

# Geological Survey of Northern Ireland

## ETI Committee Briefing

21 June 2012

### PLANS BY TAMBORAN FOR HYDRAULIC FRACTURING FOR SHALE GAS

#### Background

A Petroleum Licence was awarded to Tamboran Resources Pty Limited on 1<sup>st</sup> April 2011. The Licence **does not include any permission for exploration drilling or hydraulic fracturing** (HF), which would be the subject of further applications and consents, as described in detail, within this brief.

Whilst Tamboran have made their intention clear that they wish to use the process of hydraulic fracturing to extract shale gas, the Department is not in receipt of any application for such permission.

The following brief sets out to provide some detail around the licence which Tamboran holds and the various stages which Tamboran will have to go through should they wish to proceed with their work programme to extract gas. Technical details are also provided in respect of the hydraulic fracturing process with an outline of the common concerns raised and how these can be addressed.

#### 1 Petroleum Licence awarded to Tamboran

##### 1.1 Application and award

Petroleum Licence PL2/10 was issued to Tamboran Resources Pty Limited on 1<sup>st</sup> April 2011. The details of the process of award are set out in **Appendix A**.

##### 1.2 Location and geology

The location of Tamboran's Licence area in County Fermanagh is shown in **Appendix B**. Tamboran also holds a Licence in a contiguous area in Counties Cavan and Leitrim under a Licensing Option from the Petroleum Affairs Division of Ireland (PAD). Information on the geology of the exploration target and locations of previous wells are also shown in **Appendix C**.

The Northwest Irish Carboniferous sedimentary basin straddles the border and occupies much of Counties Fermanagh, Tyrone, Cavan, south Donegal, Leitrim, Monaghan and Sligo. Drilling has shown that there is a thick succession of up to 2500 metres of Lower Carboniferous rocks in this basin. These are mainly marine sediments and include organic-rich shales and deltaic sandstones that form potential hydrocarbon source and reservoir rocks.

Until recently, the target of exploration in the Basin has been oil and gas in the sandstone formations. These rocks tend to be more porous and permeable than the

shales. Several wells were drilled in 1965-66 and two, yielded gas from the sandstones of the basin, but not in commercial quantities. The sandstones were found to have lower porosities and permeabilities than needed for conventional gas production.

Exploration continued in 1980, focusing on improving the flow from the sandstones by using hydraulic fracturing. Flow-rates increased almost tenfold in the Dowra No. 1 well in Co. Cavan. Thus encouraged, an exploration company undertook seismic reflection surveys and drilled four wells during 1984 and 1985, two in the Republic of Ireland and two in County Fermanagh. Gas was encountered again in the sandstones but not in commercial quantities. Further exploration and drilling of the sandstone targets occurred in 2001-02 when six wells were drilled and hydraulic fracturing of selected ten foot intervals of the Mullaghmore Sandstone Formation carried out in five of these wells. The hydraulic fracturing used large volumes of a nitrogen foam and sand mixture as the main fracking fluid with smaller volumes of water-based 'slickwater' treatments. Extended well production tests were carried out in these vertical wells but gas flow rates were deemed non-commercial, although modelling at the time suggested that horizontal drilling might yield economic results. During these years the shale formations were considered only as source rocks and it is only recently, with the development of shale gas production in North America, that the potential for shale gas in the basin has been recognised.

### **1.3 Programme for the Initial Term (5 years)**

The Licence held by Tamboran contains a 'drill-or-drop' work programme for the Initial Term of five years. Tamboran must notify DETI before the end of Year Three if they wish to drill an exploration well on their licence – if they do not, then the Licence will terminate at the end of Year Three. If the company decide that they wish to drill – and that is their stated intention at the moment – then they must drill the well before the end of Year Five in order for the Licence to continue into the Second Term of the licence. The work programme for this Second Term of the licence would be submitted to, and would require approval by, the Department.

The work programme is included as a Schedule to the Licence Document (**Appendix B**). At the time of application this could only present an outline of the exploration activities proposed and the company may later vary some of the details, subject to the Department's approval, although the main element of the work programme – the 'drill or drop' well commitment - is the minimum required by the Department.

In Years One to Three, Tamboran will carry out analysis of existing exploration data in order to evaluate the licence area for its shale gas potential and plan their initial drilling programme. They also intend to drill a 'stratigraphic' borehole in 2012/3– this is a vertical borehole that will be drilled through the target shale formation to obtain solid core samples – that is, a set of cylindrical lengths of rock 4-5 inches in diameter and each up to 30 feet long. These cores and the geophysical logs recorded in the hole will provide data on the physical, mechanical and chemical properties of the shale to refine the company's resource model and inform the design of their initial exploration well and hydraulic fracturing programme.

Tamboran must notify DETI if they wish to carry out field-based exploration activities such as the above stratigraphic drilling and any seismic surveys. These applications will be screened to ensure that the proposed work will not have any adverse impact on any of the nearby ASSIs or other environmentally designated sites.

As part of their preparation of a drilling application Tamboran will carry out baseline studies on a range of environmental parameters which would support their Environmental Impact Statement. Although a matter for the Department of the Environment (Planning Service) to decide, it is anticipated that any application to drill an exploration well with associated hydraulic fracturing would require an Environmental Impact Statement and the company are proceeding on this assumption. Tamboran have engaged SLR Consulting Ltd. to scope the environmental baseline studies and they will be discussing their proposals with the relevant regulatory authorities in the near future.

#### **1.4 Reporting and regulation of operations under the Licence**

Under the general terms of the Licence, Tamboran is required to submit an annual report on work programme activity and audited financial statement. In practice, the company maintains regular contact with the Department to discuss their progress and will periodically seek advice on their exploration proposals as these develop.

Requirements of the periodic reporting will be specified as part of the consent given by DETI for any seismic or drilling and authorisation for the individual operations, but is expected to involve weekly reports of, *inter alia*:

- Progress against schedule
- Interim technical results
- Analysis of problems
- Health and Safety
- Contacts with officials
- Contacts with individuals and organisations.

On receipt of a formal application, DETI will seek the guidance of the DSO and DECC regarding the levels of Public Liability and Employer's insurance and bonds required to cover the operations, costs incurred if the Company absconds or defaults, costs of site restoration etc.

#### **1.5 Tamboran's proposed work plan**

Tamboran's outline work programme is summarised in their Licence, **Appendix B**. The specific details are not yet developed although it is thought that they will shortly apply to DETI to drill a vertical stratigraphic borehole for rock sampling right through the section, perhaps to a depth of 1200 m. Their subsequent work programme will be predicated on the results of that borehole. From general discussions with the company GSNI believes the following may be proposed:

- If the results of the stratigraphic test borehole are encouraging, Tamboran will apply for permission to construct an engineered 'well pad' and drill an exploration well. The well will be hydraulically fractured and gas production tested.

- If these results are encouraging, Tamboran will then apply to drill further wells on the same pad and to establish a second well pad to confirm the production characteristics at different depth zones and in different areas of their licence.
- If these appraisal wells confirm Tamboran's economic model, Tamboran will then apply to establish a network of further well pads, on each of which they will drill and develop several production wells.

Each of these proposed stages of exploration, appraisal and development (or production) would be dependent both on the company obtaining all the required consents for the operations involved and the technical success of the preceding stage. Whilst many of the processes involved in the drilling of exploration wells to test the shale gas production will be the same as those involved in any subsequent production plan, the scale of any proposed development would inevitably increase the range and complexity of potential impacts to be considered in the planning process.

## 2 Hydrocarbons licensing - general

DETI is responsible for awarding Licences for hydrocarbons exploration in onshore Northern Ireland and the internal waters adjacent to Northern Ireland. DETI has a statutory obligation to assess the potential environmental impacts associated with any consents or authorisations (related to energy) that it issues. However, monitoring and regulation of most environmental impacts falls to DoE. Further details regarding the roles and responsibilities of the relevant government departments; can be found in section 5.

A petroleum licence grants the Licensee 'exclusive rights' to explore for and, if successful, produce oil or gas from an area but, under the terms and conditions of the licence, the Licensee requires additional consents to carry out specific activities, such as drilling, in the licence area. The licensing system covers petroleum exploration, development and production, with different terms of the licence corresponding to each of the different phases in this cycle:

- Initial term (5 years) - Exploration – evaluation of acreage, identification of prospects, exploration drilling;
- Second term (up to 5 years) - further exploration or appraisal of discovery leading to submission of field development plan;
- Third term (up to 20 years, which can be extended at DETI's discretion) - development of field and production period, field decommissioning.

Term	Length (years)	Phase	Expiry of Licence
Initial	5	Exploration	At end of the Initial Term unless the Licensee has completed the agreed Work Programme.
Second	5	Appraisal and development	At end of the Second Term, unless the Department (DETI) has approved a Development Plan.
Third	20	Production	DETI has discretion to extend the Licence if production is likely to continue past 20 years.

In the Initial Term the primary objective of a Licensee is to evaluate the prospectivity of an area and to test this by drilling an exploration well. The most common approach is to include a 'drill or drop' well commitment in the licence work programme whereby the applicant intends to carry out further evaluation of the licence area in the hope of identifying a drillable target.

Full details of this process are given in **Appendix A**.

### **3 Hydraulic Fracturing**

#### **3.1 Use of hydraulic fracturing**

Extraction of natural gas from Tamboran's target formation, the Bundoran shale, will require the process of hydraulic fracturing (HF), also known as 'fracking'. The process is described in a DECC brochure presented in **Appendix D** and in the recent report by Aberdeen University ([Ref 1](#)). Tamboran have not as yet, made a formal application to proceed with a work programme which includes hydraulic fracturing but have clearly stated that it is their intention to do so.

#### **3.2 Basic process**

In brief, the process in Co Fermanagh is expected to entail:

- Drilling a vertical well to about the middle of the geological target formation, in this case the Bundoran Shale (**Appendix C**);
- Deviating the well horizontally for up to 2km within the shale formation;
- Installing steel casing to line the walls of the well and cementing this in position;
- Perforating the casing with a controlled pattern of small holes along the horizontal leg of the well;
- Pumping water and sand under high pressure through the perforations, in successive stages or intervals of the horizontal leg, to open up microfractures or small cracks in the surrounding shale;
- Recovering a proportion (about 30%) of the water up the well bore to the surface, where it is treated, stored for use in the next well on the well pad;
- The sand and some of the water remain in the cracks and keeps them open, allowing gas to flow into and up the well bore for collection at the surface.

#### **3.3 Background**

Hydraulic fracturing (HF) has been routinely applied worldwide in conventional oil and gas exploration and in geothermal exploration for decades. The shale-gas application differs primarily from this conventional application, in that higher volumes of water are required to open up cracks and the horizontal length of the wellbore, which is fracked, may be greater than 100 metres. The fracking programme is designed to create a microfracture network in a certain volume of shale rock around the horizontal well bore. The fractures may extend for tens of metres to a few hundred metres away from the wellbore, depending on the fracking system used, the mechanical properties of the shale and the prevailing underground stress regime.

In most applications historically, small amounts of various chemicals have been added to the water to improve the performance of the fracture process. These include

surfactants to reduce friction; biocides to prevent the growth of algae; and hydrochloric acid to reduce calcification. Although it has been reported that hundreds of chemicals are used in the USA this relates to the total number of individual chemical constituents used in the estimated 1 million fracking operations carried out since the 1950s, and includes proprietary variations of the same chemicals. Usually, no more than twelve different chemicals are used in a well and often fewer than this. For example, Cuadrilla proposes using four different chemicals in their Lancashire exploration project and the Environment Agency has carried out a risk assessment of these, concluding that they do not pose a risk of harm to groundwater or the environment. In the event, Cuadrilla has only used a non-toxic polyacrylamide friction reducer and a sodium salt to act as a tracer. Tamboran has undertaken not to use chemical additives; they believe they can avoid using chemicals as the depths of operation are relatively shallow and the pressures needed to fracture the shale are lower than in the shale gas plays in the USA.

