GGERFS Company Demand Analysis

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Executive Summary

Geothermal energy has been on the policy agenda in Scotland for the past five years following a study on the potential for deep geothermal energy in 2013 that was commissioned by the Scottish Government. A Geothermal Energy Expert Group was subsequently established to consider the way forward and this led to a specific Geothermal Energy Challenge Fund, which was launched in 2015, and a learning journey in 2016 to a geothermal energy demonstration site in the Netherlands that is using water from disused coal mines. Scottish Enterprise also attempted to stimulate the market as part of a wider report, published in 2017, on Scottish oil and gas diversification opportunities.

In spite of these interventions there are still barriers to the implementation of geothermal energy schemes in Scotland, and the wider UK, and a lack of demonstration projects that could provide the necessary economic and technical evidence for wider exploitation. The decision to establish the Glasgow Geothermal Energy Research Field Site (GGERFS) in Scotland was therefore seen as an opportunity to build on this key UK asset in a way that would create a focal point for market and economic development.

The objectives of the study were to produce:

1. A comprehensive database of companies in Scotland that are, or have potential to be, active in the geothermal energy sector
2. A survey designed to extract information from companies regarding their potential use of the GGERFS
3. A report containing an overview of survey responses, analysis of those responses and conclusions regarding the potential use of the GGERFS by Scottish companies

Our approach to the study was based on an iterative process of consultations with stakeholders and systematic desk research to identify relevant companies. This highlighted over 70 companies that have the potential to become active in the geothermal energy market and provided subjective evidence on the situation in Scotland as well as opinion on the potential use of the GGERFS to support market and economic development.

The key messages from the consultations included:

GGERFS: The general impression was that the site is very much focussed on academic research. Also, there is the perception that its scope will not include pumping mine water to the surface to demonstrate feasibility of the thermal energy resource. Without this, it was felt that there would be limited scope for industrial involvement apart from perhaps downhole sensors. The lack of a deep borehole, which is not possible with the current funding, was also considered to be a lost opportunity. Various ideas were highlighted to increase the potential benefits to potential developers of geothermal energy and technology suppliers in Scotland.

Coal Mine Energy: Many of those consulted consider this to be the short term opportunity to mobilise geothermal energy activities in Scotland due to the extensive resource (i.e. disused mines). In some cases, water is already being pumped to the surface and treated to avoid contamination from rising floodwaters. The main issue is to match up supply and demand. Mine water is also considered to be an interesting option for energy storage. The UK Coal Authority is keen to encourage good practice in exploiting mine energy resources and is planning two demonstrators in England.

Deep Geothermal: The deep geothermal energy opportunity is considered to be more speculative at present although there are some areas of Scotland with potential. The main barrier seems to be the economic feasibility as there is a high degree of uncertainty until an exploration well has been drilled. There also appears to be some innovative drilling technologies, but these are not yet proven, and also some regulatory challenges.

Barriers to exploiting the geothermal energy resource: There are two main barriers that appear to be inhibiting potential developers. The first is the risk of obtaining heat from underground resources. The second is related to demand and the market price for hot water. It seems that it is currently quite difficult to make the business case for geothermal energy and this is particularly the case in Scotland/UK due to the lack of district heating networks. These are seen as a key enabler of geothermal energy developments as they address one of the current barriers but they are relatively scarce compared with the situation in some other European countries like Denmark.

Current developments: In spite of the barriers it seems that there are a number of projects in Scotland at the development, or exploratory, stage that may be implemented but some of the earlier ones (including those that were supported by the Geothermal Energy Challenge Fund) have failed to proceed. There are also some interesting projects in Cornwall and Wales as well as a growing number elsewhere in Europe (in addition to the Heerlen project). These could offer valuable evidence for potential developers in Scotland.

An overview of key sub-sectors in Scotland was derived from the company database and indicates that Scotland has relevant industrial capability in professional & technical services, well design & drilling, topside components and heat pumps, sensors & instrumentation and geological modelling. What is missing is a market for the geothermal energy supply chain both in Scotland and the UK.

The findings of the research and consultation activities provided the basis for a SWOT analysis for the exploitation of geothermal energy in Scotland and related economic development. From this, 10 specific development options, or issues, were derived including:

1. Foster Local Authority interest in renewable powered heating
2. Build on experience from other countries
3. Educate public sector energy managers
4. Encourage the Coal Authority to pioneer 'mine energy' innovation in Scotland
5. Lack of demonstrators
6. Key players are SMEs
7. Perception of lack of appropriate public/private funding mechanisms
8. 2025 deadline to phase out gas-powered housing
9. Export opportunities in other coal mining regions
10. Deep geothermal

The report then concludes with more specific recommendations on how the GGERFS could be the focal point for both market and economic development in Scotland by creating an innovation platform to demonstrate technical feasibility and provide evidence-based guidance for potential developers. This includes the expansion of the GGERFS to take advantage of the 5th generation district heating network that is being developed by Clyde Gateway in the nearby Shawfield area. These complementary assets offer the potential to establish a 'mine energy innovation platform' (at marginal cost) in the Dalmarnock/Shawfield area of Glasgow that could be world leading. The way forward for deep geothermal action is less obvious, as the techno-economic issues are more challenging, but it is clear that there are some novel drilling technologies that could make a difference to the economics and the potential for energy storage is also a possibility. The report therefore concludes with two main recommendations that are presented as objective statements:

1. Create a focal point for mine energy innovation around the GGERFS
2. Incentivise innovative oil & gas industry companies to demonstrate new technologies that could unlock Scotland's deep geothermal resources

Six specific actions have been proposed to achieve these objectives and these have the potential to both develop the market in Scotland and the associated technology supply chain.

Table of Contents

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1 Introduction

This report details the results and conclusions from the study entitled 'Glasgow Geothermal Energy Research Field Site (GGERFS)'. It is based mainly on extensive consultations with stakeholders during late February and March 2019. A database of companies (in Microsoft Excel format) that are already involved in the geothermal market, or have the potential to enter it, has been provided separately.

1.1 Background

Geothermal energy is one of the options to produce low carbon heat and the potential was initially considered in a 2013 report commissioned by the Scottish Government[1]. This led to the formation of a Geothermal Energy Expert Group in 2014 and the launch of a Geothermal Energy Challenge Fund in 2015 as part of the Low Carbon Infrastructure Transition Programme (LCITP). This allowed the potential for geothermal resources at sites in Fife, North Lanarkshire, Aberdeen, Aberdeenshire and Clackmannanshire to be explored.

In 2016, the Scottish Government prepared a guidance document[2], with key stakeholders, on the regulatory framework and sponsored (with Scottish Development International) a 'Learning Journey' for Scottish stakeholders to an operational mine water demonstration site at Heerlen in the Netherlands.

In spite of these initiatives there are clearly still barriers to the exploitation of Scotland's geothermal energy resources and so the decision by the UK Government to establish one its two geoenergy research field sites in Scotland is seen as a potential opportunity for economic development. The Glasgow Geothermal Energy Research Field Site (GGERFS) is being developed and will be operated by the British Geological Survey (BGS) in the Dalmarnock area of the city. The scope of geothermal energy in this report is aligned to the three sources of heat identified in a Scottish Government report namely, coal mine water, aquifers and deep geothermal. Further details are provided in Section 4.1.

1.2 Objectives

The objectives of the study were therefore to produce:

- A comprehensive database of companies in Scotland that are, or have potential to be, active in the geothermal energy sector
- A survey designed to extract information from those companies regarding their potential use of the GGERFS
- A report containing an overview of survey responses, analysis of those responses and conclusions regarding the potential use of the GGERFS by Scottish companies.

The report was also expected to provide recommendations (which SE can discuss with BGS) regarding how the GGERFS could be best developed to maximise benefits to Scottish companies and how the GGERFS can be marketed effectively to companies in Scotland and internationally.

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[1] *Study into the Potential for Deep Geothermal Energy in Scotland, Aecom Energy for the Scottish Government, August 2013*

[2] *Regulatory Guidance: Geothermal Heat in Scotland, Scottish Government, Directorate of Energy and Climate Change, updated February 2017*

1.3 Methodology

The evidence for the report was gathered through an iterative process of consultations with stakeholders, company interviews and desk research. Those organisations that contributed to the study are listed in Appendix A.

