CHAPTER 8

GEOLOGY AND LOGISTICS ISSUES IN A DENSELY POPULATED AREA

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Abstract

The recent exploration of hydrocarbon source rocks in Europe and indeed in the rest of the world has looked to the US for guidance on the shale attributes, the new techniques, the effects of exploration on the environment and new regulations required for successful and safe exploitation. But this has been a steep learning curve even for major oil companies, which were slow to respond to the early success in the Barnett Shale. They have bought and taken over companies in order to gain expertise in the US basins and can now apply this to the rest of the world. It seems likely that exploration will only be as easy as in the US in those countries near the bottom of the population density list and those where investment in nuclear and renewable energy has been or is lower. The incentive of a high gas price and security of supply will however drive exploration in the higher density populated countries. Peter Voser, CEO of Royal Dutch Shell plc, has stated that 'We underestimate what [shale gas] could do to the world in the next 10 to 20 years. It's a big deal and necessary – globally.' Gerhard Roiss, chief executive of Austrian oil and gas company OMV AG, is quoted as saying that 'While Europeans worry about the potentially negative environmental aspects of exploiting shale gas, OMV has a simple message: Shale gas is a necessary part of a sustainable European energy mix. Not to embrace shale gas risks the future competitiveness of European industry'. Already cheap gas in the US is regenerating their energy intensive industries and providing chemical feedstocks. The US has also used shale gas to displace coal in their energy mix, thereby probably reducing their carbon dioxide emissions.

If favourable geology and technology combine with political and social acceptance it is likely that peak oil and gas are unlikely to be referred to again and we should use this breathing space to prepare to adopt green energy policies. Once the source rocks in their hydrocarbon kitchens are exploited there will be no new hydrocarbons.

8.1. Summary of History and Selected Activity in the US

8.1.1. History of Exploration

US shale gas history goes back to 1821, when the first well in shale produced gas to light a few local buildings. The Big Sandy field in Kentucky, a giant gasfield, was discovered in 1914. The longevity is important because America has grown up with onshore conventional and unconventional hydrocarbon exploration and production for nearly 200 years and the technological changes over this time which have extended the scale and geography of the production from shale have largely been accepted, until recently. The US had been quietly and more sustainably exploiting shale gas from other foreland basin shales since this early date, a model also advocated for the UK (Selley 1987), but which fell on deaf ears for about 20 years after publication.

Europe has not experienced production from shales, except on a very small scale in Sweden, although evidence for some gas seeps at the surface and explosions in non-coal mines is probably associated with gas from shales.

Exploration and production in the US is typified by a paradox. Despite the wide open plains and fields, with its low population density, and because the shale gas window lies under Dallas-Fort Worth conurbation there has been an incentive to get in close to the urban area (Plates 8.1 & 8.2). The US population in general is more accustomed to onshore conventional hydrocarbon production than Europeans despite there being some large fields like Wytch Farm (UK) and Groningen (Netherlands). This relationship has been smoothed by the royalty cheques landowners receive in the US. The European conventional fields have mostly quietly produced without too much trouble, although Groningen has induced earthquakes. However had they been discovered today permission to develop would face much greater hurdles than when they were approved.

Chesapeake Energy was drilling with 12 rigs in the 220,000 acres it leased at the end of 2011 in the Barnett shale. Chesapeake previously reported it

Plate 8.1: Photograph of Fourth Street A#1 Well, Operated by Dale Resources (Now Chesapeake) in the Barnett Shale of the Fort Worth Basin, Texas, US. The Skyscrapers are in the Central Business District ('Downtown') of Fort Worth. Reproduced by Kind Permission of Copyright Holders Powell Shale Digest©, Photograph by G. L. Wilson.

Plate 8.2: Line up for Chesapeake Shale Gas Exploration on the Dallas-Fort Worth International Airport Runway, Within the Barnett Shale of the Fort Worth Basin. Reproduced by Kind Permission of Copyright Holders Powell Shale Digest©, Photograph by G. L. Wilson.

expected to complete a Barnett well every 15 hours, on average, during 2012, but the latest reports suggest that a lot of licences will not see drilling because of the gas price collapse. At Dallas-Fort Worth International Airport seismic reflection data has been acquired (Fig. 8.2) and horizontal wells are positioned very close to the edge of the runway and then drill right under the runway, providing the opportunity for hydrocarbon recovery from beneath already developed sites (brownfield rather than greenfield sites). US wells have also been sited close to reservoirs (Plate 8.3).

In 2006 Halliburton estimated that 35,000 shale gas wells were drilled in the US. In the 10 years between 2000 and 2010 about 168,000 new gas wells were drilled.

Current trends in the Barnett Shale, in addition to drilling longer laterals, are for larger hydraulic fracture jobs and more stages, which increases initial production (IP). Infill wells are reducing spacing to 10 acres. Re-fracturing of the first horizontal wells has commenced. Both infills and re-fractures are expected to improve Estimated Ultimate Recovery from 11% to 18%. Pad

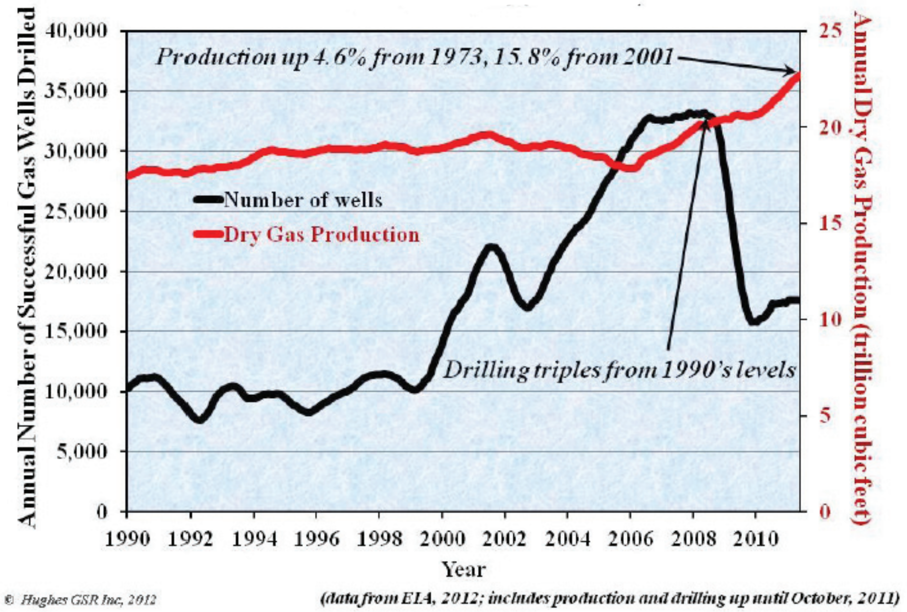
Plate 8.3: Exploration in the Marcellus Shale, Adjacent to Beaver Run Water Reservoir. Reproduced by Kind Permission of the Photographer. Photo: Robert M. Donnan©, 2010.

drilling, especially in urban areas, and recycling of water are increasing. Up to 2010 about 15,000 wells had been drilled in the play, over an area of 13,000 km², resulting in an average well density of 1.15 wells per km², but regionally there may be about 6 wells per km² (Lechtenböhmer et al. 2011).