### 3.4 Worldwide Experiences of Hydraulic Fracturing

The information below provides a short synopsis of the attitudes and experiences of a number of countries, to the hydraulic fracturing process (quoted partly from a recent study by Aberdeen University for the Environment Protection Agency (EPA – Ireland), see Bibliography, [Ref 1](#)):

- **USA** - Both exploration and production of shale gas are fully underway, encouraged by deregulation in 2005. Subsequently, US gas prices have fallen in response to increased domestic production. The widespread use of HF to extract shale gas has been central to this expansion of the gas market. Shale gas now accounts for approximately 30% of US domestic gas production. A few states have imposed moratoriums, notably New York State, and many states have improved their regulation in response to public concerns and incidents of pollution.
- **Canada** - Shale gas is being developed in a number of provinces, principally Alberta and British Columbia. The regulation of HF is split between the federal and provincial governments. Concerns have been raised about the potential environmental impacts and the provinces have adopted different policies. Quebec has imposed a moratorium, Nova Scotia, British Columbia and Alberta are conducting reviews into fracking procedures and their potential impacts, and the state has ordered further scientific reviews.
- **France** - The Government of France banned fracking in May 2011 in response to pressure from environmental groups – i.e. not in response to any tangible incident in France or elsewhere involving leakage or contamination from a HF programme. In this case, exploration permits were revoked for three companies who admitted that HF formed part of their appraisal plans – At least one of these companies has instigated legal action against the French Government. On 21<sup>st</sup> March 2012 the 'National Commission of Orientation and Following Evaluation of Shale oil and gas Exploration Techniques and Operations' was established by decree. A recent report commissioned by the government recommended carrying out HF experiments in the Paris Basin.

- **Bulgaria** - granted exploration licences for shale gas to a major operator (Chevron) but then imposed a moratorium on HF in January 2012.
- **Germany** - has large reserves of shale gas, and exploratory drilling is underway, although policy varies from state to state. Licences have been granted to Exxon, Wintershall and GdF, among others. Preliminary drafts of an environmental study due for publication in June 2012 include a recommendation for a mandatory EIA for HF if hazardous substances are used.
- **Poland** - has the largest reserves of shale gas and is set to embark on an extensive drilling (and HF) programme. The Polish Government published a new Geological and Mining Law, with secondary legislation, in January 2012 which updates the licensing system.
- **Australia** - Shale gas prospects are being evaluated in South Australia, Western Australia and the Northern Territory. These locations are far from population centres and impacts are expected to be minimal. There are well-established regulatory systems in place and the authorities adopt a risk-based approach to environmental impact assessment.
- **South Africa** - The government has imposed a moratorium on HF in response to pressure from environmental groups.
- **Ireland** - Ireland has issued an option to explore for shale gas over an area contiguous with the Tamboran licence in Co Fermanagh. The EPA commissioned a literature review study of the issues surrounding HF from Aberdeen University ([Ref 1](#)), and is likely to embark on a more detailed study later this year.

### 3.5 Recent GB experience and research

Shale-gas exploration and the issues surrounding it were considered in detail by the House of Commons Select Committee on Energy and Climate Change ([Ref 2](#)). The report concluded in favour of shale-gas exploration and development by HF in UK and made 27 recommendations regarding mitigation of potential hazards.

HF was first applied in GB to shale-gas exploration in the Preese Hall No 1 well near Blackpool, by Cuadrilla Resources. The fracking operation caused two small earth tremors of magnitudes 2.3 and 1.5. These tremors have been investigated by experts commissioned by Cuadrilla. DECC also commissioned their own panel of experts to produce a report on this matter and which DECC published on their website, inviting responses ([Ref 3](#)). This report concludes that the tremors were probably caused by water injection too close to a geological fault, which was lubricated by the process. The authors made several recommendations to mitigate this possibility, notably a requirement to establish a seismic monitoring network. Under a 'traffic light' system, operations will be halted if tremors reach magnitude 0.5, a level usually imperceptible.

The authors of this report saw no reason why Cuadrilla Resources should not be allowed to proceed with their shale gas exploration activities and recommended

cautious continuation of HF operations. The report recommended that further HF operations should be preceded by:

- Appropriate baseline seismic monitoring to establish background seismicity in the area of interest;
- Characterisation of any possible active faults in the region using all available geological and geophysical data;
- Application of suitable ground motion prediction models to assess the potential impact of any induced earthquakes.

The consultation period has closed and DECC are currently evaluating the responses. DECC are unlikely to make any decisions about future fracking in Lancashire and elsewhere before July 2012.

The Royal Society and Royal Academy of Engineering are currently reviewing the process and are expected to report shortly ([Ref 4](#)).

### **3.6 Hydraulic fracturing in Ireland**

13 vertical wells were previously drilled for hydrocarbons in the Lough Allen basin, including one well that was fracked in 1981 and five in 2002. These targeted the tight gas sandstone overlying the Bundoran shale. It was at that time that the organic content of the Bundoran shale, and its potential for gas, was recognised. No horizontal drilling has yet been carried out in the basin.

### **3.7 Potential Problems and Publicly Expressed Areas of Concern**

Widespread problems associated with HF have been reported from the USA and Canada, most famously illustrated in a popular documentary film 'Gasland'. Some of the information shown in the film was misleading with links to the hydraulic fracturing process unproven, for example pictures of gas being ignited after flowing from water taps; this phenomenon is well known in some places – it was first recorded in the nineteenth century in Pennsylvania - and relates to natural methane in groundwater. Nevertheless other instances of groundwater contamination, surface water contamination, air pollution and loss of visual amenity associated with gas production are well documented.

Most of these problems occurred when the industry was poorly regulated by a fragmented system; the USA appears now to have firmly grasped the problem at a federal level. Extensive research is being undertaken by the Environmental Protection Agency, by various state agencies and by the petroleum industry, on issues of regulation and on the potential effects of HF and shale-gas development. Recent reports have appeared, for example, on greenhouse gas (GHG) emissions ([Ref 5](#)), on drinking water ([Ref 6](#)), and on regulation standards ([Ref 7](#)).

The issues raised by those concerned include the following:

- Risk of well blowout
- Pollution of groundwater by chemicals and methane;
- Use of undesirably large volumes of water;
- Disposal of waste water after fracking operations;
- Leakage of contaminated water from storage facilities;



- Penetration of radon into homes sited over fracking operations;
- Danger from radon in produced gas;
- Air pollution and GHG emissions from escaping produced gas ('fugitive emissions');
- Radioactivity of returned water and solids;
- Earthquakes;
- Size, visual impact and noise of drilling and production pads;
- Increased road traffic;
- Climate change impact of shale gas compared with our energy sources.
- Abandonment of wells and restoration of well-sites.

Measures to regulate the various processes which may give rise to these hazards and eliminate or mitigate them will be the subject of conditions attaching to any Planning Permission.

All of these issues are under assessment and research. DETI is keeping a close eye on developments in DECC and other regions for examples of best practice. Close liaison between the relevant government Departments will also be vital in ensuring appropriate regulation of any shale gas extraction operation. An informal forum of Northern Ireland regulators was established in 2011 and has met twice. The Forum is currently being formalised, following the recent agreement of the DETI and DoE Ministers that it should be.

### **3.8 Shale Gas Regulators Forum**

The Regulators Forum will bring together the relevant government departments, including: DETI; DoE (Planning Service, NIEA, Drinking Water Inspectorate and Environmental Policy Division); HSENI; DCAL; DARD and NI Water. The Forum is still in its infancy but a Terms of Reference for the group is currently being drafted and will be formalised over the coming months. The overarching aim of the group will be to facilitate the sharing within government of information relevant to shale gas exploration and to ensure any gaps in legislation, regulations, engineering and environmental standards are identified and solutions proposed.

## **4 Application for exploration drilling**

### **4.1 Planning approval**

If Tamboran wishes to carry out any drilling on their licence they must, as a minimum requirement, notify Planning Service (DOE), the Health & Safety Executive and receive approval from DETI. For a conventional exploration borehole, without hydraulic fracturing, Planning Service will determine whether this requires planning permission or whether it is deemed 'permitted development'. In the past, exploration boreholes in Northern Ireland have often been classified as permitted development but the most recent well, drilled in 2008, was subject to planning permission.

### **4.2 Environmental Impact**

For exploration wells drilled for shale gas, which would include hydraulic fracturing, and be sited on a large well pad, the Planning Service has indicated that these would

require both Planning Permission and an associated Environmental Impact Assessment.

The Company will prepare an Environmental Impact Statement (EIS) that addresses potential impacts on a range of parameters specified by legislation. In addition the company, or its environmental consultants, will consult with the regulatory authorities and relevant environmental stakeholders to ensure that it is in possession of all the information that these bodies believe that it will need to include in its EIS – this will include both existing and new data. The EIS will be informed by the results of monitoring various environmental conditions and parameters over at least 12 months.

Irrespective of whether any specific drilling operation requires planning permission, the consenting authorities are required to carry out a Habitats Regulation Assessment (HRA) to determine whether the proposed activity might have a significant adverse impact on any of the conservation sites designated under the Northern Ireland legislation that implements the Birds and Habitats Directives. Depending on the scale and nature of the proposed operation this may require only the screening stage or it may require a more detailed Appropriate Assessment. The proposed operation would not get approval to proceed if it is deemed likely to cause significant environmental harm to any of the designated Special areas of Conservation or Special Protections Areas. DoE has final responsibility for this decision.

#### **4.3 Environmental baseline studies**

Prior to submission of the Planning Application and EIS, DoE and DETI may themselves conduct baseline studies of various environmental parameters, including groundwater and surface water quality, air quality, seismicity, noise and radioactivity. This is one of the subjects which the Inter-departmental Forum on Shale-gas will discuss (see Section 3.8).

### **5 Roles of NI Departments**

#### **5.1 Prior to Planning Application for exploration well with associated hydraulic fracturing operations**

Prior to the Planning Application and during the period of preliminary exploration, which may include stratigraphic drilling, the principal Departmental roles are:

- **DETI** - monitoring terms and conditions of the Licence; technical and Habitats Regulation assessments of application to undertake work, such as stratigraphic drilling and geophysical survey, within the limitations of 'Permitted Development'; consultation on baseline studies of seismicity.
- **DoE** - assessment of application to undertake work, such as stratigraphic drilling and geophysical survey, within the limitations of 'Permitted Development'. Any required water abstraction or discharge licences. Consultation on baseline studies of water quality, air quality, radioactivity and radon, traffic density, noise.
- **HSENI** - monitoring observance of HSENI Regulations during any Permitted Development operations.

During this period, Departments will collaborate through an Inter-departmental Forum (see Section 3.8) in sharing and reviewing research, reviewing and identifying gaps in legislation and regulations and defining engineering and environmental standards.

## **5.2 Planning process for exploration well with associated hydraulic fracturing operations**

During the planning process the principal roles are:

- **DOE, Planning Service** - Planning Service is responsible for the planning process. Also implications of the Waste Management Directive.
- **DOE, NIEA** - will be involved in planning process as statutory consultees with primary responsibility for the associated EIA process and will advise on aspects such as the protection of groundwater and surface water; water licensing; environmental permitting for the transport, storage and disposal of hazardous waste; assessment of potential impacts on designated environmental sites.
- **DETI** - will be involved in planning process as statutory consultees and will advise on aspects such as well construction and completion, technical standards, geology and hydrogeology, macroseismic and microseismic monitoring.
- **HSENI** - will be involved in planning process as statutory consultees and will advise on health & safety issues associated with well construction and completion.

## **5.3 After Planning Approval for exploration well with associated hydraulic fracturing operations**

Departments will regulate the various engineering processes according to the standards and protocols previously established and the conditions attached to the Planning Permission.