A list of Scottish companies with the potential to form part of the supply chain serving the geothermal energy market is provided in Appendix B. Some of those were identified from the consultations. Others from a systematic process involving a review of appropriate Scottish, UK and European trade bodies, conferences, previous Scottish reports on the subject and relevant UK/EU research projects. Feasibility studies funded by the Low Carbon Infrastructure Transition Programme (LCITP) were also reviewed. Each of the sources were searched and the results filtered to find appropriate companies, with focus on evidence of employment in Scotland, and relatedness to the geothermal sector. Adjacent sectors such as subsurface drilling and geoscience, and also heat recovery and transformation (such as heat pumps), were automatically included. Indirectly relevant sectors, such as district heating, are represented but other heat generation methods (such as CHP) have been excluded. The framework for selecting the supply chain elements is provided in Section 4.

In the appropriate sectors, companies are automatically listed when a Scottish address is provided. When not, and where possible, a location search is conducted to identify if any relevant Scottish presence or subsidiaries exist. Some large international firms have been included, as they have a Scottish footprint, even though it may not have been possible to verify the nature of their presence.

The main sources were as follows:

Trade Bodies

- Aberdeen Renewable Energy Group
- Association for Decentralized Energy (ADE)
- British Drilling Association Ltd (BDA)
- British Refrigeration Association (BRA)
- European Geothermal Energy Council
- European Heat Pump Association
- European Technology & Innovation Platform on Deep Geothermal (ETIP-DG)
- Federation of Environmental Trade Associations (FETA)
- Ground Source Heat Pump Association (GSHP)
- Heat Pump Association (HPA)
- Scottish Renewables
- Subsea UK
- UK District Energy Association
- Well Drillers Association

Conferences

Conferences, seminars, industrial exhibitions and workshops were surveyed. Where possible both participants and exhibitors were reviewed.

- British Drilling Association "Solutions for the Future of the Geotechnical Industry" seminar Edinburgh February 13th, 2019
- Scottish Renewables Low-Carbon Heat 2018 Conference, 24 April Glasgow
- American Association of Petroleum Geologists GTW Series Geothermal Cross Over Technologies Workshop
- The Geological Society Bryan Lovell Meeting 2019: Role of geological science in the decarbonisation of power production, heat, transport and industry21 –23 January 2019
- Institution of Civil Engineers (ICE) Turning up the heat! Innovation in the UK's deep geothermal resources, Newcastle Lecture, Newcastle 13 March 2018
- All Energy Exhibition and Conference Glasgow, 2018
- European Geothermal Congress, The Hague Netherland, 11-14 June 2019

Reports

Quite a few studies and feasibility assessments have been conducted over the last several years in Scotland and the UK. Reports have been published mainly commissioned by Scottish Government, Scottish Enterprise or by the UK Government. The following reports were reviewed:

- Scottish Oil and Gas Diversification Opportunities[3]
- Feasibility study reports on projects that were funded by the Geothermal Energy Challenge Fund:
    - Deep Geothermal Single Well, Aberdeen Exhibition and Conference Centre
    - Guardbridge Geothermal Technology Demonstrator Project
    - Hill of Banchory Geothermal Energy Project
    - Fortissat Community Minewater Geothermal Energy District Heating Network
- Study into the Potential for Deep Geothermal Energy in Scotland (Ref 1)
- Geothermal Energy Potential in Great Britain and Northern Ireland[4]

1.4 Report Outline

This report is structured into seven sections. This introduction (Section 1) provides the scope, objectives and methodology of the report. Section 2 provides an overview of the GGERFS, which forms the context of the study. The responses from meetings with stakeholders are aggregated and presented in Section 3, which identifies areas of common agreement and concern amongst the respondents as well areas where opinions differed. Feedback is aggregated around the understanding and potential for industry collaboration with GGERFS, the opportunities for coal mine water energy, the opportunities for deep geothermal energy, geothermal energy in general and developments cited by respondents.

Section 3 does not include any interpretation of the feedback from stakeholder consultations. This is presented in Sections 4 to 7 including a mapping of the geothermal energy supply chain, and an assessment for the key sub-sectors in Scotland (Section 4); a SWOT analysis of current situation in

[3] Scottish Oil and Gas Diversification Opportunities: Heating & Cooling, Water and Energy Storage and Systems, Arup Report for Scottish Enterprise, December 2017

[4] Geothermal potential in Great Britain and Northern Ireland, SKM, September 2011

Scotland (Section 5), which provides the logic for development options (Section 6); and our recommendations both for the GGERFS and wider actions (Section 7).

2 Overview of the GGERFS

The Glasgow Geothermal Energy Research Field Site (GGERFS) is a £9m UK Geoenergy Observatory to study low-temperature energy from the flooded mine workings below Glasgow. The funding has been provided by the UK Government. The National Environment Research Council (NERC) and the British Geological Survey (BGS) are the implementation partners. One of the aims of the GGERFS is to contribute to a better understanding of the potential for warm water in disused coal mines to be used for renewable heat.

The site will feature a number of boreholes of various depths, which will enable research into the area's geology, underground water systems and the potential for mine water geothermal heat. Measurements will be taken from the boreholes, such as temperature, seismicity, water movement and water chemistry. It will be open to the whole of the UK science community to undertake research and continuous data from state-of-the-art sensors from the boreholes will be free and accessible to all stakeholders via an online portal. It is expected that academics will bid for funding from NERC and/or EPSRC to carry out research.

Work on the site started in November 2018 and one bore hole has already been drilled. Another 11 will be completed by October 2019, of which six will be into mine waters. Site tests will commence late 2019 and it is expected to be partially operational for research purposes in late 2020.

The current plans do include pump testing of the boreholes, and it seems that discussions have been held with SEPA and Scottish Water. A 2nd planning application would be necessary for further infrastructure such as heat pumps, chillers, mine water pipes and water treatment facilities.

BGS is developing an innovation strategy for the site but it is not yet available. We also understand that a BGS innovation panel was established around 18 months ago and that NERC is planning to hold an innovation workshop in Glasgow on 3rd June (Strathclyde TIC).

It seems that there is the potential for collaboration with Clyde Gateway, which is developing a 5th generation heating & cooling network in a new commercial development nearby (Shawfield) and is also pioneering the use of other sustainable energy sources. It is also hoped that evidence from the site will help to stimulate demonstrator sites around Scotland and that the Glasgow observatory could perhaps be the hub for commercial schemes. The data, monitoring, observations and analysis performed at GGERFS could provide such evidence and form the basis for advice to other schemes.

One of the leading companies (TownRock Energy), which is a member of the BGS innovation panel, prepared a proposal to develop a "high level strategy for the BGS's UKGEOS project to engage with the private sector and local communities". The vision is for a series of direct use geothermal demonstrator technologies to be built on-site that can be used both commercially and as a publicly accessible demonstrator for awareness raising and educational purposes.

3 Key Messages from the Interviews

A variety of responses pertinent to the GGERFS and the wider geothermal sector were received. These responses are grouped in this Section 3 in aggregate. There was a general level of common agreement to many of the answers, but where respondents provided differing perspectives, these are also recorded here as such. Purely respondent feedback is presented here, any additional analyses or comments are presented in the following sections.

3.1 GGERFS

3.1.1 Awareness at industry level

BGS has run launch events and worked in partnership on feasibility projects with some of the companies identified by the survey. A few of the contacts had been involved in the planning of the GGERFS. However, in general, it seems that there is limited awareness of the specific activity and objectives of the site.

A couple of respondents were aware that BGS have published their science plan on the UK GEOS website, but hadn't had the time to look at it. One was aware that BGS is looking for a person from industry to serve on their Scientific Advisory Board. Another (Town Rock Energy) is participating in a BGS Innovation Panel.

3.1.2 General Impression – Academic Facility

The general impression is that the facility is very much a research site, for use by the academic scientific community. A few respondents have noted that the funding stream through NERC, and then BGS, is an academic route that is typically meant to sustain universities. One comment was raised about NERC not wanting to fund industry oriented projects, and this was questioned. In general, industry contacts felt that academic institutions and BGS were open to industrial collaboration, with a few actively engaged with the academic community.