In Pennsylvania alone 1400 shale gas wells were drilled in 2011, which is one well per 40 square kilometres. The state has an area of 46055 square miles (119283 square kilometres), but about half lies within the Appalachian fold-belt, which is outside the prospective area.

The increase in drilling at about the turn of the century reflects the success in the Barnett Shale play in the Fort Worth Basin in Texas (Fig. 8.1). Drilling for gas peaked in 2008, when the gas price exceeded $12/mcf (12 dollars per thousand cubic feet). Gas production then increased to present, reflecting this increase in successful wells. In 2012 the gas price at Henry Hub in the US is now down to below $3/mcf (Hughes 2012). Gas prices in Europe are 3–4 times higher than the Henry Hub price.

Figure 8.1: US Natural Gas Production and Successful Gas Wells in the Period 1990–2011. Reproduced by Kind Permission of J. D. Hughes of GSR Inc. and the Post Carbon Institute.



Europe is attractive for gas exploration because of its large market, good pipeline infrastructure and high (increasing) import dependency and therefore high gas prices. The main difference is that mineral rights are held by the states rather than landowners, which is the legal position in the US.

8.1.2. Factors Relevant for Shale Gas Exploration and Production

Already in Europe and elsewhere shale gas exploration has proved more of a challenge than it was in the US. This applies before any production is envisaged. Various gas in place figures (GIP) have been calculated prior to analysed data from wells becoming available. One example is the study by Advanced Resources (2011), providing estimates for most countries, with recovery factors of about 25% assumed. The UK recovery factor (21%) is lower than other countries presumably because of the high amount of land which cannot be easily reached beneath cities and towns. Exploration is at a very early stage in most countries and the infrastructure and technological support is likely to be slow to be mobilised compared to the US.

The reasons for this may be grouped as follows:

1. Geology
2. Exploration licensing
3. Logistical constraints in Europe
4. Population/urban setting and environmental resistance
5. Agency (Environmental) regulation
6. Government attitude/tax Poland has talked about a tax on production before there is even proof that it can be produced
7. Public acceptance
8. Reaction of companies

1. Geology

The main targets in Europe are shales of Lower Palaeozoic (Alum Shale and others), Carboniferous, Jurassic, Cretaceous and even Tertiary ages. The Tertiary shales are in deep basins with high geothermal gradients. The oldest plays are comparable in age respectively with the thermogenic shale gas plays of Conasauga and Utica, the Carboniferous play with the Barnett and Woodford, and the Jurassic-Cretaceous plays with the Haynesville and Eagle Ford in the USA. The Conasauga has no conventional fields associated and is not one of the best prospects. The US shales have different characteristics and, notably, host biogenic gas in Devonian shales (Antrim and New Albany) in the northeastern USA. Europe has fewer Devonian black shales, most of which are within the Variscan fold belt but biogenic gas, suspected in some basins, is known from the Alum Shale in Sweden. The most attractive shales are already proven hydrocarbon source rocks, having provided hydrocarbons to conventional fields. These include the Paris Basin and Lower Saxony Basin in Germany and Wessex Basin, UK where Lower Jurassic shales (Toarcian and older) are the source rocks and foreland basins of the Pyrenees, Alps and Carpathians.

Lower Palaeozoic

The Cambro-Ordovician Alum Shale of Sweden, Denmark and the east Baltic is an immature source rock in Latvia, the source to small oilfields off eastern Sweden (island of Gotland) and a target for Shell where it outcrops in southern Sweden and licences in Denmark where it is concealed and mature for thermogenic gas (Pool et al., 2011). This shale gas play is more fully described in a later section. An equivalent play may exist in the UK (Smith et al., 2010), formerly on the opposite side of the Tornquist Ocean to Scandinavia and Poland.

In Poland Silurian and younger Ordovician shales are the primary target, with Alum Shale at greater depth. Silurian shales are a proven source rock for oil here and have high total organic carbon (TOC) contents and high maturity in the Czech Republic also (Schulz et al., 2010).

Chevron has just bought a stake in a Lithuanian company with a view to exploration.

Carboniferous

The geology of Europe, before the Atlantic Ocean opened, has a lot in common with North America. This is particularly true of the Carboniferous system, because the European northern chain of the Variscan fold belt, which passes through Slovakia, the Czech Republic, Poland, Germany, Luxembourg, Belgium, France, UK and southern Ireland was formerly connected to the Appalachian mountains of the eastern USA. The most obvious manifestation of this connection is the Westphalian Coal Measures which extend between the Ukraine, western Europe and east Canada-USA, but basinal Lower Carboniferous and basal Namurian shales are also a widespread facies both within the Variscan fold belt and on its foreland.

The northern chain also extends, significantly, into Texas, southern USA as the Ouachita mountains. Northwest of these mountains lies the Barnett Shale of the Fort Worth Basin, in a foreland basin. Exploration of the Barnett Shale and experimentation with hydraulic fracturing and horizontal drilling by Mitchell Energy and later Devon Energy led to a rapid improvement in productivity, which caused the worldwide exploration now taking place.

Shales of similar ages to the Barnett Shale occur in Europe to the north of the Variscan fold belt. In Ireland they are known as Clare, Benbulben and Bundoran shales (Lough Allen Basin), in the UK Upper and Lower Bowland Shale (Pennine Basin), in the Netherlands Epen Formation (West Netherlands Basin), the Rhenish Alum Shales and older shales in Germany (Kerschke et al., 2012). Some of the basins are within the foreland of the Variscan orogen, either directly adjacent to the foldbelt, (Clare Basin) and flexed down by overthrusting of the orogen (foreland basin) or farther north in extensional basins. The different types of basins give different geological sequences and because Coal Measures occur above the targets, along with early industrial complexes and power stations population density tends to be higher in the foreland basins. The extensional basins away from the fold belt contain a different facies, limiting the development of shales geographically by a southerly delta influx but thicker than US foreland basin sequences.