Tamboran will of course be required to adhere to the relevant EU Directives regarding Water (abstraction and disposal), Waste Management, Air Quality, etc.

## **5.4 External liaison**

Members of the informal forum have met once with counterparts from the Republic of Ireland (Petroleum Affairs Division and the Environmental Protection Agency), with the intention of ensuring that regulation of HF is consistent across the Tamboran licence areas on each side of the border.

Counterparts at Department of Energy and Climate Change (DECC) and the Environment Agency (EA) in UK are well advanced in their consideration of various issues surrounding HF. DETI officials hold monthly telephone conference calls with DECC, EA and the British Geological Survey, again with the intention of ensuring that GB, NI and RoI regulations are coherent. DECC liaises with an EU Technical Working Group on shale gas extraction and report on their progress at these teleconferences.

## **6 Implications for landowners of hydraulic fracturing**

### **6.1 Access to land**

The 1964 Act gives the Department the power to acquire ancillary rights by agreement, or, if satisfied that it is in the public interest to do so, by making a "mining facilities order", to compulsorily acquire such rights including "a right to enter upon land and to sink and bore holes for the purpose of searching for petroleum".

However, the Department has not exercised such rights in respect of either minerals or petroleum. Licence holders have been expected to reach agreement with individual landowners for access to, and use of, land for the purpose of drilling, and this system has proved satisfactory to date.

### **6.2 Exploration: seismic surveys and exploration boreholes**

Most seismic surveys are shot along roads using Vibroseis trucks, but where off-road access is required for the seismic source the Licensee will normally agree a modest one-off access payment with the landowner. The seismic contractor is liable for any damage caused to property by their equipment or operations.

Where the Licensee wishes to drill an exploration borehole they will negotiate with local landowners to obtain access to and use of a site for drilling. Drill sites for petroleum exploration wells are usually between 0.5 and 2 hectares in area although shale gas drill pads for multiple deviated boreholes may be approximately 3 hectares. Rental payments can be significant. The safe permanent abandonment of exploration wells is required as part of the well consent procedure. Restoration of the drill site following drilling is normally a condition of planning permission.

### **6.3 Development: production boreholes**

If exploration is successful and the Licensee's development plan is approved by all the relevant regulatory authorities then the long-term rental income for the landowners could be substantial. It is common for Licensees to enter into prior agreements with landowners that are subject to the company receiving approval for their development. For conventional wells production may last 10 to 20 years whereas shale gas wells may stay in production for 20 to 30 years before they are permanently plugged and abandoned (sealed with cement).

Compensation may be payable to the former owners (at the time that the 1964 Act came into effect) of the mineral rights, including petroleum, to the land within a circle of radius of a quarter of a mile around a production well. The 1964 Act sets out the arrangements by which the compensation is paid to the Department, claims to entitlement made and determined. The Petroleum Production (Royalties) Regulations (Northern Ireland) 1965 set the rate at 7.5% of the value of the petroleum produced and determined how this value is calculated. The former owners of the mineral rights are not necessarily the same as the current landowners as the mineral rights are not always included in land transactions.

## **7 Tax and royalties**

The Petroleum (Production) Act (Northern Ireland) 1964, with a few exceptions, vests ownership of petroleum resources in DETI. DETI will receive royalties from any producer of oil or gas in Northern Ireland at the rate of 7.5% of the value of the petroleum produced as set out in the Petroleum Production (Royalties) Regulations (Northern Ireland) 1965. DETI may then pay 'compensation' to anyone who, before the passing of the 1964 Act, held the mineral rights including petroleum for the 'appointed area' of the petroleum well.

The following are payable to the state:

- Ring-fenced corporation tax at 30% of profits (which does not decrease in line with 'normal' corporation tax).
- Supplementary petroleum tax at 32% of profits.

## **8 Estimates of recoverable shale gas**

Tamboran Resources have estimated that 0.9 to 1.8 Tcf (trillion cubic feet) of gas may be recoverable from the basin in reports published on their website. If this estimate is reasonably accurate then this represents a potentially significant resource for Northern Ireland.

From the information available, including the area, depth and thickness of the Bundoran Shale Formation sub-crop and the total organic content (TOC) measured from cuttings samples retrieved from deep exploration wells or outcrop rock samples, it is possible to estimate the volume of gas in place and then estimate the proportion of this that may be recoverable. This is what Tamboran have done and their estimates are reasonable – some of the assumptions or values of the parameters used could be challenged but it is reasonable to assume that there is a significant resource potential.

However, further information, derived from laboratory analysis of fresh rock core samples from the complete thickness of the Bundoran Shale Formation in the most prospective part of the basin, is needed to gain more accurate estimates of the gas in place and its producibility. Ultimately, the latter can only be determined by HF and production in one or more exploration wells. At this stage, before a single well has been drilled to test the shale gas potential of the basin it would not be sensible to rely heavily on desktop calculations.

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7. USA - University of Texas Energy Institute: Fact-Based Regulation for Environmental Protection in Shale Gas Development [Report Summary](http://energy.utexas.edu/images/ei_shale_gas_reg_summary1202.pdf) [http://energy.utexas.edu/images/ei\\_shale\\_gas\\_reg\\_summary1202.pdf](http://energy.utexas.edu/images/ei_shale_gas_reg_summary1202.pdf)

## **Appendix A      Issue of Tamboran Licence**

### **History**

Exploration for petroleum in Northern Ireland commenced in the 1960s following the introduction of the Petroleum (Production) Act (Northern Ireland) 1964 (the 1964 Act) which vested ownership of undeveloped petroleum in Northern Ireland in the Department of Commerce, and gave the Department powers to grant licences and to make regulations governing these. In recognition of the fact that they were thereby being deprived of their property rights, the 1964 Act also made provision for compensation in lieu of royalties to be paid to the then owners of mineral rights around the producing wells.

### **2010 Regulations**

All of onshore Northern Ireland was available for licensing under an 'open door' system – i.e. no licensing rounds – and this remains the case. The Petroleum Production Regulations (Northern Ireland) 1987 (PPR 1987) established revised terms and conditions for petroleum licensing and included Model Clauses to be used as a template for this. On 30 April 2010 DETI made two new Statutory Rules, the Hydrocarbons Licensing Directive Regulations (Northern Ireland) 2010 (HDLR 2010) implemented Council Directive 94/22/EC in Northern Ireland by introducing new arrangements and requirements for granting and using licences relating to the prospection, exploration and production of hydrocarbons. The Petroleum Production (Amendment) Regulations (Northern Ireland) 2010 (PPAR 2010) amended the 1987 Regulations to complement the Hydrocarbons Licensing Directive Regulations by introducing new requirements for applications for petroleum licences and new provisions for licences. The amendments brought licensing arrangements in Northern Ireland more closely into line with those in Great Britain.

### **2010 Licensing round**

On 29<sup>th</sup> June 2010 the Department published a [Notice](#) (2010/C169/4) in the Official Journal of the European Union announcing the availability of all of onshore Northern Ireland for Petroleum Licence applications. The new Rules perpetuated the 'open door' licensing system whereby licence applications could be submitted at any time. However, in recognition of certain changes to the licensing terms and conditions, and arrangements for the making and determining of licence applications, the notice stipulated that all applications received by 27<sup>th</sup> August 2010 would be considered together.

Guidance for applicants was made available on the DETI and Geological Survey (GSNI) websites, and the latter also included a Q & A section where the Department posted answers to questions raised by potential applicants so that the same information was available to everyone. A Review of the Petroleum Prospectivity of Northern Ireland, written by GSNI with input from the British Geological Survey (BGS), was also made available to potential applicants.

a. Licence applications received

Five eligible applications were received by 27<sup>th</sup> August 2010. Three of these applications were for separate areas and two applications included overlapping areas.

b. Assessment of applications

The five applications were assessed against the published criteria set out in the Regulations and the Guidance. Experienced personnel at the Department of Energy and Climate Change (DECC) carried out the validation of the financial viability and capacity of the applicants on behalf of DETI. A preliminary assessment of the technical and environmental components was carried out by DETI and GSNI before the applicants were called to interview.

c. Interviews

The applicants were invited to interviews in Netherleigh on 23 and 24 September 2011 where they gave presentations on their applications to Senior Officials from DETI, GSNI, BGS and DECC.

The applications were assessed against the published criteria by the panel.

d. Outcome of application assessment and interview process

The panel agreed that licences should be offered in respect of the three applications for non-competed areas. In the case of the two applications in competition for the overlapping areas, after further discussions between the Department and the applicants, one of the applications was withdrawn and the Department agreed to offer a licence to the remaining applicant.

e. Consultation process

The petroleum legislation does not specify that a statutory consultation is required for the granting of petroleum licences. The Department has nevertheless historically operated a similar consultation to that specified for minerals licensing in the Mineral Development Act 1969. Advertisements are placed in the local newspapers and sent to a range of organisations giving notice of the Department's intention to grant the petroleum licences, and the consultees are given four weeks to respond.

In the case of the licence offered to Tamboran Resources Pty Ltd:

- § A newspaper advertisement appeared in the Fermanagh Herald on 17 November 2010 and again on 24 November. It also appeared in the Impartial Reporter on 18 November and again on 25 November.
- § Notice was also sent to the following organisations:
  - NI Tourist Board
  - The National Trust
  - NIE plc
  - British Telecom
  - Department of Education
  - Department of Agriculture and Rural Development
  - Department of Health Social Services and Public Safety
  - Northern Ireland Environment Agency - NIEA
  - Northern Ireland Office
  - Department of Environment - Planning Service



Invest NI  
Department of Culture, Arts and Leisure  
Department of Employment and Learning  
Office of First and Deputy First Minister  
Northern Ireland Water  
Roads Service  
Department of Social Development  
Royal Society Protection of Birds (RSPB)  
Fermanagh District Council

Contact details in DETI and GSNI were given so that further information about the prospective licences could be sought.

f. Outcome of the Consultation

DETI received nine responses from consultees and, although no significant issues were raised, the contributions were included in the Initial Guidance to Licensees that was sent out to the companies with the Licence documents.

g. Habitats Regulations Assessments (HRA)

As the competent authority with respect to authorisations and consents relating to petroleum exploration, DETI has a responsibility under The Conservation (Natural Habitats, etc) Regulations (Northern Ireland) 1995, amended in 2004, 2007, 2009, 2011, to carry out an assessment of potential adverse environmental impacts on designated European 'Natura 2000' sites of activities carried out under petroleum licences in Northern Ireland. The Department carries out the Appropriate Assessment of the different elements of the licence work programme that have the potential to affect the environment and that require additional consents from DETI and other NI regulatory authorities. Activities requiring Appropriate Assessments include, but are not limited to, seismic surveys and exploration drilling. The Department's approach has been agreed with NIEA and is consistent with that adopted by the Department of Energy and Climate Change (DECC) with respect to onshore petroleum licences in Great Britain, and reflects the nature of petroleum exploration programmes. In Northern Ireland DETI and DoE, rather than DECC, collaborate in making the necessary assessments.

In terms of the petroleum licence granted to Tamboran Resources, the initial work programme consists of further evaluation of the prospectivity of the licence area by means of desk studies including seismic reprocessing and interpretation of existing exploration data. If and when, the company decides that it wishes to carry out more significant field-based operations it must submit those proposals to DETI who will carry out the required HRA as part of the approval process.

h. Execution of the PL2/10 petroleum licence by DETI and Tamboran Resources Pty Ltd.

The licence was signed and sealed by the Department and executed by the company with effect from 1<sup>st</sup> April 2011.

In common with all other petroleum licences, the DETI Minister had no involvement with the granting of this petroleum licence.

## **Petroleum licence terms and conditions**

### Duration

Petroleum licences consist of up to three terms which correspond to the exploration, appraisal and development (or production) phases:

- § a five-year Initial Term, during which an agreed Work Programme of exploration must be carried out (to prevent expiry);
- § a five-year Second Term, during which a Field Development Programme must be approved (to prevent expiry); and
- § a 20-year Third Term, called the production period.