Given the perception of the field site as a research project, and lacking a visible commercial aspect, some companies were uncertain on how to use the facility. However, all except one respondent were positive on the requirement for the site and its usefulness to provide scientific evidence of the viability of mines as a geothermal energy source.

3.1.3 Heat Network

A common question about the facility was about why it was not using the heat to supply consumers. It was claimed there are no production wells, and the scheme is not to scale, but can produce some heat that would be useful as a demonstrator.

Some were aware that Clyde Gateway is building a District Heating (DH) scheme, and considered that the site could feed into that network. DH is seen as a key enabler for the growth of geothermal, as it provides a network with an aggregation of consumers. Any geothermal project with a view to being commercially viable will need to secure consumers to sell to.

A demonstration project of heat supply could help establish the viability for commercial developers. There are a few mine water projects of significance around the world, but none so far in the UK.

Currently, it would appear that developers are reluctant to construct mine water schemes as the technology is thought to be unproven. A commercial demonstrator could reduce the perceived risk.

Using the heat was also seen as important in order to test the sustainability of mine water resources. Without extracting a heat load from the mine water there was little to be gained in understanding how the temperature evolves over time or the thermal resistance of the well. There is always some uncertainty about how long the heat will last from a geothermal source?

Heat storage was also raised as a significant opportunity for the site as the ability to store energy between seasons is a big differentiator from other water sources such as rivers or sea water.

3.1.4 Technical viewpoint

A few participants identified the scientific issues that could be addressed by the site. These included:

- Characterization of the water flows within old mine workings. Mines can consist of many ponds that build up with water. The ponds are connected by driveways and it is important to understand how water flows between them. However, it was also questioned if the site would be investigating thermal capacity and recharge rates, as there is a perception that it does not have planning permission to pump water due to the pollution risk.
- The chemistry of water over time would require careful monitoring, as coal mines can contain pollutants.
- GGERFS is projected to have 11 boreholes. This number would be perfect to balance the water front between injection and production wells. It would need a sensor network to optimise the reservoir.
- The ground has the potential for both heating and cooling, but in industry this is considered to be unproven as established schemes are not common.
- Information on what environmental controls need to be put in place. This would be useful for environmental companies and concerns water quality derived from drilling into coal mines, and analyses of where the flow goes.
- Securing the necessary licences/permits/approvals for the planned drilling at the site would give BGS what was perceived to be unique experience that could be shared with future developers and other interested stakeholders.
- Techniques to develop directional drilling from geothermal source to point of use.

The potential to further develop the site with a deep geothermal borehole was highlighted by one respondent. There was apparently an aspiration to drill to 2000m but this was excluded due to funding constraints. There is potentially enough land to drill a deep geothermal well and a depth of 1000m was considered to be sufficient by the respondent to achieve a viable demonstration project.

3.1.5 Industry Engagement

Industry engagement is perceived in two phases. The first is during the construction phase. Here it was noted that the infrastructure is already contracted and that there is no longer any opening to be involved. The second is to collaborate on the ongoing scientific programme. Here it was felt that there is some, but limited, scope for involvement.

In general, most consultancies, drilling contractors and developers do not self-fund R&D activities. Some consultants explained that profit margins are tight, and that their businesses are focussed on working on projects with billable hours. This would limit any activity that requires matching funds, even if part funded through R&D grants. Full (100%) grant funding would be required. These companies generally do not participate in NERC or UK GEOS funded activities, primarily because the infrastructure contracts had been awarded to other organizations, or because the scientific programme was not seen to be aligned with their commercial interests. The companies consulted that do self-fund R&D were not participating in any direct involvement at the site, with the exception of a sensor developer. Where R&D is conducted, public funding support from Scottish Government or EU sources was cited as an enabler to investment.

There is some interest in the lessons and outcomes from the project, to demonstrate principles and to have a better understanding of all aspects of mine water geothermal requirements covering the full range of technical, regulatory and commercial challenges. The data from the project could be used to promote the industry more widely.

The 15 year timescale of the project was raised as an issue. It was perceived to be too long for commercial organizations, and it was hoped that it would be possible for any industry-facing activities to be implemented at an early stage.

3.1.6 Sensors

The most promising area for industry participation was identified as the testing of new sensor technologies such as downhole and temperature profile monitors. Ultimately, they would be applied for better optimisation of the reservoir heat extraction, balancing heat flow with sustaining reservoir temperature.

It was noted that BGS is interested in innovation in sensors and data processing.

A question was raised about how open the site would be for external use. What are the terms for IP? Can a third party install their own instrumentation on BGS facilities?

3.2 Coal Mine Energy

3.2.1 Resource

Although not considered to be traditional geothermal, disused coal mines are perceived to be a realistic energy source with high potential, as they overlap with centres of population. There are no significant geothermal projects in the UK, but there are some in the pipeline as summarised in Section 3.5 below.

In some senses mine water is considered lower risk than deep geothermal resources. Knowledge of the resource is well established as Coal Authority maps are very detailed. At shallow depths (100-300m), there is exceptional understanding of the nature of mine workings. One respondent did point to a need for further site studies by specialist geologists to assess the feasibility of projects.

The quantity of heat energy that is available can be determined by thermodynamic calculations with a reasonable degree of confidence. Temperatures of 20 to 25^{o}C have been quoted as expected temperatures, although some respondents claim lower temperatures.

Furthermore, the cost of several mine water boreholes is a fraction of one deep geothermal well, which helps lower barriers to development of a project.

Some mines have water rising to the surface (this is known as 'rebound') and the UK Coal Authority is responsible for managing and treating the water to prevent any contamination with water tables. Currently this is a liability but the heat could be used rather than going to waste. According to the Coal

Authority the current level of heat lost to atmosphere is 11MW across those mines in the UK that involve water treatment. There is clearly an opportunity to extract the heat within this essential process. Around 12 mines in Scotland are in rebound, with others at risk, and we understand that SE is carrying out a mapping study of these sites.

The key difference compared to deep geothermal is the low enthalpy of the system and the need for a heat exchanger and heat pumps to extract and upgrade the heat. However, heat pump technology is now well established.

3.2.2 Inter-seasonal heat storage

Many respondents highlighted the potential for utilising mine waters to store heat. Most focus has been on the heat generation capability of disused mines but potentially of more interest could be inter-seasonal heat energy storage. During the winter the mine would generate heat, and during the summer heat could be stored in the mine.

This concept has already been established at the Heerlen mine water project in the Netherlands. Here the water resource is actively heated during the summer from cooling of data centres or other cooling loads. It was argued by one respondent, that in theory it would be possible to get to 30^{o}C at mine water schemes.

3.2.3 Competition from other water sources

Alternative sources of heat including rivers are considered less risky. The water may be cooler, but greater volumes of flow are available. The sea and a River Clyde scheme have been cited as examples. It was stated that access to rivers is much easier than mines, and also that although mine water may be warmer, the temperature difference may not be sufficient to warrant the additional costs and risk.

3.2.4 Risks of mines and new technology

The chemistry of the water from mines is one of the important factors cited as a technical challenge. In some mines, water has to be treated to prevent contamination of the water table or surface water and the natural environment. In addition, damage to pumps and equipment through e.g. corrosion has also been observed.

Given the low heat level, and potential for heat dissipation, efficient solutions are required that could imply a bespoke development for each mine.

One respondent noted that closed loop operation (recirculation) was an established option, but that there may be advantages to open loop wells. Heat pumps work well in closed loop situations, but more experience is needed for open loop operation.

Overall, the key risk is that there is a general unfamiliarity with mine water heating systems and experience needs to be built up. The Coal Authority expressed concern that some consultants, drillers, etc. that are interested in, but not familiar with, mine workings could make mistakes with the consequent risk of failure and bad publicity. They are therefore planning two demonstrators at sites in England (with BEIS funding) involving both mine energy and district heating.

3.3 Deep Geothermal

3.3.1 Resource

Respondents were aware that Aberdeen, Midland Valley and the Cairngorms regions of Scotland are seen as the most promising areas for deep geothermal in Scotland and several participated in corresponding LCITP (Low Carbon Infrastructure Transition Programme) studies or were aware of the resulting reports. However, questions were raised by some respondents around whether the temperatures are sufficiently high to justify the costs. The perception is that geothermal is technically possible, but that Scotland does not have the temperature gradients required. The rock formations are there but not the resource, and examples such as Iceland, and Indonesia were mentioned as places where temperature gradients are higher. Other places cited to have potential include North America, the Caribbean, and the Gulf of Mexico.