Jurassic

In the Lower Jurassic a widespread organic rich development is present in the UK's Wessex, Weald and Cleveland basins, in France in the Paris and Aquitaine basins. In Germany in the Northwest German Basin, in Switzerland's Molasse Basin and in the West Netherlands Basin are the equivalent Posidonia Shales (Toarcian age). The main organic mudstone in the UK is older than the Toarcian. In most of these basins the shale is a proven source rock and there are also some high maturity areas associated with Cretaceous intrusions (Schulz et al., 2010). LNG has targeted the Etropole Shale in Bulgaria.

In the Austrian Vienna Basin OMV explored the Mikulov Formation (Upper Jurassic), which has provided the source for conventional hydrocarbons. The basin also extends into the Czech and Slovak republics. Farther west in Europe the equivalent-aged Kimmeridge Clay is organically rich but less mature. Overlying organic rich beds are likely to be similarly immature for gas (e.g. Wealden of NW Germany).

Tertiary

Tertiary shales are a target for shale gas because of deep burial, overpressuring and high geothermal gradients in the Pannonian Basin and the Carpathian-Balkan Basin.

2. Licensing

European countries have responded differently to shale gas opportunities. Poland has allocated licences over its prospective areas. The UK has delayed the 14th round of onshore licensing, which is likely to see a similar development. Some countries have issued licences, but then back-tracked by imposing conditions or banning hydraulic fracturing.

Three basins in Poland are prospective (Baltic, Lublin and Podlasie), which are foreland basins NE of the Caledonide fold belt. The Baltic Basin extends along the east coast into Lithuania and Latvia and the Lublin Basin extends into Ukraine. Poland has granted 112 licences for shale gas exploration.

In July 2012 Poland announced the collaboration of 5 state companies to develop the Wejherowo concession along the Baltic coast (Wright & Kulkarni 2012). Investment is expected to be $515 million, where $8–13 million is the average cost of a well (2–3 times greater than in the US).

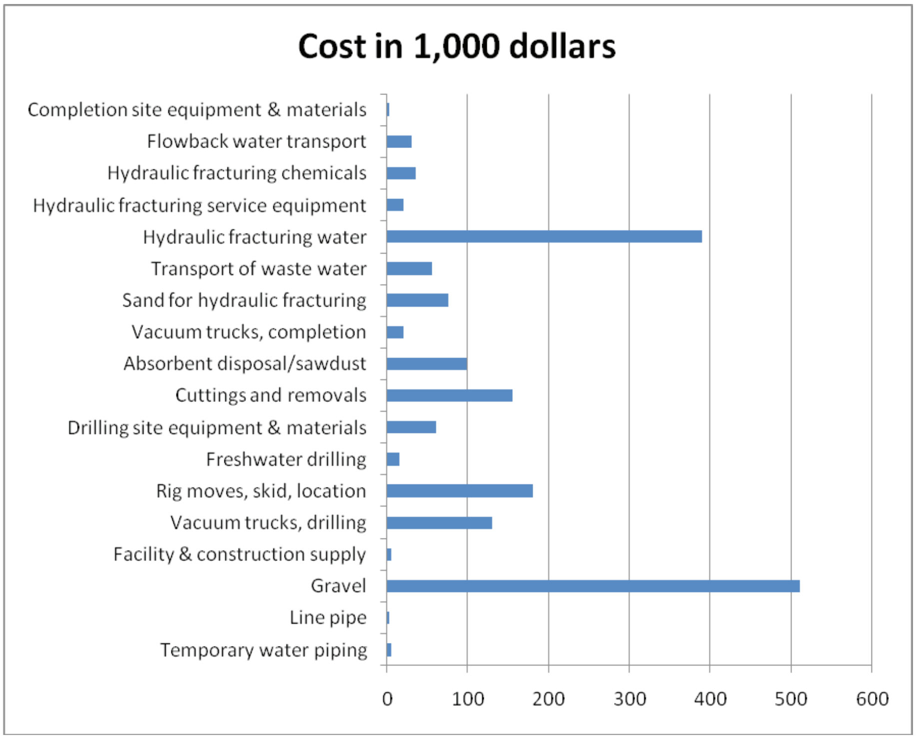
In the UK since the 2008 licensing round awarded 3 licences for shale gas, one only has seen drilling of 4 wells, all vertical. One horizontal is in the planning stage. On a handful of other licences, originally intended for conventional or coalbed methane, exploration has included deeper wells in which samples of shales have been taken.

In Ireland Enegi Oil plc has been awarded a licence covering 495 km^2 in the Clare Basin. Enegi expect the prospective shales to be about 150 m thick. In the Lough Allen Basin Tamboran Resources Pty (986 km^2) and Lough Allen Natural Gas Company Ltd (467 km^2) have licences. Tamboran currently has the most advanced plans, having sampled outcrops and expects to drill shallow cored boreholes initially (100–200 m), then a deeper 1200 m well. The company is considering an Environment Impact assessment prior to seeking permission to drill.

3. Logistical Constraints

Unconventional hydrocarbon exploration requires more transportation services for drilling, compared to conventional exploration, because a greater volume of materials is required for the hydraulic fracturing (water, sand proppant and chemicals) and for disposal of removed wastes, which require treatment (Fig. 8.2). This might be technically more feasible with local, already established transport companies and treatment works in high population areas, but the additional road journeys pose a problem for intensive drilling. Each hydraulic fracturing stage pumps about 300,000 gallons of water and up to 200 tons of sand and 20–40% of the fluids and solids used in hydraulic

Figure 8.2: Extra Costs of US Shale Gas Exploration in $1,000 (Carr et al., 2012, Based on Deloitte's Proprietary Wellsite Logistics Model, Assuming Four Wells Drilled from One Pad).



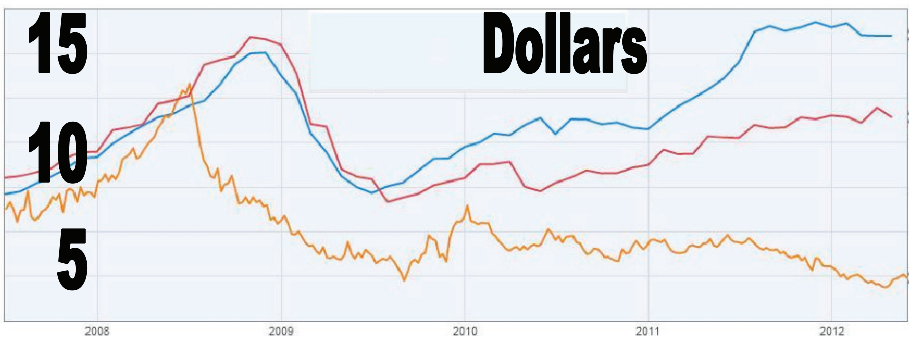
fracturing flow back to the surface as hazardous waste and require transportation to treatment and disposal sites. In the US waste waters are injected into nearby deep disposal wells. The increased handling of materials offers a greater possibility of accidental spills.