Under the HDLR 2010, DETI is required to ensure that these periods are sufficient to allow the activities for each period to be completed, but do not extend beyond such time as DETI determines to be necessary properly to perform the activities for the appropriate period. DETI is also required to ensure that the proposed work programme is sufficient to explore the licence area fully.

However, DETI recognises that, as Northern Ireland is relatively under-explored, there is potential for small and start-up companies to be granted a Petroleum Licence before attracting the necessary operating and financial capacity to explore and exploit the licence area fully. In such a case, the Applicant can apply for a Petroleum Licence with a 'Drill-or-Drop' Commitment. This licence will contain a 'Break Point', normally at the end of the third year. The Work Programme associated with the licence will consist of two parts: Part I relating to the proposed work up to the Break Point; and Part II relating to the proposed work for the remainder of the Initial Term. If the licence has not terminated by the Break Point, Part II of the Work Programme will include drilling a well. Such a licence will require the financial and technical capacity in respect of Part I to be in place at the time of application. In respect of Part II, a Firm Well Commitment (or agreed equally substantive activity) must have been made and the associated financial and technical capacity must be in place before the Break Point. In the absence of such commitment and financial and technical capacity, the licence will terminate. In this Guidance, an application for a licence without a Firm Well Commitment is referred to as an application for a Petroleum Licence with a Drill-or-Drop Commitment.

## **Tamboran - Licence area and work commitment**

In the case of PL2/10, Tamboran Resources Pty Ltd applied for, and were granted, a petroleum licence with a drill-or-drop commitment. DETI offered the company a smaller area (~746 km<sup>2</sup>) than they applied for (~1160km<sup>2</sup>) because the Department deemed that the proposed work programme for the eastern part of the application area was not sufficient to explore that part adequately.

The licence grants the Licensee exclusive rights to 'explore for, bore for and get petroleum'. A Petroleum Licence does not grant *carte blanche* to carry out all petroleum-related activities from then on. Some activities, such as drilling, are subject to further individual controls by DETI, and a licensee remains subject to controls by other bodies such as the Health and Safety Executive Northern Ireland, the Planning Service and the Northern Ireland Environment Agency. Furthermore, the grant of a Petroleum Licence in no way waives the requirement for the licensee to get any necessary permission from landowners, planning authorities, etc. It is the licensee's responsibility to be aware of, and comply with, all regulatory controls and legal requirements.

Tamboran's licence document includes a two-part work programme as outlined above. Years 1 – 3 correspond to the 'firm' work commitments and comprise re-processing, re-interpretation and analysis of existing exploration data over the licence area, augmented by the drilling of shallow boreholes to obtain fresh cores of the target shale beds for geochemical and geomechanical analysis. The company will complete their resource assessment and review the economic model. They also plan to carry out a preliminary environmental review of the licence area. On the basis of this work Tamboran will make the decision to drill or drop the licence before the end of Year 3. If they decide that they wish to drill they will carry out fund-raising.

Should the company decide to proceed to Part II of the work programme, they will finalise their well planning and submit their applications for planning permission (including a detailed Environmental Impact Statement) and other required consents. The planning application and EIS will necessarily be based on a series of environmental baseline studies and other reviews, carried out at the Licensee's expense.

The operations associated with exploration drilling for shale gas including hydraulic fracturing are subject to a range of legislation in Northern Ireland. The Model Clauses in the PPR 1987 and PPAR 2010 set out various responsibilities of the Licensee with respect to compliance with good oilfield practice, avoidance of harmful methods of working, including the prevention of the escape of petroleum into waters or water-bearing strata, the health, safety and welfare of workers, the preservation of the amenity of the licence area, avoidance of interference with fisheries and the disposal of waste. The Licensee also requires the consent of the Department to drill, complete or abandon a well, and the Department has the powers to impose conditions as to operational methods, to enter sites, make inspections and recover the costs involved. The Licensee is liable to pay for damage caused by its operations and must ensure that it has sufficient funds available to discharge its liabilities for damage attributable to the release of petroleum. The company must also indemnify the Department and acquire and maintain insurance sufficient to pay compensation for any damage

caused by its operations. Prior to drilling a well the Licensee must nominate an operator, to be approved by the Department, with experience and expertise appropriate for the proposed drilling operations. The Licensee is also required to provide documentary evidence that it has received any planning permission required for the well before DETI gives its approval to drill.

Exploration drilling for shale gas, including hydraulic fracturing, will require planning permission by virtue of the area of well pad and the duration of the operations at the site. The planning application should also be deemed an EIA development because of its potential effect on the environment and, as such, the planning application would be accompanied by an Environmental Impact Statement. Water abstraction, impoundment and discharge are all subject to regulatory control by NIEA and legislation passed to implement the Water Framework and Groundwater Directives in Northern Ireland ensures protection of surface waters and groundwater aquifers, including from hazardous substances. The planning process will also take into consideration the potential effects of the drilling operations on other industries in the area such as tourism and agriculture, as well as the impact of increased traffic and noise. However, at the exploration drilling stage these may be of limited impact and duration.

Should exploration drilling be approved, and the results deemed a success by the company, then it may wish to submit a development plan which would be subject to additional regulatory control appropriate to the production, storage and transport of petroleum products. Such a development plan, by virtue of its size and duration, would potentially have a much greater impact on the licence area than exploration and the planning process would reflect this.

### **Withdrawal of licence**

As long as a licence holder continues to operate within the terms of his licence there are no grounds for the Department to withdraw that licence. Withdrawal of a valid licence in such circumstances would almost certainly lead to litigation, with the licensee suing the Department to recover all that he had invested since being granted the licence, compensation for loss of potential future profits and possibly exemplary damages.

## **Appendix B**

## **Tamboran's Petroleum Licence**



Department of

**Enterprise, Trade  
and Investment**

[www.deti.gov.uk](http://www.deti.gov.uk)

**TAMBORAN RESOURCES PTY LTD**

**Petroleum  
Licence**

**PL2/10 (Lough Allen Basin – North)**

Dated 1<sup>st</sup> Day of April 2011

Petroleum Licence

Tamboran Resources Pty Ltd.

And

Department of Enterprise, Trade and Investment

PL2/10 (Lough Allen Basin - North)



## PETROLEUM (PRODUCTION) ACT (NORTHERN IRELAND) 1964

### THE DEPARTMENT OF ENTERPRISE, TRADE AND INVESTMENT

**THIS LICENCE** made the <sup>15<sup>th</sup></sup> day of April two thousand and eleven BETWEEN THE DEPARTMENT OF ENTERPRISE, TRADE AND INVESTMENT (hereinafter called "the Department" which expression shall where the context so requires or admits include its successors and assigns) of the one part and Tamboran Resources Pty Ltd. having a UK Establishment registered at 27 Frances Street, Newtownards, BT23 7DW (hereinafter called "the Licensee" which expression shall where the context so requires or admits include its assigns) of the other part **AND WHEREAS** the Licensee has applied to the Department for a Licence pursuant to the provisions of the Petroleum (Production) Act (Northern Ireland) 1964 to search and bore for and get petroleum within the lands hereinafter described **AND WHEREAS** the Department has agreed to grant such Licence on the terms and conditions hereinafter mentioned.

NOW IT IS HEREBY WITNESSED as follows:-

- a) The Department in pursuance of such application and agreement and in consideration of the royalties hereinafter reserved and made payable as specified in the Petroleum Production Royalties Regulations (Northern Ireland) 1965 [SR 1965 No 48] and the performance and observance by the Licensee of the terms and conditions hereinafter mentioned and in exercise of the powers conferred on it by Section 2 of the above-mentioned Act **HEREBY GRANTS** to the Licensee full and free and exclusive liberty and licence for a period of five years from the date hereof and thereafter during the continuance of this Licence to search and bore for and get petroleum within all those parts of the County of Fermanagh more particularly delineated and described on the map and list of Irish Grid co-ordinates annexed upon the following terms and conditions:-
- b) The Model Clauses in Schedule 2 to the Petroleum Production Regulations (Northern Ireland) 1987 [SR 1987 No 196] as amended by the Petroleum Production (Amendment) Regulations (Northern Ireland) 2010 [SR 2010 No 169] ("the Model Clauses") shall be deemed to be incorporated in this Licence with the following modifications:-
  - i) In Clause 9 (2) after the words "shall be accompanied by a copy of an Ordnance Survey map for the relevant area drawn to the scale of 1:50,000" insert "or such other map as the Department may allow,".
  - ii) In Clause 9 (2) for the words "at least 28 days written notice" substitute "at least 42 days notice".
  - iii) In Clause 9 (3) for the words "within 14 days" substitute "within 28 days".



- c) The Licence shall be subject to the following terms and conditions which are in addition to and not in derogation of anything in the said Model Clauses contained:
  - i) The Licensees shall not carry out any work within or in close proximity to an Area of Special Scientific Interest (ASSI) without the prior written consent of the Department.
- d) The Licensees will pay all of the Department's advertising and mapping costs incurred in the processing of this licence.
- e) The Licence shall be governed by, and interpreted in accordance with, the laws of Northern Ireland.

## SCHEDULE

### Work Programme

#### Part I

##### Years 1 - 3

- i) Desktop study and review of existing exploration data.
- ii) Acquire and re-interpret gravity and Tellus airborne magnetic data over the licence area.
- iii) Acquire, re-process and interpret all available seismic data over licence area.
- iv) Sample and analyse existing borehole material.
- v) Complete resource assessment and review of economic parameters for play concept.
- vi) Drill shallow cored boreholes in target intervals and analyse core material.
- vii) Carry out preliminary environmental review.
- viii) Make drill-or-drop decision.
- ix) Carry out fund-raising (dependent on viii)

#### Part 2

##### Years Four and Five

- x) Finalise drilling location, well planning, preparation and permitting (including environmental impact assessment).
- xi) Drill exploration well to test Benbulbin and Bundoran Shale Formations gas shale play, including coring, fracturing and testing programme.
- xii) Analyse well results and carry out second review of economic potential.
- xiii) Dependent on results from xi and xii, acquire, process and interpret new infill seismic reflection data.
- xiv) Identify additional drilling targets.
- xv) Finalise drilling locations, well planning, preparation and permitting (including environmental impact assessment).
- xvi. Drill 2<sup>nd</sup> exploration well to test Benbulbin and Bundoran Shale Formations gas shale play, including fracturing, multiple horizontal legs, flow testing and seismic monitoring.
- xviii Review economic model.
- xvi. Preparation and submission of application for Second Term or relinquish licence.