There were some questions raised by respondents about the economic viability in general of targeting aquifers in Scotland, due to the inherent uncertainty in drilling of hitting a resource. It was claimed that a possible solution is to drill to target heat at depths where the temperature is increasing at a rate of 20^{o}C or more per km. One respondent cited 3km as a depth considered required for deep boreholes in Scotland, and the costs of drilling to such a depth was considered a major barrier unless public funding sources are available. An unsuccessful project in Newcastle, in collaboration with Newcastle University, has also raised the risk profile.

3.3.2 Electricity vs electricity and heat

Deep geothermal sites are associated with higher temperatures than mine water systems. They can therefore be used to generate electricity as well as heat.

One respondent claimed that the amount of electricity that could be generated would support a positive financial return, but not sufficiently large for private investors. Any well would need to sell waste heat, as well as the generated electricity, to high end users to achieve an economic return.

Finance is the most critical concern. As a rough guide and without further breakdown, a figure of £20m was quoted as required for the first borehole to be drilled to sufficient depth. The risk is therefore high with deep geothermal, since it is not known what will be produced from 2 to 6.5km down until a well is established. The respondent who provided this feedback considered that a first exploration well would need public funding to be viable. When established, this well would inform when further work would be needed and whether the project would require fracking of the formation. Conventional oil & gas industry techniques can be used for the borehole. After a successful exploration well, the respondent considered it would be easier to obtain the finance for the rest of the plant, citing that for a 6.5km deep well and including an Organic Rankine Cycle (ORC), total plant costs could reach roughly £100m.

Two respondents considered the option of repurposing offshore oil platforms that are already tied back to UK. This may provide an opportunity to postpone the decommissioning of oil rigs. All the pipelines and electrical cables are in place. An Organic Rankine Cycle (ORC) could produce up to 1MW of power (compared with conventional geothermal of 15/20MW). However, one estimate is that each well can only generate in the order of kWs.

The development of geothermal energy in the 1970’s and 1980’s in France and UK was contrasted. In Paris the emphasis was on generating heat for heat networks. In the UK the focus was on generating electricity. The Paris schemes were successful and a network of geothermal schemes has been established, whereas in the UK the research stopped as electricity generation was not seen as viable.

3.3.3 Risk of single borehole vs multiple wells

Two UK projects were cited as examples of deep geothermal energy. The United Downs project in Cornwall is being developed and can provide planning and environmental impact experience, in this case for an electricity and heat project. However, the borehole has to be quite deep and therefore expensive to get the equivalent power rating of a single wind turbine.

A 2km deep borehole in Newcastle did not reach the depths needed and failed to achieve flow rates for viable commercial heat generation. The facility is currently under use for research. It illustrates the risk of depending on a single well for the success or failure of a single project.

Several respondents argued for a portfolio approach with investment in many wells, taking an approach that some will work and others won't. This is the practice in the oil and gas industry. However, it was noted that oil production is much more valuable than geothermal energy and so one success can offset many failures. The question remains around the value of heat and its ability to absorb the cost of unsuccessful wells.

A portfolio approach is allegedly being taken by a European oil and gas group that is now investing heavily into geothermal in continental Europe (Equinor, formerly Statoil). Denmark was cited as another example of investment and willingness to adopt a 'fail fast' approach on occasion.

In conclusion, it was generally felt that deep geothermal energy needs to be exploited at scale so that it is not dependent on the success or failure of an individual well. There should be a plan for multiple sites across Scotland to spread the risks in case any single well misses its targets.

3.3.4 Established conservative and new innovative technologies

Some respondents are developing new well concepts to shorten the time needed and cost of developments. One approach is termed 'single-well' technology, which aims to be independent of geology and so reduces exploration risk and cost. Lower temperatures would be achieved and so combining this with heat pump technology is an option. The approach is not based on finding reservoirs but on targeting heat and heat transfer into casing cement and then the well. This is considered a relatively new innovation and will take seed money to develop and establish. Ultimately it should result in cheaper and more efficient boreholes.

Challenges cited from experience in the Netherlands include the quality of formation water fluids, which has led to fouling or corroding of equipment and in some cases has required replacement of submersible pumps after only six weeks of operation.

Established geothermal systems are closed loop and there is experience around this. Open loop geothermal offers new possibilities. It may be more complicated, but could be more efficient, although it would need new skills.

3.3.5 Licensing

Boreholes are covered by regulations established by SEPA. The regulations change at 200m depths, beyond which stricter rules are in force. Respondents questioned how the 200m threshold was set and the severity of change in regulations once crossing this threshold. There is some indication that schemes are developed or considered to 199m in depth, perhaps missing out on exploiting resources a little beyond this depth. This possibly has the effect of rendering potentially viable projects as unviable.

Another issue is seismicity. Limits are cited at the level of 0.2/0.3 and contrasted with levels when a lorry goes past at 0.8/0.9. It was claimed that at the Utrecht AAPG/IGA workshop, measurements were reported at 1.5/2 for geothermal developments and proved to be acceptable.

The regulation of geothermal development as opposed to production phase was contrasted with other major construction projects such as ports, where planners do not consider construction phase impacts except for some controls on noise and dust.

A general statement was made that to move the industry forward, regulators will need to increase the weighting on the scientific evidence base, such as for the case of the setting of seismicity limits and the link to actual environmental impact.

3.3.6 Best practice, Regulations and Standards

It is claimed that some of the installations have been of poor quality and problems have emerged such as boreholes not being sized properly. The drilling and installation industry is fiercely competitive in terms of cost and this may be distorting the way that contractors operate. The industry is also a new one, and the whole supply chain takes time to mature. Some respondents felt that the practice in the last five years has not been good.

The industry is self-regulating, but best practice guidance would be a significant step forward. Examples cited are a sort of British Standards but more robust, something like CIRIA (Construction Industry Research and Information Association) Engineering Standards. An example of a useful approach was an EU Horizon 2020 project that made a comprehensive review of shale gas risks (see http://www.m4shalegas.eu).

Concerns were expressed about some of the newer well concepts and it was questioned if it would be better to keep to more straightforward well concepts, applying off-the shelf techniques, leaning on the oil & gas expertise in Aberdeen and applying it to geothermal.

3.4 Barriers to exploiting the geothermal energy resource

The two main barriers to the development of a geothermal project are the risk of obtaining heat from the ground – do you get what you predict or want - and the risk of finding a consumer to buy the heat at a good price.

The issue with wells is that it can never be precisely predicted what will be found, and how fast a well gets depleted. What starts at say 80^{o}C reduces in temperature over time. There is a high level of risk extracting geothermal energy, from seismicity to geology and the high CAPEX required. Many projects fail at the first hurdle of raising sufficient funds to proceed with a test drill.

The challenge of securing heat customers is also a barrier to development. It is difficult to convince heat customers to switch to geothermal, since natural gas is familiar, reliable and relatively cheap. Public perception of geothermal energy can be limited to Icelandic volcanoes and this can deter acceptance. There is no pressure or incentive on developers of buildings to change. The Renewable Heat Incentive (RHI) scheme is limited or will be removed and developers are not yet required to develop alternatives to gas, such as for planning consent requirements, regulations around CO_2 emissions, air quality or from green taxes. This could be set to change as the UK Government has announced plans to restrict the use of fossil fuels for new housing developments from 2025. This is in addition to existing Scottish Government initiatives such as the Energy Efficient Scotland programme.

Other issues include the fact that modern housing requires much less heat than old housing stock and the need to manage the water quality from geothermal sources. Water contaminants can impact the performance and maintenance of topside heat transfer equipment.

3.4.1 Heat Consumers and risks

Geothermal projects, in common with other sources of heat, face the issue of needing to secure long term consumers of the heat. An approach advocated by some respondents is to identify single large consumers of heat and contract directly to off-take the heat. A variety of different scenarios have been identified including direct uses such as for agriculture and co-location with:

- Data centres that require cooling
- Distillery malting
- Horticulture (greenhouses)
- Onshore fish farms
- Large onshore algae farming
- Leisure centres and swimming pools
- Hospitals

A challenge for some geothermal specialist companies is that they may not be able to develop heat purchasing agreements and so are held back from developing geothermal projects. The technical skills may be suitable but the commercial side of contracting heat can be lacking in small developers.