The problems associated with fluid and material handling will drive the introduction of 'green' or reduced emission completions (RECs) in Europe, a process already underway in the US, there driven by shortage of water and costs of water handling. The regulators can encourage this. Recycling of water and using saline water is already practised in the Horn River Basin of Canada.

Horizontal production wells from fewer pad sites are essential where open land is either non-existent or already valuable for farming or recreation. One horizontal drilling pad can cover 6 acres. Four times more vertical wells would be required, covering 20 times more land area, and necessitating 13 times longer access roads and pipelines and 6 times the number of facility pads to produce from the same area (King 2010), which is only acceptable where the land is otherwise unproductive.

Whereas most of the costs of exploration are higher in Europe, the price of imported gas to Japan and Europe is also much higher than the US Henry Hub gas price (June 2012, Fig. 8.3). Shale gas exploration has been so successful in such a short time in the US that it is no longer profitable to explore for gas at present.

Figure 8.3: Price of Gas at Different Places (Japan Liquefied Natural Gas (LNG) Import Price 16 Dollars, Henry Hub Gas Spot Price (US) 2.4 Dollars, Europe Gas Pipeline Import Price 11 Dollars.



Rigs and Other Drilling Requirements

Shale gas drilling costs need to be reduced, particularly in the US. Eagle Ford operators have now driven down their average drill time to 19 days per well compared to 23 days in 2011. Bakken drilling time is also vastly improving with operators cutting off an average of 30 days drill time per well between 2004 and 2009.

Some companies involved in unconventional exploration deploy their own drilling rigs, Composite Energy (for coalbed methane exploration, now owned by Dart Petroleum) and Cuadrilla in the UK possess their own rigs. This gives greater flexibility to drill when required, which helps to reduce some costs, but in house expertise may not aspire to what is available outside.

In Poland there were 15 land rigs available in 2011, but only 5 were suitable for deep shale wells and many more would be needed if shale gas exploration was successful. Thirty three wells have been drilled so far (Dec. 2012). Orlen Upstream used a new DRILLMEC DM-1300 rig from Italy for their Gozdzik well, in addition to another contracted rig operating simultaneously, so that the problem of a shortage of rigs might be overcome. Of about 60 land rigs owned by KCA Deutag this year only 9 were in Europe, with 16 in Russia and most of the rest in Africa.

IHS Petrodata Petrodaily Rigs Europe lists offshore rigs but there is no equivalent onshore service yet.

The total number of rotary rigs operating in October was 3,458 down 10 from September and 183 (7.4%) lower than last year (IHS) and similar figures in Table 8.1. Over half of the total number in the world was operating in the US. If shale gas production becomes established elsewhere in the world this proportion will inevitably decline. Note the small number currently operating in Europe. Four rigs were operating in Poland in November (James Williams personal communication).

For plug and perforate and mechanical, ball drop or remote actuated sliding sleeve completions Halliburton envisaged that insufficient pressure pumping equipment will be available in Europe, so initially at least, coiled-tubing assisted fracturing is likely to be used (Hsieh 2011).

Poland's biggest oil companies, Orlen and Lotos, gas company PGNiG and four R&D organizations have formed a consortium to develop technologies

Table 8.1: WTRG Economics's Weekly Rig Count, Based on Data from Baker Hughes, Reproduced by Kind Permission of James L. Williams.

Worldwide Rotary Rig Count				Change		Percent Change	
	October 2012	September 2012	October 2011	Monthly	Annual	Monthly	Annual
Latin America	412	411	438	1	(26)	0.2%	-5.9%
Europe	124	124	122	0	2	0.0%	1.6%
Africa	104	108	81	(4)	23	-3.7%	28.4%
Middle East	377	381	308	(4)	69	-1.0%	22.4%
Far East	242	230	259	12	(17)	5.2%	-6.6%
International	1,259	1,254	1,208	5	51	0.4%	4.2%
Canada	365	355	508	10	(143)	2.8%	-28.1%
United States	1,834	1,859	2,017	(25)	(183)	-1.3%	-9.1%
World	3,458	3,468	3,733	(10)	(275)	-0.3%	-7.4%

to produce shale gas. This is probably a reaction to ExxonMobil's withdrawal. Orlen are also reported to be interested in taking over some of the Exxon-Mobil licences.

Service Companies, Cost of Drilling, Pipelines

According to Schlumberger drilling a shale gas well in Poland costs almost three times as much as in the US: $11 million compared to $3.9 million for a depth of 2000 metres. Shale depths in Europe are on average 1.5 times greater than in the US, translating into the need for powerful rigs, more powerful pumps and more fracturing fluids, according to the Oxford Institute for Energy Studies. In the Vienna Basin OMV estimated that drilling a well more than 16000' (4877 m) deep could cost more than $20 million.

In US pipeline owners are obliged to allow anyone to pay to use them to move gas from the well to the market, whereas in Europe there is no obligation to allow third-party access.

4. Population Density

The European Union is primarily an economic entity possessing some federal characteristics. Its population density has been estimated at 116 people per km² (Table 8.2). Large areas of European countries have very low population density

Table 8.2: Selected Countries, Population Area and Population Density (Data from Wikipedia).

