results, in combination with regulatory delays and low prices for oil, coal and renewable energy alternatives, many companies have pulled out of the country and shifted attention to Ukraine.[11,12] There a similar trend seems to envelop, with regulatory obstacles and in addition a precarious geopolitical situation driving companies to postpone their activities or withdraw from the country altogether.[13]

Austria is not listed by the EIA with shale gas resources, but the IEA has estimated that they equal at least 20 years of domestic consumption. The current regulatory framework in Austria discourages shale gas production, as the environmental impact assessment process takes 3-4 years per well.[14] In Denmark, Total has two licences for drilling, but the gas reservoir properties did not match up to expectations for the Vendsyssel-1 shale gas well, which was therefore abandoned.[15]

Most activity in Europe is in the United Kingdom, which lifted its moratorium on shale gas at the end of 2012, starting its "dash for gas" as the media dubbed it. Geological surveys have indicated sizeable shale gas resources in England across large parts of the north, the midlands and the south-east. Expectations are still very indicative, but there could be reserves of well over 20 years of British total gas consumption. Opposition is still strong, with a temporary moratorium in Scotland until the results of an ongoing impact assessment are out, and the Welsh government instructing local authorities to turn down applications for concessions.[16] The Labour party said earlier this year that it would ban fracking if it won the election. Despite the opposition, fracking has been approved in Lancashire (after the community's secretary overturned Lancashire county council's rejection) and North Yorkshire (after High Court ruling).[17] Following government approval, Cuadrilla started site construction work in Lancashire (near Blackpool) in January 2017.[18] The UK shale gas will be used mainly for national consumption and will very likely not be exported.

[8] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future".
[9] https://blogs.wsj.com/emergingeurope/2012/03/21/poland-urges-more-shale-gas-exploration-after-new-lower-estimate/
[10] Polish yearly consumption of gas is about 0.016 tcm, two-thirds of which come from Russia. Financial Times, Eni joins shale gas exodus from Poland, January 15, 2014.
[11] https://www.ft.com/content/ffa09b60-6036-11e4-98e6-00144feabdc0#axzz3nzWJQ5Sz; https://www.theguardian.com/environment/2015/oct/09/polish-shale-industry-collapsing-as-number-of-licenses-nearly-halves
[12] Financial Times, Eni joins shale gas exodus from Poland, January 15, 2014.
[13] https://imformed.com/shale-gas-market-in-europe-remains-uncertain/
[14] IEA (2014) Energy Policies of IEA Countries – Austria 2014 Review. Executive Summary and Key Recommendations. http://www.iea.org/Textbase/npsum/austria2014SUM.pdf
[15] http://www.rigzone.com/news/oil_gas/a/142688/mainland_europe_shale_gas_what_now
[16] https://www.theguardian.com/environment/2016/sep/26/labours-pledge-to-ban-fracking-in-the-uk-is-madness-says-gmb
[17] https://www.theguardian.com/environment/2017/feb/01/scottish-government-launches-public-consultation-fracking
[18] http://www.bbc.com/news/uk-england-lancashire-38520562