***Deliverables: Copies of all reports and raw, processed and interpreted data will be supplied to the Department in hard copy and industry-standard digital formats. At end of Initial Term (or at end of Year Three if decision is taken to drop licence) produce licence summary report.***

5

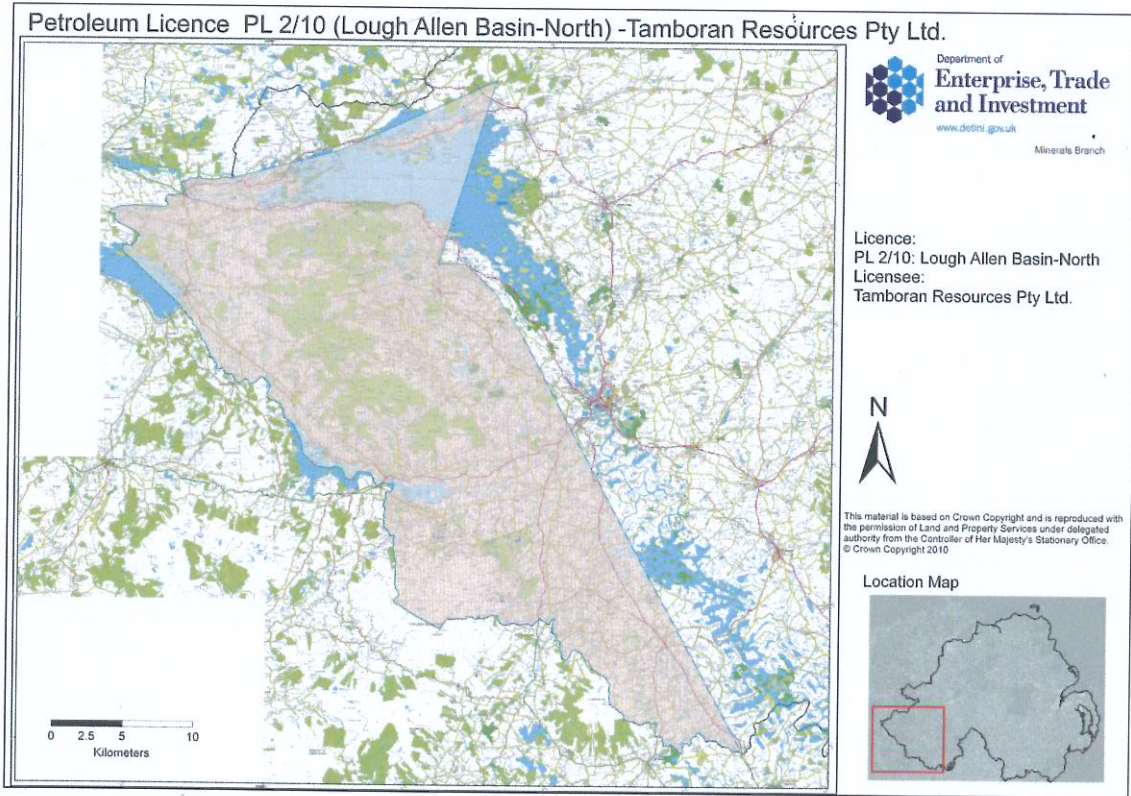
## ANNEX

Licence area boundary corner points, quoted as Irish Grid references:

	m EAST	m NORTH
From the border between Northern Ireland and the Republic of Ireland at	197285	359920
ENE to	205000	362000
NE to	216000	367000
S to	212000	354000
E to	214000	354000
SE to	216000	352000
SE to	218000	349000
SE to	226000	334000
To meet border at	234005	319345
Follow border WNW back to close at	197285	359920



Annex



The Tamboran Licence area is shown below in **Figure C1**.

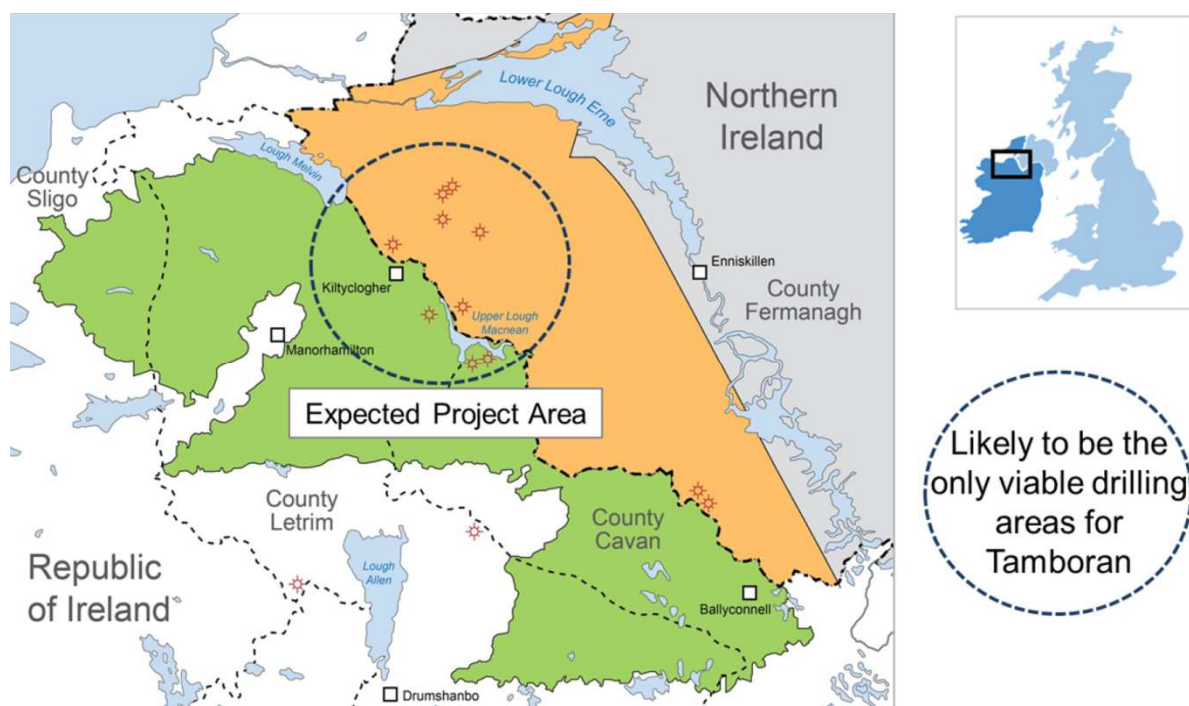
**Figure C2** shows a simplified schematic cross section across the Irish Northwest Carboniferous Basin. The basin comprises a layer-cake sequence of limestones (blue), sandstones (orange) and shales (paler orange).

The Irish Northwest Carboniferous basin straddles the border and occupies much of Counties Fermanagh, Tyrone, Cavan, south Donegal, Leitrim, Monaghan and Sligo. Drilling has shown that there is a thick succession of up to 2500 metres of Lower Carboniferous rocks in this basin. These are mainly marine sediments and include organic-rich shales and deltaic sandstones that form potential hydrocarbon source and reservoir rocks.

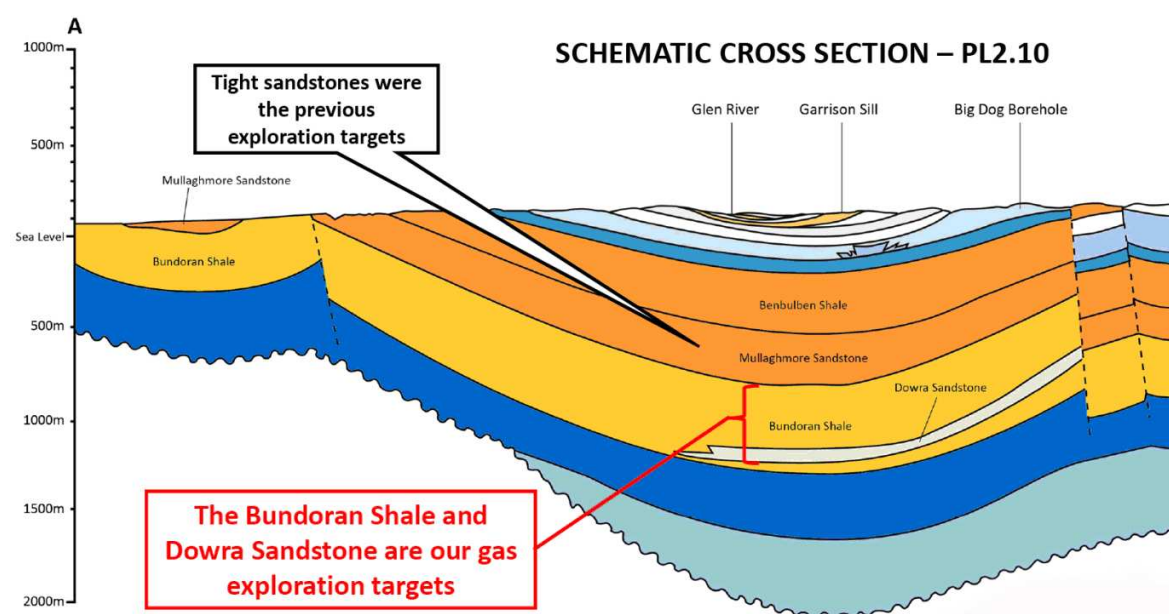
The complex bedrock geology of the area is shown in **Figure C3**. This shows the rocks as mapped at outcrop or inferred to lie beneath any superficial cover of peat and glacial material. The Bundoran Shale is outlined in red and in this figure is coloured olive-green.

GSNI conducted a detailed airborne geophysical survey (the Tellus Project) across Northern Ireland in 2005/6. **Figure C4** shows the summary radioactivity map. Within the Licence area, radioactivity of shales and sandstones appears relatively subdued west of Lower Lough Erne, although the signal may be partially masked by saturated peat. The limestones immediately to the west of Lower Lough Erne, and which underlie the Bundoran Shale, show highest levels of radioactivity. The radioactivity of these rocks has not yet been analysed in the laboratory. The rocks east of Lough Erne appear to be more radioactive than those of the Licence area.

Estimated levels of in-house radon (**Figure C5**) over the outcrops of Bundoran shale are low-medium, suggesting that fracking this formation would not release radon in unusually high levels. Any high levels of radon in the collected gas could be dissipated by interim storage, as the half-life of radon is only 3.8 days. Relatively high in-house radon levels are estimated over the limestone west of Lower Lough Erne, and over sandstones north of Belcoo and southeast of Garrison.

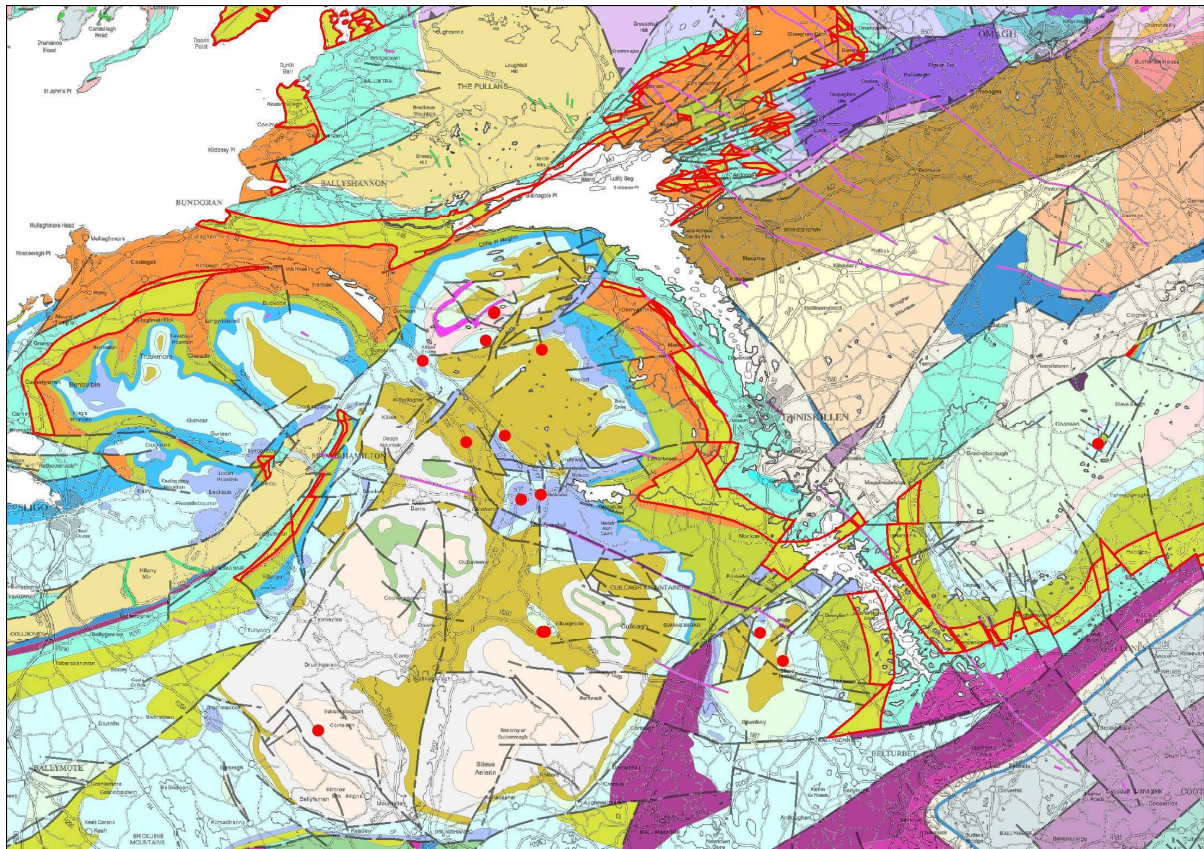


**Figure C1** Tamboran's Petroleum Licence area in Northern Ireland and Licensing Option area in Ireland (taken from a presentation made by Tamboran to DETI)