Country	Population	Area km^2	Density
European Union	503,492,041	4,324,782	116
Netherlands	16,751,323	33,783	496
Belgium	10,839,905	30,528	355
United Kingdom	62,262,000	242,910	256
Germany	81,844,000	357,123	229
Luxembourg	511,800	2,586	198
Italy	59,464,644	301,308	197
Switzerland	7,952,600	41,285	193
Czech Republic	10,507,566	78,867	133
Denmark	5,587,085	43,098	130
Poland	38,538,447	312,685	123
France	63,632,000	543,965	117
Portugal	10,561,614	92,090	115
Slovakia	5,445,324	49,036	111
Hungary	9,957,731	93,029	107
Moldova	3,559,500	33,843	105
Slovenia	2,057,740	20,273	102
Austria	8,452,835	83,879	101
Albania	2,831,741	28,703	99
Turkey	74,724,269	769,604	97
Spain	47,212,990	503,783	94
Serbia	7,120,666	77,474	92
Greece	10,787,690	131,957	82
Romania	19,042,936	238,391	80
Macedonia	2,059,794	25,713	80

Croatia	4,290,612	56,542	76
Bosnia-Herzogovina	3,868,621	51,209	76
Ukraine	45,560,272	603,628	75
Bulgaria	7,364,570	111,002	66
Ireland	4,588,252	70,273	65
Lithuania	2,988,381	65,300	49
USA	314,691,000	9,161,074	34
Latvia	2,070,371	64,562	32
Estonia	1,294,236	43,432	30
Sweden	9,522,998	410,314	23
Finland	5,424,420	303,893	18
Norway	5,043,500	323,782	16
Russia	143,200,000	17,075,400	8

in mountainous areas like the Alps, Ardennes and Scottish mountains but this also applies to the US Rockies and Appalachian mountains, where exploration is unlikely for the foreseeable future. The countries are in order of density of population and it seems likely that those with the highest densities will find the most difficulties in accommodating exploration.

One reason for this is the amount of physical space already occupied by houses and other buildings in high density countries. This reduces the opportunity for exploration and restricts likely productive areas. In low density population areas of the US small earthquakes are unlikely to be noticed but in high population areas sensitivity is increased and in property-owning areas this leads to worries about subsidence. Inhabitants within coalfield areas of Europe are familiar with induced earthquakes, but many of these people had a vested interest in the success of the associated development. This is less likely to be true with respect to shale gas exploration.

In the past in conventional hydrocarbon fields deviated drilling was able to permit development under villages and towns (e.g. Wareham in England). This cannot be envisaged in shale gas at the present time in many places in Europe, in contrast to the US (see above).

The population density figures are probably also a rough indication of the level of environmental opposition which can be mustered, but with online communications both cooperation and cross fertilisation have never been easier.

5. Agency Regulation

Based on some of the negative experiences in the US regulatory agencies in Europe have been preparing guidelines connected with exploration and production. The studies are primed with recent research on the vertical extent of hydraulic fractures which might affect aquifers (Davies et al., 2012). The organisations include the European Commission, environment and water authorities in various countries, so that conflicting regulations may be suggested and applied by different organisations.

Also pre-emptive measurement of methane in groundwater by BGS is being undertaken in the UK to provide evidence of background levels prior to widespread drilling. Some high values are already known (Darling & Gooddy 2006). The water agencies in the UK (Environment Agency, SEPA) will probably encourage monitoring of water wells before, during and after shale gas well drilling.

OMV sought to conduct experimental hydraulic fracturing in a region in Austria known as the Weinviertel, or wine region. Public opposition was extensive and a new environmental bill was passed requiring that a full environmental impact study be conducted prior to hydraulic fracturing, with the result that OMV withdrew plans for drilling in September 2012.

The International Institute of Political Science (IIPS) has prepared a study on 'Shale Gas in Poland and the Czech Republic: Regulation, Infrastructure and Perspectives of Cooperation', that highlights the possible triple layer of regulation being imposed on shale gas exploration, from the EC, the nation state and local authorities. It is important to provide a regulatory regime which at the same time can provide a framework within which companies can operate and safeguard the environment and local people's sensible priorities. This is difficult where licences are awarded, but hydraulic fracturing is subsequently banned (Bulgaria, France).

6. National Government position with respect to shale gas

In the US the long production history of shale gas and long-standing familiarity with hydraulic fracturing in conventional exploration and substantial onshore production are factors that do not apply anywhere else. Even in the US in more populous areas state legislation in Pennsylvania (May 2010) and New York (August 2010) banned hydraulic fracturing.

Some governments welcome shale exploration to achieve a security of supply for at least part of their energy supplies. However, the attitude of other governments reveals that exploration and production will not be universally accepted. For example Poland, putting security of supply first and France (banning hydraulic fracturing in July 2011) are at opposite ends of the spectrum.

Bulgaria also banned hydraulic fracturing in January 2012, despite having previously awarded 6 licences to 5 companies (Sheehan, 2011).

Romania and the Czech Republic have banned hydraulic fracturing. The latter is using the ban to allow about 1–2 years to prepare legislation to cover shale gas exploration. Two licences for Hutton Energy were revoked. In Romania Chevron has four licences.

Hydraulic fracturing was suspended 'voluntarily' in the UK in Cuadrilla's Lancashire licence after the first hydraulic fracturing induced earthquakes at the Preese Hall well (de Pater & Baisch, 2011; Green et al., 2012), but DECC has now allowed a resumption in operations (Dec. 2012).

OMV have recently announced they would withdraw from exploration in Austria, citing the enactment of a new environmental law.

A recent report for the German Environment Ministry recommends a ban near to aquifers and mineral springs.

In France the ban on 'hydraulic fracture stimulation of wells following drilling', in July 2011 did not, initially, prevent unconventional hydrocarbon exploration in some extant licences.

There is no timetable for any changes. This is an incentive to make greener completions standard in Europe, but France is relatively independent-minded because of its nuclear energy.

In September 2011, the French licensing authorities asked Total to submit a report to them detailing the exploration methods for unconventional gas expected to be used in its exploration licence of Montélimar, in southern France. The work programme described in the report did not envisage the use of the hydraulic fracturing technique. Nevertheless, the government withdrew Total's exploration permit in October 2011. The exploration permits of Schuepbach for two shale gas licences in the regions of Ardeche and Larzac in the south of France were also withdrawn.

In April 2012, a report commissioned by the French Government recommended the establishment of a national commission on shale exploration and exploitation techniques.

A key focus of the commission will be establishing the conditions for environmentally acceptable hydraulic fracturing operations, including regulations for managing risks and protecting the environment during the experimentation of new techniques for shale exploration. The commission is expected to initially focus on the oil shales of the Paris Basin.

The Irish energy minister Mr Rabbitte, revealed that no hydraulic fracturing will be permitted "pending further detailed scientific analyses". Nicola Dunleavy, a lawyer specializing in environmental issues, said a plethora of legislation, rules and directives already in place could apply to shale gas developments in Ireland. It was not completely clear whether the Irish authorities would demand Environmental Impact Assessments (EIAs) before exploration licences were granted, although they would almost certainly before any extraction work went ahead. A report in May 2012 stated that the Environmental Protection Agency of Ireland will license any extraction of shale gas on a commercial scale (Healy, 2012).