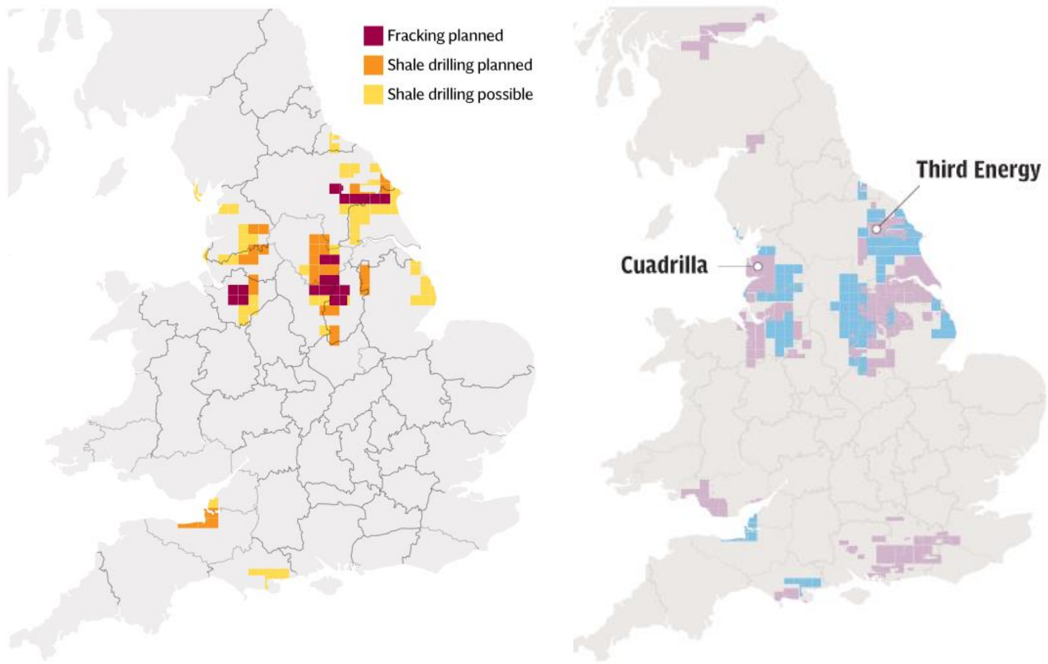

Figure 3-3. Exploration plans for new licences in the UK / Fracking map (Jan 2016)

ource: The Telegraph, http://www.telegraph.co.uk/finance/newsbysector/energy/12130426/UK-shale-gas-ex light-to-frack.html

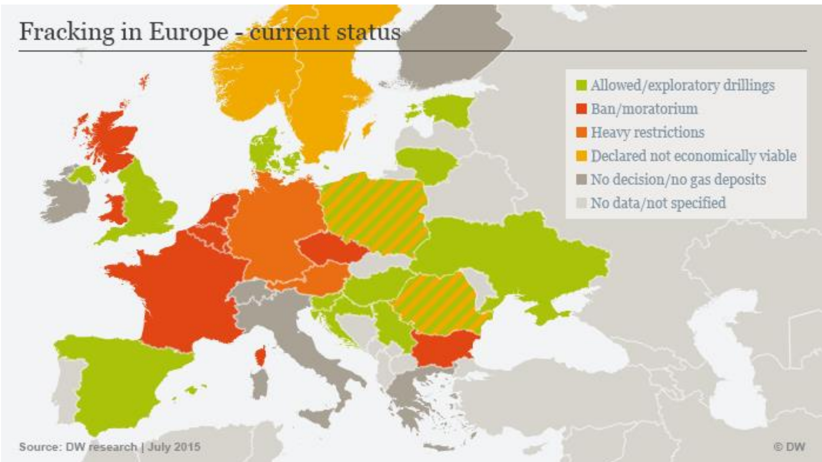

Figure 3-4. Legal positions on hydraulic fracturing in Europe (July 2015)

Source: http://www.dw.com/en/what-ever-happened-with-europes-fracking-boom/a-18589660

3.3 Main technologies used

The technologies that make it possible to produce shale gas are a combination of horizontal (or directional) drilling and hydraulic fracturing ("fracking"). Hydraulic fracturing involves the injection of a fluid of water, sand and chemical additives ("proppant") in the wellbore at very high pressure, causing the shale rock to crack and keeping the cracks open, allowing the gas to be released.[19] Fracking is not unique to shale gas production: it is also used in conventional gas production to increase the production rates and the total amount of gas that can be recovered. Fracking for shale gas is similar to that for tight gas, but fluid volumes and pressures are higher.[20]

[19] JRC (2012), "Unconventional Gas: Potential Energy Market Impacts in the European Union"
[20] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future"

Due to the length of the horizontal section in shale gas wells, the downhole pressure is usually not sufficient. Therefore, portions of the horizontal section are isolated and treatment is performed in multiple stages ("multi-stage fracturing").[21] There are also other methods for increasing the pressure, such as plain seawater or CO_2 or N_2 injection (often called enhanced hydrocarbon, oil and gas recovery).

Technological improvements have made shale gas economically viable. Apart from the improvements in horizontal drilling and fracking, other technologies that have been improved are water management, infrastructure planning and well pad design. It is becoming common to use a single pad from which multiple wells are treated to increase efficiency and reduce infrastructure costs, land use and environmental impacts. Microseismic monitoring is also improving.[22] The technology has only been applied and proven on onshore shale gas fields so far.[23]