An alternative approach is to supply into an existing district heating network, where the issue of aggregating multiple 3rd party off-takers is solved by the heat network operator. The challenge for geothermal projects is the need, complexity, cost and risk of developing the heat network simultaneously with the geothermal project, which itself has its own considerable costs and risks. It is felt by many that it is much more realistic to find established district heating networks, and then develop boreholes to supply them. If district heating is already in place, the risk of not being able to find a consumer to whom to sell the heat is reduced. Once established many heat networks have the capacity to grow into neighbouring estates and take on board additional sources of heat. Although geothermal energy may not be the prime source of heat for a network, it could be accommodated as the schemes develop.

Although heat in general is quite cheap, when derived from natural gas, some respondents claim that geothermal projects can in theory compete with gas/biomass generation. However geothermal projects are hard to fund because the financial returns tend to be discounted to account for the perceived risk. Having multiple heat users exacerbates the risk and the business model becomes complex. Several respondents perceived from their customer experience that there is currently little or no incentive for developers to use low carbon heat sources, despite the range of offers from Scottish Government and delivery partners including LCITP and Energy Efficient Scotland. The Renewable Heat Incentive scheme is about to run out and a successor scheme has not yet been announced.

3.4.2 District Heating Networks

District heat networks are seen as a key enabler for the development of geothermal energy. However, it was felt unlikely by many respondents that heat networks would be established with mine water as the primary heat source. Mine water heating is not yet established and the uncertainty around costs and technical risk are a barrier. Some respondents stated that private housing developers are currently not keen to develop district heating schemes at all.

Major utility companies have been mentioned in the building and operation of district heating networks. It is considered that local authorities would not have the appetite to take on the cost and risk of owning a heat network on their own, but operating in partnership with a private utility, which has the necessary skills, is possible.

Aggregating and supplying heat to consumers would be provided by a dedicated heat Energy Service Company (ESCo), including such as that proposed by Scottish Government to establish a public energy company. There are questions around how such entities are or should be regulated to solve the conundrum of allowing consumer choice with the fixed and long term nature of heat generation and supply projects. Ofgem requires flexibility to switch between suppliers but district heating networks have a very high capital cost and a lifetime of over 40 years. It was noted that there currently is not a regulator for heat networks.

Building out district heating networks at new build developments is considered easier than retrofitting to existing housing. Brownfield sites are more complex and would need financial support. Retrofitting is more costly and problematic, although high-rise buildings are more amenable to retrofit. However, each scheme needs to be considered on an individual basis. More housing developers are looking at district heating options, and many developments are located near old mine sites. The recent UK Government announcement of a ban on gas supply to new housing from 2025, was cited as focussing attention on the supply of renewable heating to homes. This is in addition to existing Scottish Government initiatives including the District Heating Loan Fund delivered through the Energy Saving Trust.

A factor in the success of any scheme is finding anchor loads with high demand and year-round processes, such as leisure centres or a large hospital. With these anchor loads, developers can build out from that. This could help alleviate fuel poverty. The Townhead area of Glasgow was cited as an example of an area of high fuel poverty next to a district heating scheme covering the University of Strathclyde estate.

3.5 Current developments

3.5.1 In Scotland

Many existing and potential geothermal schemes in Scotland were identified by respondents. An existing small scheme is:

- Shettleston, East End of Glasgow - 25 houses, with heat pump and mine water. It has been operating for almost 20 years

A high profile potential development that did not go ahead is:

- Kilmarnock (project HALO), which could have been a large scale single well demonstrator but plans for geothermal energy were abandoned. The reason for the change of approach is unclear but the scheme attracted a large amount of private investment (£5M+). Scottish Government funding had been offered through the LCITP (£1.8M). This illustrates the pressures facing commercial developers to minimise risk

A feasibility study funded by the Low Carbon Infrastructure Transition Programme (LCITP) looking at St. Andrews identified the potential to feed geothermal energy into an existing district heating network:

- Guardbridge site – 5 miles from St Andrews. It already has a biomass heating plant and pipeline of 3 to 4 miles feeding a district heating network. There was some consideration of supplementing the hot water scheme with geothermal heat (hot rock scheme) but there is no indication that it will be implemented.

New housing developments offer the possibility of geothermal heat supply. Options that have been considered include sites near collieries:

- The Heartland project; a large housing development near the Polkemmet colliery in the central belt. This would be a mine water scheme offering surplus heat, but has not been able to proceed.
- Blindwells colliery site in East Lothian; an actively pumped large geothermal resource. It could generate heat but currently the developer is not considering district heating as part of the scheme.
- Monktonhall is particularly interesting and was originally assessed as a sister development to an equivalent mine water scheme in Heerlen in the Netherlands. The development is for 6,000 homes and Midlothian Council are reported to be keen to have district heating using a waste-to-energy plant. They are also reported to be looking at mine water as a heat storage resource.
- The Springfields housing development at Durieshill near Stirling foresees the construction of about 3,500 houses. It would be a new build site area near the M80/90. The geothermal assessment found the investment costs to be too high which was a major barrier.
- The local MP for Clackmannanshire is reported to be very interested in a potential scheme at Alloa covering extensive mine workings. This could involve an industrial estate, glassworks and horticulture.

Other noted projects include:

- A potential Dumfries and Galloway project at the old Chapelcross nuclear power station site. It appears to be moving forward and is a deep geothermal concept with water temperature probably at 250°C/260°C.
- A proposed Strathleven regeneration community project around Dumbarton is 2 miles from a Highland fault line, and near Dumbarton rock which is an extinct volcano.

These indicate that there is a community of stakeholders in Scotland that have an interest in exploiting the potential of geothermal energy.

3.5.2 In other similar countries

Many respondents are aware that the other UK GEOS site in the UK is in Cheshire. It is reported to have 22 boreholes, 50m to 1400m deep.

Two sites in Cornwall are cited as geothermal projects:

- The United Downs project is under development. It is a deep geothermal concept 4km down, providing both electricity and heat (CHP)
- A swimming pool in Penzance (Battery rocks) will also be complete this year to provide heat for the pool

Factors behind the development of projects elsewhere include:

- The city of Paris is claimed to have very similar geology to parts of the UK. It has a network of 40 deep geothermal systems. The focus was on heat rather than electricity and this has proved successful.
- In Germany and France development has been driven by funding of heat networks by the public sector.
- Germany, France, Norway and Sweden are noted as having more favourable geology than Scotland.
- Holland and Sweden have a lot of hot aquifer reservoirs such as the Delft sandstone region. However, corrosion is a big issue and has resulted in systems being shut down after a matter of weeks.
- One of the respondents is supporting a development in Alberta, Canada to repurpose an oil and gas well into a heat source for lumber drying and other commercial uses. Heat storage is an important agenda item in Canada. They have -30°C in the winter and +30°C ambient temperatures in summer.

The development of district heating networks has also been commented upon:

- The planning system in London is cited as an example after regulations introduced by the Mayor of London. Large developments cannot obtain planning consent without a large district heating or decentralised energy scheme.
- Denmark is cited as a country with extensive district heating networks. This means that any new developments already have customers used to taking the heat and so the barriers to introducing new networks are lower than the UK. It was also noted that in Denmark, they are also connecting data centres to heat networks.
- The technology is efficient enough for heat networks. It is claimed that 40km transport of heat in Denmark is possible for only a couple of kelvin drop in temperature.
- The heat network industry in the Netherlands has in part been driven by greenhouses with underfloor heating and piping.

Mine water projects have been identified in several countries:

- The Heerlen project in the Netherlands is one of the most famous demonstrators for mine water heating. The project has a high profile due to its role in an EU project. It received a €30m grant from the EU, plus regional support. The scheme now operates on a commercial basis. The site has over 200km^2 of heating/cooling. A pension fund building has lots of IT loads generating waste heat that is used by the heat network. The mine water use as a heat storage system was noted by several respondents.
- Mieres in Spain (Asturias) is a mine water scheme that was set up with public funding and involves a university and hospital. It is now claimed to be commercially viable in operation.