The EU has a Technical Working Group on the regulation of shale gas extraction. Three reports for the EU have considered different aspects of shale gas and revealed inconsistencies and gaps in legislative control. EU regulations have also been implemented in Poland for licensing awards. New awards will be by competitive tendering, rather than the first come first served approach which formerly applied.

7. Public Acceptance of Risks

There is no human endeavour entirely free from risks. Impartial, scientific and evidence-based assessment of risks is essential in any undertaking and this is magnified in importance at operations close to habitation. Websites for example Shale Gas Information Platform (SHIP of GFZ Potsdam) provide such information and advice, helping to inform the public and encourage greener best practices in the industry. Reduced emission completions (RECs) are now commonly used in the US to reduce the environmental footprint caused by fugitive methane emissions and they are part of the solution to a more acceptable exploitation in Europe. GFZ Potsdam also has its European Sustainable Operating Practices (E-SOP) website to encourage adoption of the latest developments in US completions. Worldwide exploration now has the opportunity to leapfrog into these advanced techniques, eliminating some of the old techniques and mistakes which have caused pollution, overuse of resources and added to the operator's costs in the US.

In the UK a charitable trust has been set up with the aims of providing scientific information for the public to make more objective decisions rather than what is sensationally provided in the media or exaggerated by pressure groups (http://www.senseaboutscience.org/). This is not confined to earth science issues.

In the US agents from drilling companies offer three- to six-year drilling leases to property owners. The payment can be from $15 up to $6,000 per acre. This can have a positive impact on public acceptance, although it may cause the drilling rig to be sited across the farmyard wall. Inevitably, in some areas other inhabitants are affected, but including those who have not received such payments. These are the property owners upset by US evidence that house purchase prices are reduced near to shale gas exploration. UK newspapers avidly took these results and helpfully showed property owners how their houses might be devalued, without taking the differences between the US and elsewhere into account. As far as I am aware, in contrast to the US, hydrocarbons in European countries are the property of the state or crown rather than individual landowners. This reduces the likelihood that any of the local population will support the development in which they will have no direct financial benefit.

Hydraulic fracturing was banned in North Rhine-Westphalia in 2011 by the regional authority.

8. Reaction of Companies

ExxonMobil have embarked on a more open debate, including a website and a published report about hydraulic fracturing in response to its ban in North Rhine-Westphalia (http://www.naturalgaseurope.com/exxonmobil-and-shale-gas-in-germany). One well was fractured but the others have been capped pending a lifting of the ban (Table 8.3).

ExxonMobil drilled 2 wells in Poland and ceased further exploration reporting that gas flows were too small. The company also abandoned a joint venture with Falcon Oil in the Mako Trough in Hungary, in 2009, after 4 wells and 2 disappointing results of hydraulical fracturing in the Foldeak-1 well. MOL

Table 8.3: Shale Gas Wells with Available Information.

Well name	Country	Operator	Spud year	Hfracture
Preese Hall	UK	Cuadrilla	2011	HF
Grange Hill	UK	Cuadrilla	2011	
Becconsall	UK	Cuadrilla	2012	
Anna's Road	UK	Cuadrilla	2012	
Ince Marshes	UK	Igas	2012	
Lovestad A3-1	Sweden	Shell	2009	
Hedeberga B2-1	Sweden	Shell	2010	
Oderup C4-1	Sweden	Shell	2010	
GH-2	Sweden	Gripen AB	2012	no HF
Six other wells	Sweden	Gripen AB	2012	no HF
Motala	Sweden	Aura	2011	no HF
Lewino 1G-2	Poland	San Leon/ Talisman	2011	
Chopin 1	Poland	San Leon/ Talisman	2011	
Belvedere 1	Poland	San Leon/ Talisman	2011	
Rogity 1	Poland	San Leon/ Talisman	2012	
Szymkowo	Poland	San Leon/ Talisman	2012	
Siciny 2	Poland	San Leon/ Talisman	2012	
Lelechow SL 1	Poland	San Leon/ Talisman		
Lebien LE1	Poland	3Legs/Conoco	2010	
Lebien LE-2H	Poland	3Legs/Conoco	2011	HF
Legowo LE1a	Poland	3Legs/Conoco	2010	HF
Warblino LE-1H	Poland	3Legs/Conoco	2011	HF
Warblino LE-1H	Poland	3Legs/Conoco	2012	
Strzerzewe LE 1	Poland	3Legs/Conoco	2012	
Wytowno 1	Poland	BNK	2011	HF
Lebork S-1	Poland	BNK	2011	HF

Starogard	Poland	BNK	2011	
Gapowo B-1	Poland	BNK	2012	
Miszewo T-1	Poland	BNK	2012	
Krupe 1	Poland	ExxonMobil	2011	HF
Siennica 1	Poland	ExxonMobil	2011	HF
Markowola-1	Poland	PGNiG	2010	HF
Lubocino 1	Poland	PGNiG	2011	HF
Opalino 2	Poland	PGNiG	2012	
Lubocino 2H	Poland	PGNiG	2011	HF
Lubycza Krolewska	Poland	PGNiG	2012	
Trzek 3	Poland	Aurelian Oil & Gas	2011	
Syczyn OU-1	Poland	Orlen Upstream	2011	
Berejowo OU-1	Poland	Orlen Upstream		
Gozdzik OU-1	Poland	Orlen Upstream	2012	
Syczyn OU-2K	Poland	Orlen Upstream	2012	
Bagard 1	Poland	Eni		
Stare Miasto 1	Poland	Eni		
Kamionka 1	Poland	Eni		
Frampol 1	Poland	Chevron		
Grabowiec 6	Poland	Chevron		
Zwierzyniec	Poland	Chevron	2012	
SIE Domanice 1	Poland	Marathon		
RYP Lutocin 1	Poland	Marathon		
ORZ Cychow 1	Poland	Marathon		
KWI Prabuty 1	Poland	Marathon		
BRO-NM Lubawskie 1	Poland	Marathon	2012	
Foldeak-1	Hungary	Falcon/Exxon/MOL	2009	HF
Gyula-1	Hungary	Falcon/Exxon/MOL	2009	HF

BA-E-1	Hungary	Delta Hydro-carbons/ Cuadrilla	2011	
Damme 2/2A	Germany	ExxonMobil	2008	
Damme 3	Germany	ExxonMobil	2008	HF
Oppenwehe 1	Germany	ExxonMobil		
Niederwohren	Germany	ExxonMobil	2009	
Schlahe 1	Germany	ExxonMobil	2009	
Lunne 1	Germany	ExxonMobil	2011	
Nopke 2	Germany	ExxonMobil	2011	
Botersen Z11	Germany	ExxonMobil	2011	
Sohlingen Z15	Germany	ExxonMobil	2012	
Varnhorn Z2	Germany	ExxonMobil	2012	
Boxtel	Nether-lands	Cuadrilla		
Peshtene R-11	Bulgaria	LNG	2011	
Saribugday 1	Turkey	Shell	2012	

also withdrew from Hungary (Sheehan, 2011). RAG and Cuadrilla obtained 1mmcf 'flow back' by re-completing a well (Anon, 2011), possibly gas, and sold condensate via a nearby pipeline (Lucas website).