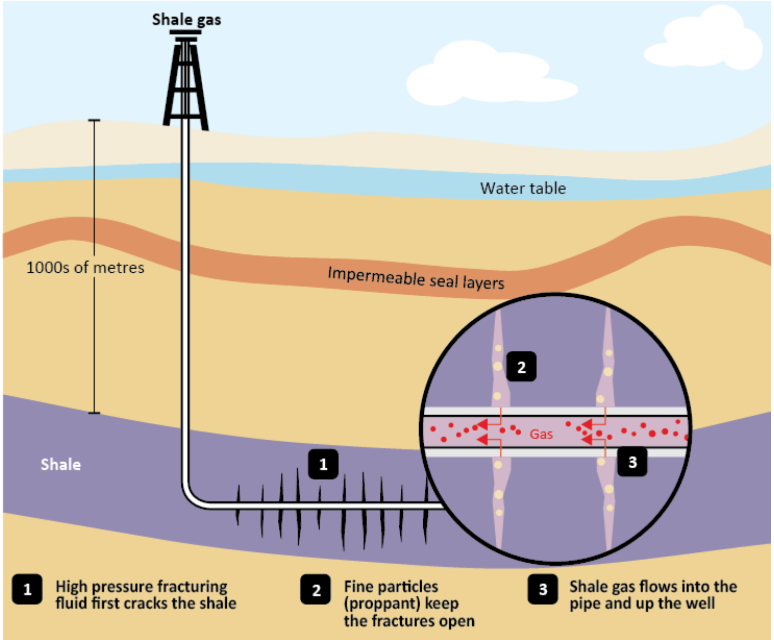

Figure 3-5. Schematic depiction of hydraulic fracturing

Source: http://www.nt.gov.au/d/Minerals_Energy/Content/Image/UnconventionalOilandGas/ShaleGasProduction.PNG

3.4 Investments

The business case for shale gas is different from that for conventional gas. It takes several years to reach and sustain a production plateau and requires continuous drilling during this period. Most of the capital costs are recovered within the first few years after the investment decision (rather fast). But Opex remains high when producing. Therefore shale gas producers are required to adjust/reduce their production level when prices are not favourable enough to recover Opex. The business case for shale gas is therefore less influenced by price instabilities on the medium-term: after recovering the initial investment in the first few years, it can adjust its production in response to market signals, positioning itself as a "swing producer".[24]

Development and production costs vary per location. The IEA estimates that the threshold costs for the main locations that are being developed in the United States and Canada range between USD 3 and USD 7 per million British thermal units (MBtu).[25] The JRC estimates that the USA can produce around 30,000 bcm at around $5/GJ and another 30,000 bcm at $9/GJ in an optimistic case, and 1,000 bcm at $5/GJ and another 9,000 bcm at $9/GJ in a more conservative case.[26]

[21] JRC (2012), "Unconventional Gas: Potential Energy Market Impacts in the European Union"
[22] JRC (2012), "Unconventional Gas: Potential Energy Market Impacts in the European Union"
[23] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future"
[24] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future"
[25] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future"
[26] JRC (2012), "Unconventional Gas: Potential Energy Market Impacts in the European Union"

3.5 Key challenges

Shale gas production is only commercially viable if there is enough water available for drilling and completing wells, and if the cost and environmental impact of treating and disposing of the water is not prohibitive. Fracking carries the risk that routes to potable aquifers are opened up, and fracking fluids could end up there, which has led to concerns from the public.

The environmental impact of shale gas is still unclear. Academic studies have conflicting results on the impact of fracking on ground water.[27] The energy intensity of production is higher than for conventional gas, but it is likely to have substantially lower CO_2 emissions compared with coal-fired power plants.

Also important for the business case is the concentration of resources and recovery factors, which are both much lower than for conventional gas fields (yield of recoverable resources is between 0.04-0.6 bcm/km^2, compared to 2-5 bcm for the world's largest conventional gas fields, and recovery factors were estimated up to 20% in 2011). Shale gas production therefore covers large areas and it requires more wells drilled closely together. The very dense patterns of surface wells have given rise to concerns in densely populated areas.

[27] http://www.climatechangenews.com/2014/04/09/austria-should-decide-on-use-of-shale-gas-resources-iea/

4. Potential carbon feedstock from shale gas

4.1 CO_2 streams

Depending on the quality of the shale gas, there might be a need to remove the associated gases like CO_2 (acid gas removal) to get the methane quality that is required for the market. This might lead in some fields to a new stream of CO_2. However, at the moment – given that the development of shale is still in its infancy in the EU, and particularly only present in the UK – there is uncertainty over the shale gas quality and its composition. A report on UK shale gas processing mentioned that a central processing facility could be used to reduce costs for the acid gas removal (if necessary) to meet the required specifications for the National Transmission System (The UK’s Gas Quality Specification for carbon dioxide is “Not more than 2.5% molar”).