- Another is being built in Germany (possibly at the Prosper-Heaniel coal mine which has now closed)
- An abandoned mine site at Springhill, Nova Scotia, has been operating for over 50 years

None of the respondents specifically mentioned the proposal announced by Bridgend Council, Wales at the Caerau colliery, which involves the BGS. Interestingly, the Coal Authority is planning two demonstrators in England to help encourage the market to develop.

4 Scottish geothermal company base

4.1 Definition of the 'geothermal energy' sector

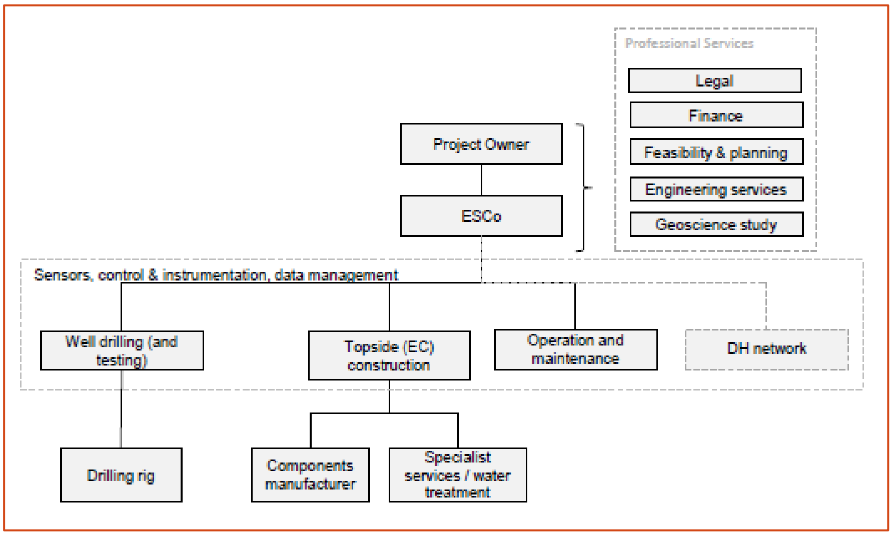
The Scottish Government[5] commissioned a report in 2013 to study the potential for deep geothermal energy in Scotland. This highlighted three sources of geothermal energy with significant potential:

- Abandoned mine workings, such as those in Scotland's Midland Valley
- Hot sedimentary aquifers, which are bodies of permeable rock that can conduct significant quantities of groundwater
- Hot dry rocks, which in Scotland are likely to exist in high heat production granites such as those in East Grampian and to the north of Inverness

Clearly, all of these are possible in Scotland but the consultations clearly indicate that the short term business opportunity is related to the abandoned mines where there is scope to intervene in ways that will create local demand.

4.2 Geothermal energy value chain

Various international agencies have investigated the structure of the supply chain for geothermal energy. A short review identified supply chain maps reported in European[6], German[7], Icelandic[8] and Scottish[9] studies. The previously reported Scottish Enterprise Supply chain map[9] was selected as the basis for the analysis in this study and this is shown below.



[5] https://www.gov.scot/policies/renewable-and-low-carbon-energy/geothermal-energy/
[6] *Magagna, D., Shortall, R., Telsnig, T., Uihlein, A. and Vazquez Hernandez, C., Supply chain of renewable energy technologies in Europe - An analysis for wind, geothermal and ocean energy, EUR 28831 EN, Publications Office of the European Union, Luxembourg, 2017, ISBN 978-92-79-74281-1, doi:10.2760/271949, JRC108106*
[7] *GeothermieZentrumBochum e.V. (GZB),* http://www.geothermie-zentrum.de/en/projects/value-chain-for-geothermal-energy.html
[8] *Icelandic Geothermal Cluster,* http://www.icelandgeothermal.is/iceland-geothermal/
[9] *Scottish Oil and Gas Diversification Opportunities: Heat & Cooling, Water and Energy Storage & Systems, Final Report, 6 December 2017, ARUP / Scottish Enterprise*

This provides a framework for segmentation and mapping of the current and potential suppliers in Scotland.

4.3 Key sub-sectors in Scotland

Much of the feedback from consultations included the anecdotal message that ***"the supply chain won't develop until there is demand for geothermal energy in Scotland/UK"***. In spite of this there are a significant number of both active and potential companies in Scotland that could form the basis for economic development actions. Those that were identified are summarised in Appendix B.

4.3.1 Professional Services Firms – Engineering and Geoscience

Several professional services firms in Scotland were identified that have undertaken activity in the geothermal sector. Many have worked on projects including LCITP feasibility studies.

Some have included large international multidisciplinary engineering consultancies, covering expertise in electrical, mechanical and civil engineering. It has been noted that typically, these firms are generalist in nature covering a variety of sectors and that geothermal energy is a niche area. Firms with a presence in relevant European countries (e.g. Germany or Denmark), including a history of extensive heat networks, can draw upon expertise from their partner offices. With one or two exceptions, these firms do not employ dedicated specialists, at least in Scotland, and this is not likely to change until market conditions change.

In general, consultancy businesses typically do not self-fund R&D, except for a few firms. To build up expertise in Scotland would require fully funded projects on a consistent basis.

A couple of companies are developing unique products or engineering construction related offerings in partnership with other firms. Development of a Scottish market with an opportunity to develop, test and refine new technologies would provide growth opportunities for these companies.

Geoscience service firms tend to be smaller in turnover and number of employees and have access to expertise from the oil and gas sector. It was widely recognized that Aberdeen is a potential centre of excellence in this regard, particularly for deep geothermal projects. Given the size of the oil and gas sector compared to the potential geothermal sector in the near to medium term, it is unlikely that oil and gas firms will experience a significant change in employment or turnover metrics.

4.3.2 Professional Services Firms – Legal and Financial

Legal and financial professional service firms were not often cited by respondents. However this sector is known to be an important component of the wider Scottish economy.

One Glasgow based legal firm (Dentons) was cited as holding a workshop on Renewable Energy law and this was reported to be useful in drawing industry participants together. A growth in advisory services could be anticipated as regulations are developed around geothermal drilling standards, regulations around heat networks and commercial contracts for heat purchase.

Financial professional service firms were not mentioned during the survey. It could be that the nature of these services are generic across many industries, however, financial investment into the sector is a key concern. Financial institutions were not usually identified as the source of investment into geothermal projects. Instead building developers, oil and gas exploration and production companies, or utilities have been identified as potential candidates. However, in Scotland there has been limited to no success to date with many proposals. The one financial institution to be cited was the Green Investment Group (formerly the Green Investment Bank), which was originally set up by the UK government to invest in renewable infrastructure, and which is now under private ownership. It has the potential to invest in geothermal projects if the sector develops appropriately. In all cases the high perceived risk of the technology and business models is seen as a barrier to investment.

For deep geothermal projects there is need to spread risks and the approaches adopted in oil and gas exploration could be useful. There is at least one large oil and gas exploration and production firm investing in geothermal projects in Europe but not known to be active in Scotland.

4.3.3 Project Owners and ESCos

Local Authorities are central to the development of district heating networks, through their planning role for developments. On continental Europe, established heat networks are also owned and operated by local authorities. Feedback during this study suggests that this is unlikely to be the case in Scotland due to the risks involved at this stage for the development of the sector. However, partnership could be possible between local authorities and private operators to deliver heat network services to local communities. Utilities or specialist energy companies could develop to fill this role.

4.3.4 Well design, drilling and testing

The strength of Scottish expertise from the oil and gas sector, particularly for deep geothermal energy, was mentioned several times. Resource assessment, well design, drilling, completion and maintenance specialists from oil and gas were considered ideal for technology transfer. Scotland and Aberdeen is a centre of excellence for drilling, especially for hot rocks where wells as deep as 4km are needed to get hot water. Standards and best practice learned from the oil and gas sector were considered to be useful for deep geothermal projects. Other skills cited for the sector are for resource mapping. Also the ability to deal with hot liquids from wells was mentioned, as it was noted there that hot oils are obtained from oil wells.

One issue for the sector is that the oil and gas market is orders of magnitude larger than the geothermal sector. For a large concern, geothermal remains a small niche with limited material impact at group level. However, it was noted that at least one multinational diversified oil services company has acquired a specialist geothermal company in the USA, and that a European oil and gas concern has a dedicated geothermal business unit with apparently “significant” investment ambitions.