Polish company Orlen have produced an optimistic appraisal of the economic effects of shale gas success in Poland (PKN Orlen, 2012). Taking over licences from ExxonMobil and possibly Talisman is a further indication of their intent.

Because of the hydraulic fracture ban in France, Vermilion Energy have deferred drilling two vertical wells and re-completing existing wells in the Paris Basin shale oil play. Toreador resources (ZaZa) have re-focused on conventional plays in the basin.

Shell have withdrawn from their Scania, southern Sweden licences after drilling 3 shallow wells, citing low gas contents (Pool et al., 2012), whereas smaller companies are exploring an even shallower variation on the same play, in an area to the north, already known to produce (sustainable) gas.

8.2. Models for Exploration in Urban Areas

Seismic reflection surveys (using vibroseis trucks) have been conducted in urban areas, for example Chicago, in Bath, UK for hot spring protection and Paris (France), Long Beach and Los Angeles, US (Freed, 2009) for conventional hydrocarbon exploration and Fort Worth-Dallas airport (Plate 8.2). When surveying close to sensitive urban sites vibration monitoring can be employed to ensure no damage is done and crews can be instructed to avoid road ironmongery and other marked services. Urban seismic in the US can be acquired using vibroseis trucks one third the size of conventional trucks: the result is not compromised (Griffin, 2008).

In Lancashire after consultations with residents and the local MP, Cuadrilla confirmed that the minimum distance between detonations (dynamite used as source for 3D seismic) and homes would be increased from 250 m to 500 m, where possible, in the built-up areas of Lytham, Wrea Green, Kirkham and Wesham. Detonations have been restricted to between 9 am and 6.30 pm.

In the US drilling within urban areas is being attempted, pioneered by Chesapeake (Plate 8.1). This is probably the closest exploration analogue that US has with some European countries where the population density is nearly 10 times greater (Table 8.2). Near Fort Worth conurbation drilling occurs adjacent to the international airport and within sight of the central business district (Davidovich, 2011; Plate 8.1). Drill pads can comprise 30 wells, with 7.5' between well heads and 330' interwell distance for 500 acre units. The time taken from terminal depth to spudding the next well is less than 8 hours and lateral lengths might reach 7000' (2134 metres) (Griffin, 2008). New types of rigs called flex rigs and walking rigs allow these improvements in drilling times.

The main objections to drilling are noise, safety during drilling, inconvenience on roads or use of land, its effect on property values, visual impact, safety (from vandalism) on completion and setting a precedent for drilling in the urban environment (Spady & Poole, 2004). Noise mitigation can be tailored to individual sites and uses acoustic barriers encasing the drilling rig. Light use is directed downwards and shielded from surrounding housing. An additional factor which is a burden on the agency responsible for maintaining roads is the impact of large increases in lorry journeys on road surface deterioration. This problem is one Europe and the rest of the world can learn from the US and insist on closed loop cycling of water at the site to minimise these journeys.

In Charleston, West Virginia one well was donated to the university to offset energy costs. Owing to local neighbourhood reaction the initial preferred location was moved onto a sports field farther away from urban buildings. Drilling noise was anticipated to be less than 70 dbA at 200 feet away (61m). Novel extra expenses compared to normal exploration included running a sewer video camera because of fears of collapse due to lorry movements and a bond for the cost of repaving the street if it were to be damaged. This well was able to be serviced from the adjacent river which limited the lorry journeys (Spady & Poole, 2004).

Operators are keen to be seen to be open in the information given (Cuadrilla, 2012), but this is scrutinised carefully by anti-shale gas organisations and exposed where breaches are noted. Cuadrilla exceeded a time limit on drilling designed to safeguard over-wintering birds. However, Cuadrilla is committed to informing all interested parties and conforming to all relevant regulation so that they can obtain what they are calling a 'social licence to operate'. This, in effect, aims to be a contract with the local population, rather than the licensing or planning authorities.

8.3. Selected Examples of Exploration so far in Europe

The Swedish Alum Shale play, with 2 different projects by a large and a small company presents interesting contrasts with exploration in the US and those underway in the rest of Europe. The Cuadrilla exploration in the UK is also a model for the high volume high fracturing method, applied to Europe.

8.3.1. Alum Shale (Mid Cambrian-early Tremadoc), Sweden

Exploration in Sweden is particularly interesting because it contains a number of different elements compared to US exploration.

Shell acquired licences in southern Sweden to explore a thermogenic gas play in the Alum Shale. The operator conducted a very low key exploration of the Colonus Shale Basin (in which the Alum Shale is very near the surface), right from the outset because of the potential for environmental opposition. This approach resulted in many compromises, for example, acquiring seismic reflection data from a landrover towing receivers. The quality of this seismic is very poor, in an area where good quality is needed because there are few deep boreholes: the structure and sequence is still relatively unclear (Pool et al., 2012). Analysis of the results of three wells (Table 8.3), in an area where gas shows had been previously recorded, and in particular the low thermogenic gas contents led to Shell's withdrawal.

Commercial flow rates are different for large and small companies. Smaller companies are perhaps better suited to low impact exploration and production, because margins are tighter for them. Gripen Gas AB is a small Swedish company, founded in 2010, exploring farther north, where the Alum Shale is less mature, but has flowed biogenic gas in Östergotland. The company is the largest unconventional gas acreage holder in Sweden and currently holds 583km^2 of exploration licences in Östergötland and on the island of Öland.

Methane has been known for many years, from the central part of Östergötland, where the Swedish Geological Survey reported over 50 gas seeps. The gas seeps appear to come from the bacterial degradation of the organic rich Alum Shale and at the moment the emissions add to the atmospheric flux. Gripen plan to capture the gas (also beneficial from an environmental standpoint) and convert it to electricity using micro-generators, using existing Swedish engineering and drilling technology for exploration and future exploitation.