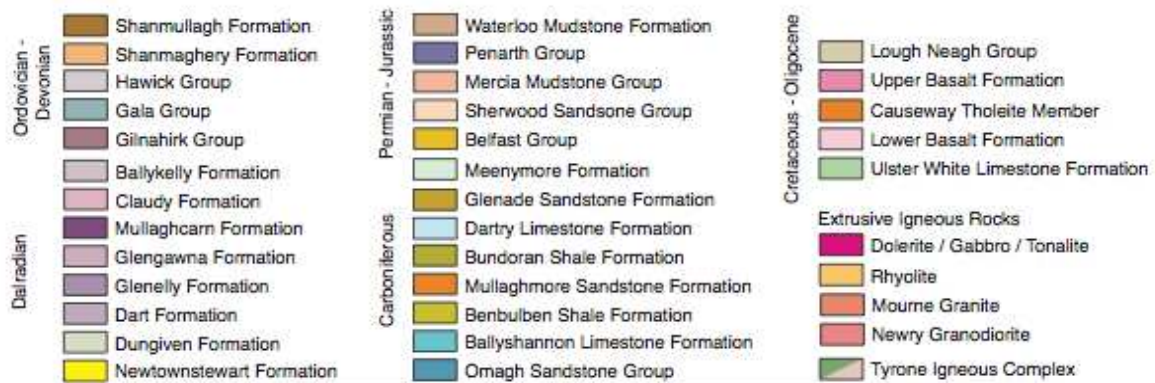


**Figure C2** A schematic northwest-southeast cross-section of the North West Carboniferous Basin, showing the target Bundoran Shale at an estimated depth below surface of 800 – 1300 metres. Width of section: 13 km approx. (Taken from a presentation made by Tamboran to DETI)

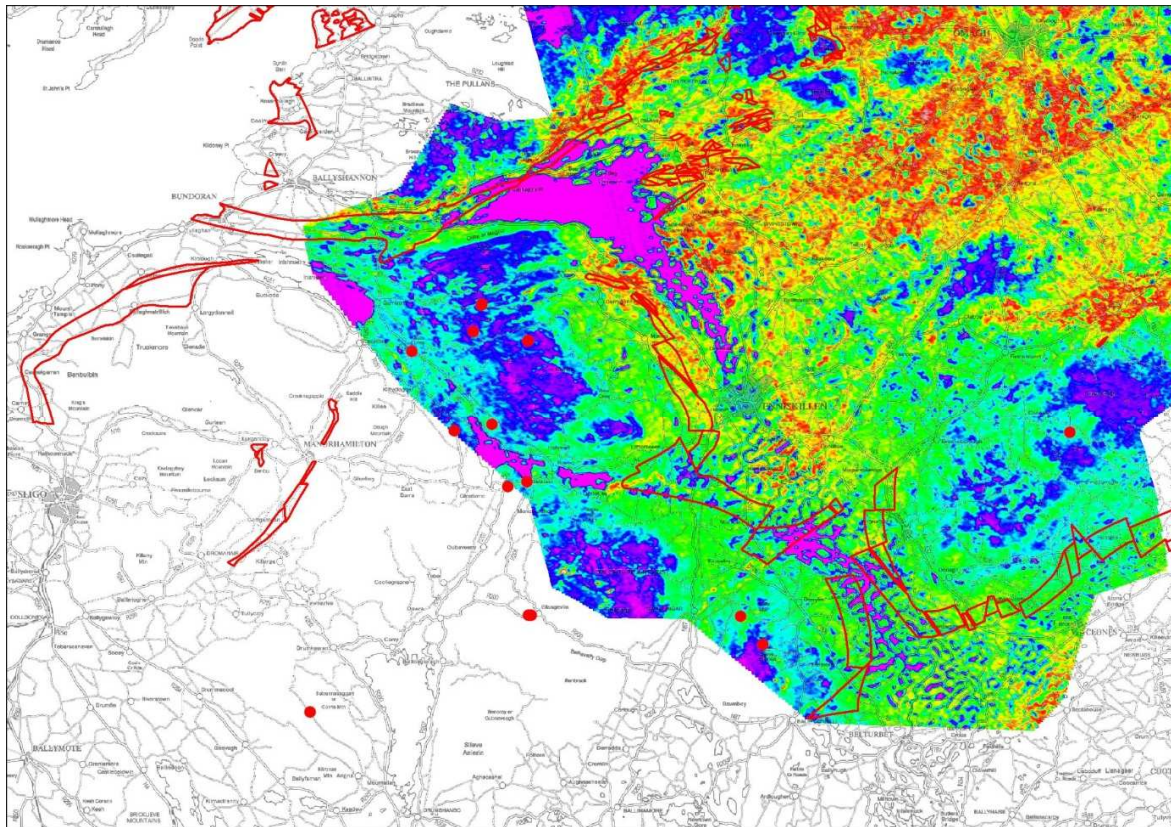




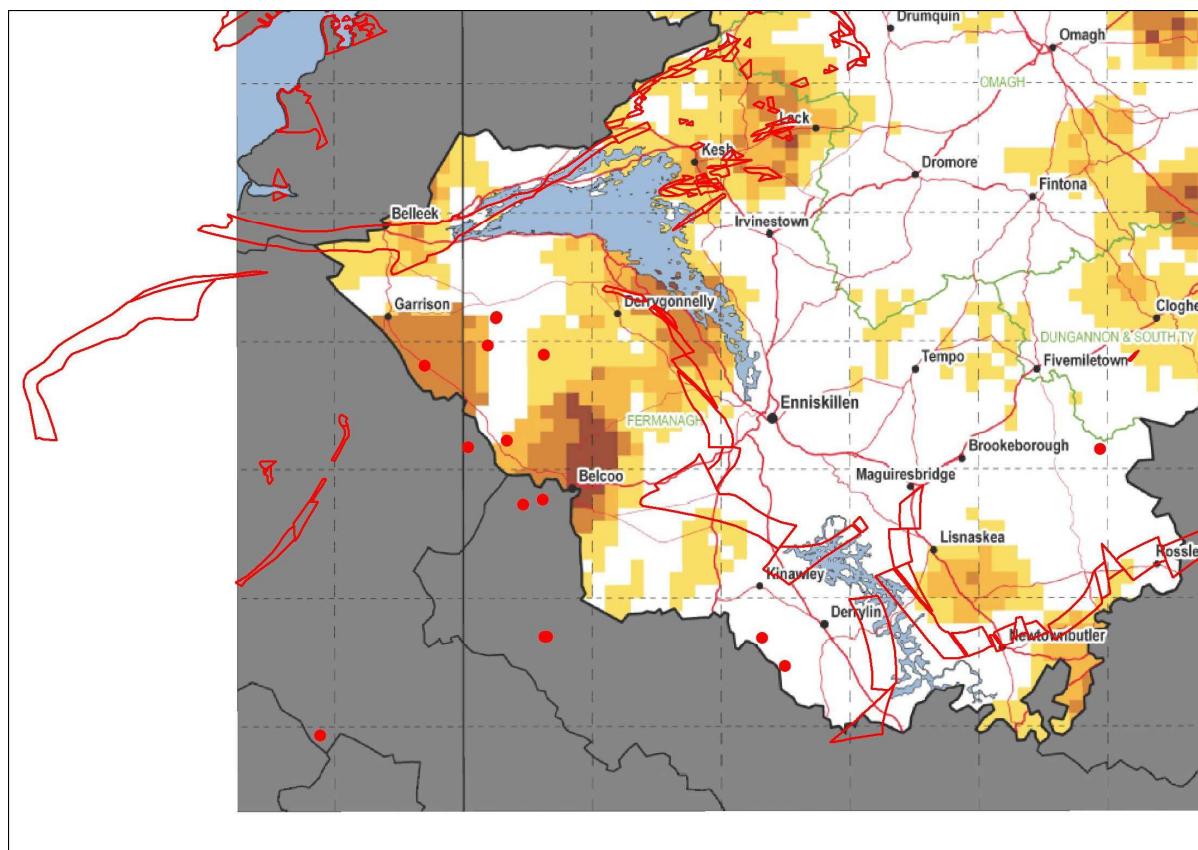
**Figure C3** An extract from the GSNI Bedrock Geology Map (legend below) showing the outcrop of the Bundoran Shale outlined in red. Red dots indicate existing wells







**Figure C4** Radioactivity (Total Count) from GSNI's Tellus airborne geophysical survey of 2005. Red areas indicate relatively high radioactivity and blue areas relatively low. Low to moderate levels of radioactivity characterise the Bundoran Shale, outlined in red. (Purple areas indicate water)



**Figure C5** An extract from the [2009 NIEA Map](#) 'Radon in dwellings'. Radon levels over the mapped outcrop of the Bundoran Shale (outlined in red) are low-medium. The map legend is shown below.



## **Appendix D**

## **DECC note on hydraulic fracturing**

This factsheet has been prepared for DECC by Dr C. Green of G Frac Technologies Ltd to assist understanding by non-specialists of the independent experts' report about the induced seismicity during hydraulic fracturing at the Preese Hall site, Lancashire, NW England.

## What is a shale?

Shale is a sedimentary rock that is predominantly comprised of very fine-grained clay particles deposited in a thinly laminated texture. These rocks were originally deposited as mud in low energy depositional environments, such as tidal flats and swamps, where the clay particles fall out of suspension. During the formation of these sediments, organic matter is also deposited, which is measured when quoting the Total Organic Content (TOC). Deep burial of this mud results in a layered rock called "Shale", which actually describes the very fine grains and laminar nature of the sediment, not rock composition, which can therefore differ significantly between shales.

## What is different about shales and why are they hydraulically fracture stimulated?

Matrix permeabilities of typical shales (the ability of fluids to pass through them) are very low (often termed ultra low) compared to conventional low permeability oil and gas reservoirs (nanodarcy  $10^{-9}$  Darcy in shales versus millidarcy  $10^{-2}$  in conventional sandstones) which means that hydrocarbons are effectively trapped and unable to flow under normal circumstances in shale, and usually only able to migrate out over geologic time. The slow migration of hydrocarbons from shales into shallower sandstone and carbonate reservoirs has been the source of most conventional oil and gas fields, hence shales have historically been thought of as source and seal rocks, rather than potential reservoirs, but much of the hydrocarbon still remains bound in the shale.

## What is shale gas?

Shale gas is produced from organic-rich (>2% TOC according to USGS) shales. The very low permeability of shale means that it is classified as an unconventional reservoir for gas (or in some cases, oil) production for the following reasons:

- **Conventional reservoirs** – Conventional gas reservoirs contain 'free' gas in interconnected pore spaces that can flow easily to the wellbore i.e. natural flow is possible. In conventional natural gas reservoirs, the gas is often sourced from organic-rich shales which has migrated to these nearby sandstone or carbonate reservoirs, over geologic time.
- **Unconventional reservoirs** – Unconventional reservoirs produce from low permeability (tight and now ultra tight) formations. The gas is often sourced from the reservoir rock itself, adsorbed onto the matrix. Due to the low permeability of these formations, it is necessary to stimulate the reservoir by creating a fracture network to give enough surface area to allow sufficient production from the additional 'enhanced' reservoir permeability.