As the extra CO_2 cleaning will increase production cost substantially it is not very likely that this will happen at large scale with shale gas. If, in the future, streams of pure CO_2 are being produced, then they will be included in the work-stream on mapping CO_2 sources (WP1, Task 1.1). But as shale gas production is often located in remote areas, far from other chemical production facilities, it is unlikely that these CO_2 streams will be easily used as feedstock for the processing industry.

When producing shale gas there are also smaller CO_2 streams from pumps and generators in the field. These flows are too small to allow for Carbon Capture and can be disregarded in further research.

4.2 By-products

When producing shale gas, substantial streams of other hydro-carbons (called Natural Gas Liquids – NGLs) can often be co-produced and separated. Some of them (like ethane (for plastics), butane and propane) are quite valuable and easy to use as feedstock for the chemical industry. Sometimes the NGLs are the main driver for the profitability of the shale gas plant and the methane is sometimes even flared.

The new stream of ethane has definitely had an impact on the chemical industry worldwide, reducing imports in the USA from European refineries and building new chemical plants in the US exploiting this new source.

So far, shale gas production is in its initial phase only in the UK and no results are known yet on the content of NGLs. If substantial amounts of especially ethane are found in the shale exploitation this would give the UK chemical industry an advantage over continental producers. However, it is too early to give indications for this potential development. The UK has recently started importing shale gas from the US for use in chemical manufacturing at Ineos’ Grangemouth refinery in Scotland. Ineos is planning to increase ethylene capacity of its plants in Scotland and Norway and include a new propylene production unit, potentially in Belgium. Both rely on imported US shale gas.[28] It is not clear yet if UK’s shale production would be cost-competitive enough to substitute these cheap US imports.

[28] http://www.bbc.com/news/uk-scotland-scotland-business-40249088

5. Future outlook and potential impact

Technological advancements in the fracturing process can improve precision of shale gas production. Potential improvements could concern the network of fractures created, a reduction of the number of fracturing stages per well or the time needed to drill and fracture, and less consumption of water. These improvements could lead to a significant reduction in costs. Microseismic monitoring is improving as well, which could enable the mapping and visualisation of how fracturing is progressing. It also provides information for the early detection of geo-hazards.[29]

There are still a lot of public concerns about shale gas in Europe, with several countries imposing moratoriums. A key factor for European developments would be technological breakthroughs to reduce environmental impacts.[30]

Economically, Europe has a very different market structure than the US, with Russian and Norwegian gas dominating the market. Combined with the increased possibilities of LNG imports, the market price is less likely to be influenced by shale gas production. We therefore conclude that the volume and price impact from shale gas for the processing industry is likely to be very low to non-existent.

[29] JRC (2012), Unconventional Gas: Potential Energy Market Impacts in the European Union

[30] IEA (2013), Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future

6. Conclusion

Compared to North America and Asia-Pacific, the technically recoverable resources of shale gas in Europe are limited. The production process has several challenges, the most important being the environmental risks. Some countries have imposed a moratorium on shale gas production until they can better assess the risks. Poland was estimated to have the largest resources in Europe, but tests were disappointing and regulatory issues led many companies to move their activities elsewhere. The United Kingdom has given concessions to start shale gas production, despite strong opposition. This shale gas would be used mainly for national consumption and is not likely to be exported to the continent. If substantial amounts of especially ethane are found in the shale exploitation, this could give the UK chemical industry an advantage over continental producers. It is therefore not clear yet how shale gas will develop in Europe, but a ‘gas revolution’ as was seen in the United States is very unlikely to occur. Outside of the UK, where there is a chance it could have an impact on domestic industry, we do not foresee that shale gas will have an impact on Europe’s processing industry and we propose to disregard it from further research.

7. Bibliography

- EY (2010), “Shale gas and coal bed methane. Potential sources of sustained energy in the future”.
- Gordon, D. (2012), “Understanding unconventional oil”
- IEA (2009), “Review of worldwide coal to liquids R&D activities and the need for further initiatives within Europe
- IEA (2012), “Golden Rules for a Golden Age of Gas – World Energy Outlook – Report on Unconventional Gas”
- IEA (2013), “Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future”.
- ISC & WPC (2013), “World Petroleum Council Guide - Unconventional Oil”
- JRC (2012), “Unconventional Gas: Potential Energy Market Impacts in the European Union”.
- WEC (2016), “World Energy Resources 2016”