4.3.5 Topside Components and Heat pumps

Some topside equipment is common to heat networks and other heat recovery sources. Most pumps and valves are standard items. For water in the range 150 to 200°C, steam and Organic Rankine Cycle turbines are readily available. Italy was cited as a centre of expertise for turbines. A steam screw expander company based in East Kilbride (Heliex) was also mentioned as a possible supplier.

Lower grade heat, at e.g. 60°C, can be upgraded to 80/90°C with Water or Ground Source Heat Pumps (WSHP/GSHP). Heat pump technology is potentially complementary to geothermal energy. One respondent stated that mine water heating is competitive with public supply gas if the depth is less than 100m. Although the mine water temperature is low, the use of heat pumps allows the heat to be upgraded or more heat to be extracted. The heat pump consumes electricity and so there is a need to consider renewable electricity to achieve zero carbon heat. Shallow mine water requires 1kW electricity to obtain 5kW of heat (x5 multiplier). For deeper mines, the temperature is maybe 40°C and so the multiplier is maybe x10-x20.

At the proposed Kilmarnock project site, the capacity of the well would have been increased by using a heat pump. The heat extracted could be doubled by dropping the operating temperature load from 70 to 50°C, to 70 to 30°C. Star Renewable Energy has been identified as the supplier of WSHP for a project on the river Clyde, and their technology is considered suitable for mine water schemes, provided the water quality is managed.

4.3.6 Sensors & instrumentation

There is particular strength in sensors and instrumentation in Scotland both in industry and academia. Respondents agreed that the site could be used as a testing ground for new sensor developments and instruments. There is the potential to involve a wide range of industrial and academic developers of new systems, ranging from water sampling sensors and soil instruments to novel temperature devices and gas sensors.

There is considerable potential to use the site to test devices that would be deployed in harsh and inaccessible locations. For example sensors and instruments to be used in offshore energy applications, in the nuclear power industry and nuclear waste storage and possible future carbon capture and storage applications.

Of particular relevance, and as an example of areas of interest, could be exploration of the use of new devices to measure underground features and ground deformation. In recent years Fiber Bragg Grating (FBG) based sensors have attracted much attention for their stability, long life and low power potential and ability for distributed sensor measurement. Clearly, the degree to which developers can access site infrastructure, such as boreholes for testing downhole sensors and instruments, would be a key determining factor in the level and type of engagement that could occur.

4.3.7 Geological modelling

Respondents agreed that there is potential to use the data generated at the test site to improve 3D geological modelling products. Currently, these models and simulation services are supplied into the oil and gas industry where there is sufficient market demand to justify product refinement and investment in new product development. The data generated from the site could be used as part of existing product development programme. It is understood that the data generated from the site will be openly available to the user community via data portals.

In terms of developing products directly for the geothermal industry, the level of interest was very low. Although the companies interviewed in this field had some prior experience of modelling geothermal features for geothermal projects, current market demand for this service is very limited. Only data that could be applied to improve products for higher demand market segments, such as oil and gas, would be of value to these companies at this time.

5 SWOT Analysis

The findings of the research and consultation activities has highlighted a wide range of strengths, weaknesses, opportunities and threats for the exploitation of geothermal energy, and related economic development, in Scotland. Each of these are summarised below.

5.1 Strengths

- ***Political will for zero carbon leadership:*** Scotland has more ambitious targets than most other countries related to climate change and this is influencing policy throughout the various public sector agencies and authorities. There are already indications that some Local Authorities are using their planning powers towards the use of renewable heat.
- ***Demonstrated track record:*** Past experience in Scotland such as with Offshore Wind in scaling from relatively little activity (compared at the time to Germany and Denmark) to world leading scale. This was achieved through leadership in complex engagement with multiple layers of public and private sector encompassing environmental, regulation, legal and commercial standards. Also, providing an open transparent framework and long term stability.
- ***Only UK research site for mine water:*** Although there are concerns that the GGERFS will be focussed on gathering data on the sub-surface environment, rather than being a practical demonstrator, it can still be regarded as an asset to support mine energy activities in Scotland.
- ***Some pioneering companies:*** There are several companies that are operating internationally in the geothermal market (both as developers and technology suppliers) including the related ground/water source heat pump market. The most commonly mentioned are TownRock Energy and STAR Renewable Energy. Several companies are also working on new well designs that could make deep geothermal cheaper and less risky.
- ***World leading oil & gas industry:*** There is some synergy with companies that are engaged in drilling, downhole sensors, wellhead systems and geophysical modelling. All of these are relevant to deep geothermal and to some extent mine water. The main barrier to cross-sector diversification, however, is that geothermal energy is not currently as valuable as oil & gas and so there are open questions about the economic attractiveness for such companies.
- ***Water industry supply chain:*** Some of those consulted have suggested that there may be more opportunity for cross-sectoral diversification from the water industry supply chain for the shallow geothermal (i.e. mine water) market. This has some synergies with the ‘Hydro Nation’ initiative.
- ***Strong and large internationally recognized academic research base:*** This includes the three universities in Glasgow, the University of Edinburgh and the University of St. Andrews. BGS (Scotland) is also co-located at Heriot-Watt University

5.2 Weaknesses

- ***Lack of demonstrators:*** The most common factor that was mentioned during the consultations was a lack of demonstrators in Scotland both for the mine water opportunity and deep geothermal. It seems that there have been a number of feasibility studies but none have yet been implemented. The main barrier seems to be the risk factor, which favours alternative sources of heat energy.

- ***Key players are very small:*** Whilst there are a number of larger companies in Scotland that could be involved in the geothermal energy supply chain, they are taking a ‘wait-and-see’ approach until the market develops. This would include the energy utilities, oil & gas companies and larger engineering companies that have an interest in diversification into renewable energy markets. The UK does not yet offer them an attractive market and export markets are either underdeveloped like the UK or already have an existing supply chain. Elsewhere, some like Eon and Vattenfall are reported to be showing some interest.
- ***Commercial developers are risk averse:*** It appears that opportunities are being missed to implement geothermal powered district heating systems when new housing and commercial developments are being planned. Many of the former, in particular, are in locations that have mine workings. Whilst the economics may be favourable, the risk profile is not. Gas fired boilers or CHP is still the preferred option. It seems that some of the smaller developers have experience of technology but have limited experience with heat offtake contracts, like power purchasing agreements for wind energy, which is a function of the small market in Scotland/UK.
- ***Lack of evidence of the commercial business case:*** As mentioned above, it seems that there is no shortage of feasibility studies but the geothermal option is not implemented due to an unfavourable comparison with other options.
- ***Existing public funding options are not considered to be fit for purpose:*** It is clear that there are a number of environmental and societal benefits that could be realised through the wide exploitation of geothermal energy resources in the UK. This is particularly the case for the mine energy opportunity. As well as the obvious contribution to the renewable heat mix it could help to regenerate ex-coal mining communities and attract economic activity. The traditional public sector funding instruments do not seem to be addressing the market failure and so it seems that more innovative forms of public/private financing models are needed. An example is the CAN DO Innovation Challenge Fund that is aimed at helping public sector organisations to create demand for more innovative solutions to their policy/service challenges. There also seems to be a case for some form of shared-risk loans rather than grants to unlock the opportunity.

5.3 Opportunities

- ***Local Authorities interest in renewable powered district heating:*** It is clear that Local Authorities are becoming more interested in district heating and renewable heating options due to both national and local policy drivers (e.g. climate change targets, fuel poverty, etc.). There are some indications of Councils using their planning powers to encourage developers to consider the option of district heating systems powered by renewable energy but this creates a double degree of difficulty as the district heating market is still quite embryonic in the UK. It seems that the geothermal option is much more compelling when there is already a district heating network in place.
- ***Exploit lessons from elsewhere:*** Successful schemes from abroad can provide know-how about how public agencies and private industry can develop the market. Countries like the Netherlands, Denmark, Germany, Poland, Spain, etc. are active in the area of mine energy both in terms of policy interventions and technology. There is also an ERA-NET for transnational

cooperation on geothermal energy research & innovation[10] that SE could join as well as a European Technology and Innovation Platform (ETIP Deep Geothermal).