## Are there other types of unconventional reservoirs?

There are three main types of unconventional (UNCON) reservoirs presently being developed; while a fourth class, gas hydrates, is also being investigated for potential production. The permeabilities and associated gas type for UNCON's are shown in Figure 1 (overleaf) and summarised below:

1. **Tight Gas Sands (TGS)** – Wells produce from low-porosity sandstones and carbonate reservoirs. The gas is sourced outside the reservoir and migrates into the reservoir over geological time. Some Tight Gas reservoirs have also been found to be sourced by underlying coal and shales source rocks, in the so-called Basin Centred Gas (BCG) accumulations.
2. **Coal Bed Methane (CBM)** – Wells produce from coal seams which act as source and reservoir to the produced gas. These wells often produce water in the initial production phase, as well as natural gas. Economic CBM reservoirs are normally shallow, as the coal matrix tends to have insufficient strength to maintain porosity at depth.



3. **Shale Gas and Shale Oil** – Wells produce from ultra low permeability shale formations that may also be the source rock for other gas and oil reservoirs. The natural hydrocarbon volumes can be stored in fracture porosity, within the micropores of the shale itself, or adsorbed onto the shale.

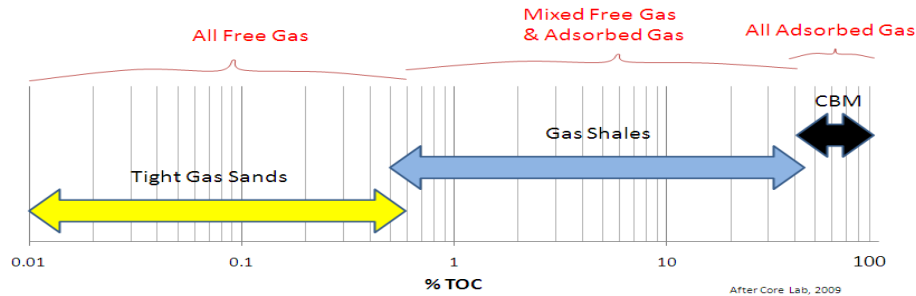


Figure 1: Unconventional reservoir associated gas variation with TOC content (courtesy CoreLAB).

## Why is interest only now happening in unconventional, and particularly shale?

Historically, there has not been any real desire to try to develop these low productivity reservoirs as they were not economically attractive, though the potentially huge resource has always been known. However, recently US shale gas (and now oil) development has been aggressively pursued, as it is present across much of the US and there was a need to secure lower risk/cost supplies, see Figure 2. The US Department of Energy (DOE) funded a number of projects in the early 1980's and 1990's to look at developing UNCON's using horizontal well drilling (developed in the 1930's) and hydraulic fracturing technology (developed in the late 1940's). This research, together with the parallel advances in 3D frac simulators and computing power, has enabled the current development of prospective shales across the US. The earliest shales were the Barnett Shale and Haynesville/Bossier Shale, with recent interest in developing other gas and oil shales throughout the US.

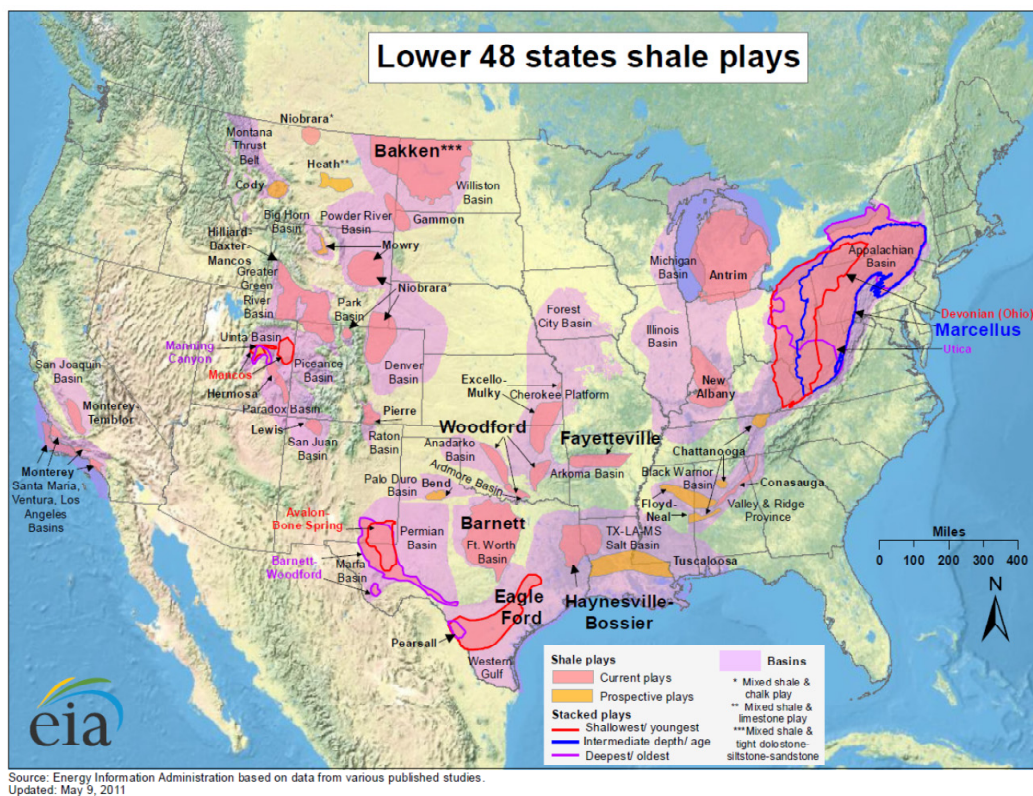


Figure 2: EIA US Shale play map for the lower 48 states (courtesy of EIA website).

## What is the history of shale?

Though shale gas has only recently started to attract attention as a potential reservoir, historically a shale gas well was the first commercial well in the US. A summary of Shale Gas history is outlined in Table 1.

*Table 1: Shale Gas History Summary*

Date	Comments
1821	1 <sup>st</sup> US commercial gas well producing from the Devonian shales in Fredonia, NY.
1859	Commercial oil well drilled
1860s to 1920s	Natural gas, including gas from fractured shales in the Appalachian and Illinois basins, is used in nearby cities.
1930's	US Transmission pipelines built for transporting gas.
1940's	Hydraulic fracturing first pumped in 1947 on a gas well Kelpner Well No. 1, located in Grant County, Kansas.
1970's	Directional drilling technology developments.
1970's to 1980's	DOE estimates of significant UNCON reserve potential.
1980's to 1990's	DOE/GRI projects multi-disciplinary projects to optimise large fracture designs, reservoir characterization and completion practices. Development of technology makes the Barnett Shale economic and establishes horizontal hydraulic multi-fracturing as the key enabler technology for shale gas reservoir development.
2001 to 2004	Barnett shale gas production overtakes shallow shale plays (Appalachian and Michigan).
2005 to 2010	Development of other major shale basins begins.
2010	Marcellus shale development begins and investment in US Shales becomes saturated. US/Canadian based companies and expertise begin to look overseas for potential resource plays that can be developed world-wide.

## How is shale development technology applied?

Each gas shale basin is different and each has a unique set of exploration criteria and operational challenges. The technology was primarily developed in the Texas Barnett Shale and rolled out to other shale plays, often with a one-size-fits-all approach. However, there is now a realisation that Barnett shale technology needs to be adapted to other plays in a structured and scientific manner. It has been stated that unconventional resources need unconventional techniques, but it is clear that the poorer the reservoir the better the technology and accuracy of data needed to be able to fully characterize and develop each play. This means that typical shale plays are often a lot more expensive and labour intensive than conventional plays to develop and the expertise needed to characterise reservoirs and optimise stimulation treatments is highly specialized.

## What is hydraulic fracturing?

Hydraulic fracturing involves the pumping of a (fracturing) fluid into a formation at a calculated, pre-determined rate and pressure to be able to crack the rock and create fractures in the target rock formation. Shale gas development typically uses water or water-based fluids as the fracture fluids, mixed with a small amount of various additives (see later). Sand is the usual "proppant" material pumped, and is needed to "prop" open the fractures once the pumping of fluids has stopped and they have leaked off into the formation. Initially, fractures were considered to grow as half penny-shaped "wings" 180 degrees apart, as well as be identical in shape and size at any point in time. However, as research and technology have progressed we now know that created fracture growth is very complicated and in naturally-fractured reservoirs complex fracture growth results from a typical hydraulic fracture treatment.

## What materials are used for fracturing?

There are two classes of materials injected during fracturing treatments, fracturing fluid, to carry the material to keep the created fracture open and the solid proppant, to keep the created "fissure" open. The main environmental concerns relate to the additives used in the frac carrier fluid, as detailed below:

**Fracturing Fluid:** The fracturing fluid should have a number of properties that are optimised for each formation: be compatible with the formation rock, compatible with the formation fluid, generate sufficient pressure drop down the fracture to create a wide enough fracture, have sufficient lower viscosity to allow clean-up after the treatment, and be cost effective. Water-based fluid are commonly used and "Slickwater" is the most common fluid used for shale gas fracturing, where the major chemical added is a surfactant polymer to reduce the surface tension or friction, so that water can be pumped at lower treating pressures. Other fluids that have been used are oil-based fluids, energised fluids, foams and emulsions.

**Fracture Fluid Additives:** Possible additives for frac fluids are listed below, but it should be stressed that not all chemicals are added for every job and in general as few additives as possible are added to avoid potential problems with the reservoir and maximise production:

- Polymers – allow for an increase in the viscosity of the fluid, together with crosslinkers.
- Crosslinkers – increase the viscosity of the linear polymer base gel.
- Breakers – used to break the polymers and crosslink sites at formation temperature, for better clean-up.
- Biocides – used to kill bacteria in the mix water.
- Buffers – used to control the pH.
- Fluid loss additives – used to control excessive fluid leak-off into the formation.
- Stabilizers – used to keep the fluid viscous at higher temperature.

## What techniques are used to analyse the location of the fractures created?

Fracture diagnostics are the techniques used to analyse the created fractures and involve analyzing data before (pre-frac), during (real time) and after (post-frac) hydraulic fracture treatments. Analysis is done to determine the dimensions of the created and also the effectively propped fracture. Fracture diagnostic techniques are divided into several groups.

- 1) **Direct Far Field Techniques:** These comprise tiltmeter and microseismic fracture mapping techniques which require delicate instrumentation to be placed in boreholes surrounding and near the well to be fracture treated. Microseismic fracture mapping typically relies on using a downhole receiver array of accelerometers, or geophones, to locate 'microearthquakes' that are triggered by shear slippage in natural fractures surrounding the hydraulic fracture. As with all monitoring and data collection techniques, however, the economics of UNCONs means that typically they are considered marginal wells and the expense is often not justified until the resource has been proved. If the technology is used at the beginning of the development of a field, however, the data and knowledge gained have been shown to be cost effective in the long run once development of the shale play begins in earnest.
- 2) **Direct Near-Wellbore Techniques:** These techniques are run in the well that is being fractured to locate the portion of fracture that is very near wellbore and consist of tracer logs, temperature logging, production logging, borehole image logging, downhole video logging, and calliper logging. In Shale gas plays, where multiple fractures are likely to exist, the reliability of these direct near-wellbore techniques can often be poor. As such, very few of these direct near-wellbore techniques are used on a routine basis to evaluate hydraulic fracture and if deployed they are used in conjunction with other techniques.
- 3) **Indirect Fracture Techniques:** This consists of hydraulic fracture modelling (see Figure 3, below) and matching of the net surface treating pressures (see Figure 4, overleaf), together with subsequent pressure transient test analyses and production data analyses. As fracture treatment data and the post-fracture production data are normally available on every well, indirect fracture diagnostic techniques are the most widely used methods to determine the shape and dimensions of both the created and the propped hydraulic fracture.