In March 2012 four wells in the Ekeby Permit were drilled and tested with encouraging results (Table 8.3). In October 2012 a 3 well appraisal programme concentrated around the GH-2 discovery, which was flared on test. The drilling results confirmed the geology of the area and established commercial flow rates from the discovery.

On the 24th October 2012 Gripen Gas was awarded the Sandön licence covering 162 km^2 in the western part of Lake Vättern, in Östergötland County, offshore with water depths varying from 10–30 metres, where biogenic gas seeps occur, often trapped beneath ice in winter. The exploration licence is for biogenic gas exploration in the predicted deepest and thickest organic rich Alum Shale in the Östergötland Basin. A Swedish drilling company already has some experience here in exploration for minerals. Aura Energy have also drilled 5 very shallow wells down to about 80 m as part of its Motala project near Linkoping where, already, seep gas has been used in farm heating.

This biogenic gas play appears to be similar to those of the northeast US in the Antrim and New Albany shales, where post-glacial bacteria-laden waters have infiltrated to the organic-rich source rocks. The age of the host rocks is different, but irrelevant to the process. The economic impact of biogenic gas production (high methane content) on Sweden may be small, yet significant:

environmentally it is better than importing gas from further afield and should reduce natural seeps eventually, in addition to those that are deliberately captured.

Thermogenic and biogenic gas is known in the offshore near Stockholm within lineaments in crystalline rocks (Soderberg & Floden, 1992) and their origins are unknown. They may equate with abiogenic gas shows in Koksher Island, Estonia, in mines in Finland and the higher hydrogen contents of Cambrian sandstones on Öland (see references in Smith et al., 2005).

8.3.2. Cuadrilla Licence in Lancashire, UK

Cuadrilla is a company formed specifically to explore for shale gas. The founders had experience and success in coalbed methane (CBM) production in the Raton Basin in the US and also experience in unsuccessful CBM exploration in the Cheshire Basin, UK. The company chose the best site in the UK, where a one-well producing gasfield (Elswick) reservoired in Permian overlies pre-Westphalian strata. In other words there was a very high possibility that the gas has been sourced from underlying gas window mature shales rather than Westphalian Coal Measures. The nearest Coal Measures (Smith, 1985) are too far away to be the source. Geochemical studies of the source for offshore East Irish Sea fields also supported this interpretation. The licence was awarded in the 13th Round of onshore licensing in 2008. Pre-existing drilling and seismic reflection data was by British Gas (BG) in the 1980s. Two wells drilled near Elswick also had gas shows in the Carboniferous section. Subsequent BGS dating of the rocks showed that the British Gas interpretations put the Variscan unconformity too low and this is a reflector difficult to follow in parts of the profiles.

Drilling the first UK shale gas vertical well began, in 2010, at Preese Hall, situated in a Carboniferous syncline, in contrast to BG's conventional Thistleton and Elswick wells, all aligned close to the same E-W trending seismic reflection profile. Hydraulic fracturing was delayed until 2011 and was halted after some minor, felt earthquakes were induced. Co-venturers Lucas published a figure of 400–500 cfd produced on test from 3 fractured zones near the base of the vertical well. Two additional vertical wells, Grange Hill and Becconsall have been drilled subsequently and recently Anna's Road, in which a horizontal leg is planned. Using data acquired in the first two wells Cuadrilla extrapolated to their 1200 km^2 licence and published a gas in place resource (GIP) of 200 tcf. No figure was given for the recovery rate. 3D seismic reflection data has been acquired using a dynamite source. The company has aimed to explore safely and engaged in full consultation with the local population, in addition to complying with regulatory authorities. Opposition in the form of pressure groups has disputed facts, demonstrated, supervised company actions, exposed any breaches of agreements and scoured for precedents of likely problems associated with shale gas operations. Cuadrilla has suggested future drilling of about 800 wells from pad sites within the licence and being able to start production in 2014 or 2015.

Hydraulic fracturing has been allowed to resume, by DECC, providing that recommendations on reducing the risks of felt induced earthquakes are followed.

8.4. Conclusions

The US has succeeded, spectacularly, in exploring for shale gas in nearly all its conventionally-productive basins. This was the result of a past history of production from shales (especially the biogenic shales), a lot of early research by the Gas Research Institute and well experimentation by Mitchell Energy in the Barnett Shale and, then, a whole continent to explore under a uniform set of regulations and with organised data and established infrastructure. No debate seems to have taken place during the exploration phase about whether it was environmentally safe to conduct, because everyone except Mitchell Energy was surprised by the success. The success in the US includes becoming self sufficient in gas in the course of about 12 years, but now at the expense of a very low gas price which is driving exploration elsewhere. Increases in recovery are going to be technology-driven and amongst those likely are pad drilling, more fracture jobs per well, but using green chemicals, salt water use, recycling, electric rigs and pumps and resulting in lower water use, disposal and fewer lorry journeys (King, 2012). Major petroleum companies were not involved in the early exploration in the US and perhaps caught up too late with shale gas there.

Europe as a whole is about 30 years behind this effort and has to deal with additional problems connected with the higher population density. Explorers in Europe need to tap into the most up to date US green completions, horizontal wells and latest improvements in productivity and speed of drilling. Exploration in Europe (and its very different constituent countries) is being held back by a combination of government policy, environmental concerns and regulations, hardware and expertise shortages, legacy data issues, infrastructure problems and perhaps the innate characteristic of pessimism compared to American's optimism. Many of the latter problems would be solved by some successful production. The Gaprowo well in Poland is evidently a step in this direction. Exploration is likely to take a different form from US experience, as it already has in Sweden, but Chesapeake's urban drilling experience in the Fort Worth Basin is a model that should be relevant to Europe.

Insufficient geological detail on exploration has been published for Europe, so far, to be certain whether shale gas can be as successful in Europe. Foreland basin sequences may contain similar geological sequences to most of those in the US, but some of Europe's other basins are extensional which, encouragingly, appears to offer a thicker or stacked shale sequence, combined with tight gas sandstones. Even so the public debate about whether exploration should be permitted has started early in Europe and may lead to curtailment of some exploration. Ownership of mineral rights by the states rather than individuals means that there is more local opposition to exploration but the royalty fees are correspondingly lower. Low gas contents probably would limit major company involvement, but such areas may be amenable to the cottage style development (Selley, 1987) of a more sustainable and locally beneficial exploitation. Low production test amounts may also put off major companies (ExxonMobil), but many smaller companies (BNK) have viewed this as a challenge to be overcome, following the steady improvements in Initial Production (IP) and Estimated Ultimate Recovery (EUR) recorded in many shales in the US.

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