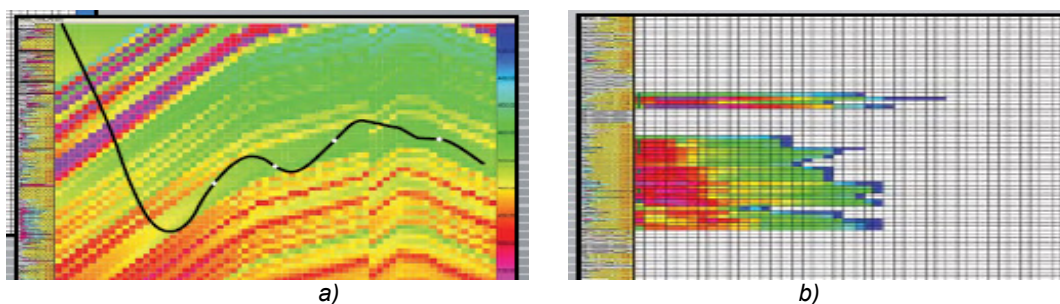


Figure 3: a) 3D frac simulator grid model and b) frac outputs (courtesy StimLAB)



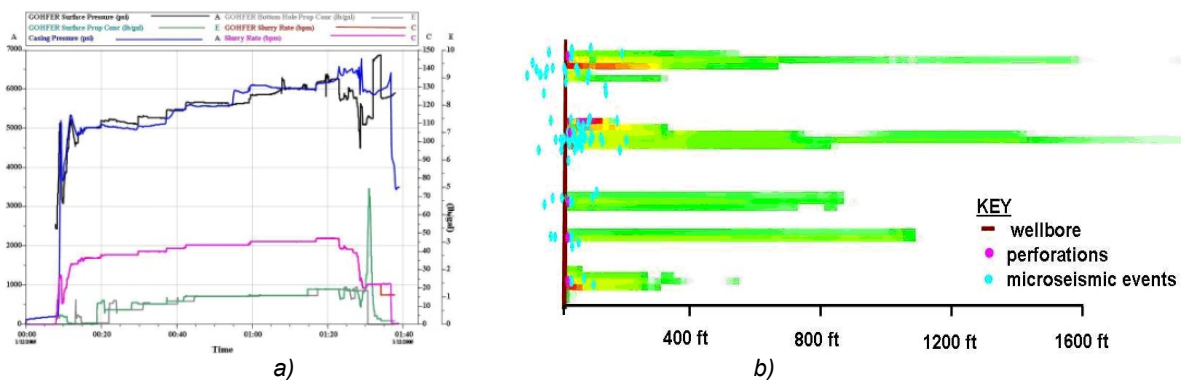


Figure 4: a) Pressure and b) Simulator output/microseismic matching for an UNCON well (courtesy FAST consortium at CSM)

## How are wells designed?

Current well construction requirements consist of installing multiple layers of protective steel casing and cement, that are specifically designed and installed to protect groundwater bearing formations, and also to ensure that the producing zone is isolated from overlying formations – this ability to isolate and contain pressure is what is termed “Well Integrity”. Figure 5, overleaf, shows a typical vertical fractured well schematic with reference to Preese Hall and the Bowland Shale formation.

### How is the well then completed?

The first stage in the completion process is to perforate the well, which refers to explosively punching a hole in the casing or liner, to connect the wellbore to the reservoir. This first part of the final stage of the completion process involves running perforating guns (a length of shaped explosive charges) down to the desired depth and firing them to perforate the casing or liner at the required depth and penetrate the formation a short distance (approx. 1ft), as shown in Figure 6.

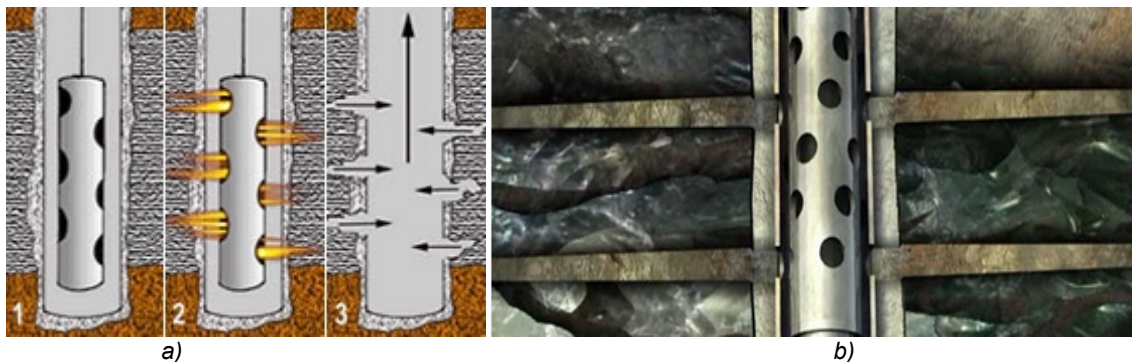


Figure 6: a) Explosive perforating to give b) the perforation tunnels through the production liner with a length of typically 10-20 inches (courtesy MPG Petroleum Inc. and Baker Hughes websites).

The second part of the process is then to hydraulically fracture the well, by pumping fluid and proppant at sufficiently high pressures to create and extend a fracture.



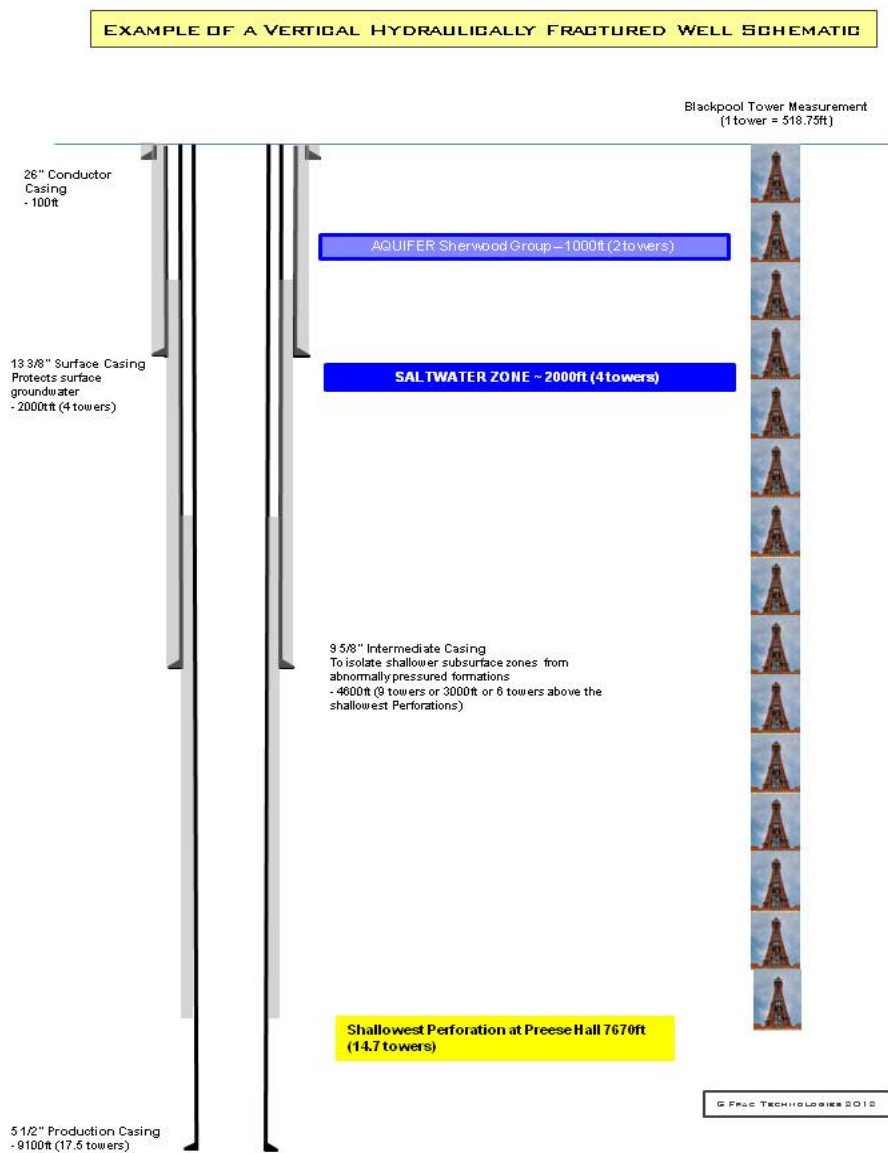


Figure 5: Typical vertical hydraulically fractured well schematic.

## How are hydraulic fracture treatments carried out?

Initially, fluid is injected that does not contain any propping agent, called 'pad', which is injected to create a fracture that usually grows up, out and down, see Figure 7a. The pad creates a fracture that is then wide enough to begin accepting a propping agent material. The pad is then followed by the proppant "slurry", a mix of the carrier fluid and proppant material. The purpose of the propping agent is to 'prop open' the created fracture, once the pumping operation ceases and the fracture closes. In deep reservoirs, man-made ceramic beads are sometimes used to prop open the fractures but in shallow reservoirs, sand can be used and remains the most common proppant. Once the fracture has initiated, fluid is continually pumped into the wellbore to extend the created fracture and develop a fracture network. Each formation has different properties and in-situ stresses, so that each hydraulic fracture job is unique and different and is specifically designed for that well by a hydraulic frac specialist (see Figure 7b, overleaf). The process of designing hydraulic fracture treatments involves identifying properties of the target formation including estimating fracture treating pressure, amount of material and the desired length for optimal economics.

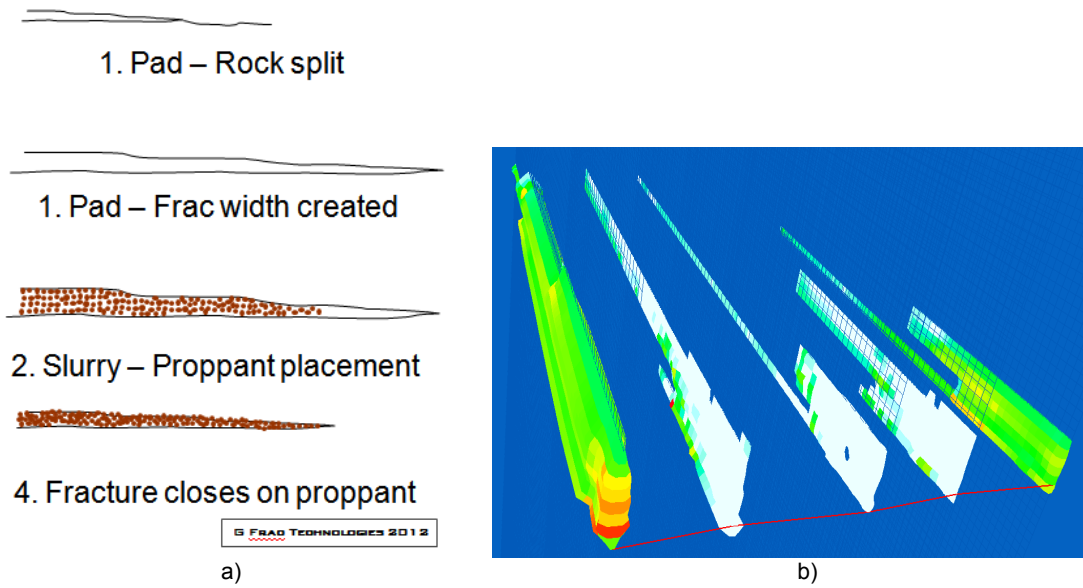


Figure 7: a) The hydraulic fracture process and b) resultant matched 3D simulator outputs.