- ***2025 deadline to ban gas fired heating for new housing:*** In his recent Spring Statement, the UK Chancellor announced that gas boilers will be banned from new homes from 2025 to reduce emissions from fossil fuels. This should be highly favourable in driving the market for district heating systems utilising renewable energy sources.
- ***Network of public sector Energy Managers:*** Since there is a strong public policy driver for the exploitation of geothermal energy resources it would seem logical to consider the various channels of influence amongst those public sector organisations in Scotland that are large consumers of energy. For example, hospitals and leisure centres. The study highlighted a network of energy managers across the Local Authorities in Scotland, which includes other organisations such as the NHS, Police, Scottish Water and some universities. This group meets regularly to discuss common areas of interest and could be quite influential.
- ***UK Coal Authority keen to encourage innovative use of mine energy:*** The Coal Authority is the UK Government agency that is responsible for the governance of the underground mines following their widespread closure. This includes addressing the problem (known as rebound) where water rises towards the surface and has to be treated to avoid contamination of the water table. It is keen to help exploit the thermal energy that is currently lost from this essential process and is also very interested in how these redundant mines could become a resource for the wider regeneration of ex-mining communities. This includes the more innovative use of mines for energy storage as well as a direct source of thermal energy.
- ***Regeneration of ex-mining communities:*** In theory, the geothermal energy potential of mine waters could be an opportunity for extensive regeneration of ex-mining communities if the right business models were put in place (e.g. community orientated ESCos).
- ***Export market potential:*** The UK was the first of the advanced nations to close its coal mines and therefore should be in a good position to use these underground assets to pioneer the development of a 'mine energy economy'. There are many other countries that could be interested in this both now and in the future. Scotland could also pioneer new well technology to develop cheaper, less risky solutions that could be exported and enlarge the global potential for geothermal.

5.4 Threats

- ***Risk of sucking in imports if the market strengthens:*** There is not yet a market in the UK for the geothermal energy supply chain in contrast to other countries with more mature supply chains such as Iceland and Italy. There are, however, a number of factors that could strengthen the UK/Scottish market but buyers are more likely to favour those companies that have proven experience in other countries. Options to create short term demand for innovative Scottish companies should be encouraged (e.g. through the CAN DO Innovation Challenge Fund).
- ***Expiry of RHI:*** A number of those interviewed mentioned that the current Renewable Heat Incentive (RHI) is due to expire and there is no obvious replacement. This would, of course, be

[10] http://www.geothermica.eu

unfavourable to the relative economic competitiveness of geothermal energy solutions but it seems (from the Chancellor's recent statement) that the policy for renewable heat has moved from 'carrot' to 'stick'.

- ***Lack of appropriate regulations & standards:*** This was mentioned by a number of those consulted. It is symptomatic of an embryonic industry but is yet another risk factor that inhibits market development. For example, there is no equivalent of Ofgem for heat networks. Also, underground heat is treated (as far as regulations are concerned) as a mineral and uncertainty exists on how to exploit.
- ***Risk of market stall from failure of early demonstrators:*** We understand that there have been some high profile failures of geothermal energy schemes (e.g. Fife, Kilmarnock and Newcastle). This is also of concern to the Coal Authority, which is trying to show some leadership by establishing a couple of exemplar good practice demonstrators in England.
- ***Lack of appropriate public/private funding mechanisms:*** As mentioned above, there seems to be a lack of appropriate funding mechanisms (both private and public) to support the implementation of potentially viable geothermal energy systems.
- ***Association with fracking:*** There is the potential for public perception to be negative around the use of drilling into geological formations due to parallels being drawn with shale gas exploration and fracking.
- ***Competition from other sources of thermal energy:*** Natural gas is currently a cheaper source of heat energy than geothermal. Other sources of energy from water (e.g. rivers, sea, sewers) may also offer better cost/benefit options for renewable heat.

6 Development Options

The foregoing SWOT analysis provides the basis for three types of development options:

- Exploit short term opportunities based on distinctive strengths
- Address weaknesses and threats through collaborative actions
- Position the cluster for future opportunities

Each of these is considered below.

6.1 Exploit short term opportunities based on distinctive strengths

The main opportunities that are in this category would include:

Foster Local Authority interest in renewable powered heating: This is a short term opportunity that is driven by the strong political will in Scotland for zero carbon leadership. It could be realised by a mix of innovative financial instruments, supply chain development actions and building on the unique GGERFS asset.

Build on experience from other countries: Scotland has the underground resources to be a pioneer in the exploitation of mine water energy but other European countries have already implemented projects. This creates an opportunity to fast-track the evolution of projects in Scotland using business and funding models that have been proven elsewhere.

Educate public sector energy managers: It is clear that public sector organisations in Scotland are keen to reduce both their carbon footprint and energy costs. Some public services, such as hospitals, schools and leisure centres, are particularly energy intensive. The same is generally true for a university campus. The main barriers are lack of awareness, funding constraints and perception of risk. One potential channel of influence is the network of Local Authority energy managers who meet regularly and could be better informed about the opportunity, and how to realise it, if there was a practical engagement mechanism with the GGERFS such as a ‘user group’.

Encourage the Coal Authority to pioneer ‘mine energy’ innovation in Scotland: The Coal Authority has funding from BEIS to invest in two sites in England where there is good potential for a heating network powered by mine water. Perhaps a 3rd could be at the GGERFS in partnership with BGS and Clyde Gateway. There are also around a dozen sites in Scotland where the mine is in rebound (water level is approaching the surface) and the hot water is pumped and treated before discharge. We understand that SE has commissioned some work to map these sites, and others that are at risk of rebound. The Coal Authority is also interested in how disused mines could be used for energy storage.

6.2 Address weaknesses and threats through collaborative actions

This category of development options can be considered as key issues to be addressed.

Lack of demonstrators: There are two obvious options to address this issue. The first is to link up the GGERFS with the nearby Shawfield advanced heating & cooling network (Clyde Gateway). This could be achieved at marginal cost as it would build on existing and emerging infrastructure. The other is to encourage an aspirational public sector organisation such as a Local Authority or a Hospital to exploit the CAN DO Innovation Challenge Scheme.

Key players are SMEs: There are some innovative and entrepreneurial companies in Scotland but they do not have the resources or power to drive the market. It can also be difficult for them to gain access to major public sector contracts due to the procurement process. Some of those consulted complained that this was the case with the construction of the GGERFS and for major regeneration schemes. This suggests that the site could be the basis for some kind of focal point to support the development of the embryonic supply chain in Scotland to increase its visibility and level of influence.

Perception of lack of appropriate public/private funding mechanisms: There is a high degree of frustration amongst the champions of geothermal energy that projects seem to stall after the feasibility stage due to lack of appropriate risk funding. It seems that there is a critical gap between public grants and commercial finance due to uncertainties about the thermal resource that can be realised at a specific site where there is a substantial heat demand. This is particularly the case for deep geothermal projects. What appears to be needed is some form of shared risk loan instrument that can unlock such projects. We understand, from other work, that SE has identified a need for such innovative funding models and is exploring options.

6.3 Position the cluster for future opportunities

These opportunities are either not realistic in the short term or need weaknesses to be addressed before they can be realised. They include:

2025 deadline to phase out gas-powered housing: The recent statement by the UK Chancellor that fossil-fuel heating systems would not be allowed in new housing developments after 2025 is a clear signal of intent and this, and other measures, will create demand in the UK for innovative and affordable renewable heat systems. This should be an opportunity for Scottish suppliers but there is a risk that it will simply suck in imports from those countries that already have a geothermal market and a mature supply chain. One way to help innovative companies to provide the evidence for new product performance could be to create an 'innovation platform' around the GGEFRS. In theory, this could be established with the support of the SE R&D Grant instrument under the option for R&D infrastructures.

Export opportunities in other coal mining regions: Scotland is well positioned to be a pioneer in the development of technologies and systems for the economic and social exploitation of mine energy resources. If so, there would be an evolving market in other coal mining regions of the world.

Deep geothermal: the jury seems to be out on whether Scotland is a good place to exploit deep geothermal resources or not due to the unfavourable thermal gradients compared with some other countries. It is a bit like the challenge of harnessing offshore wind in the deeper waters around Scotland. In the short term, it is unlikely that the economics will be favourable to a large scale demonstrator and so public funding would be necessary. We understand that there was some aspiration for a deep bore hole as part of the overall GGERFS programme but the NERC funding was insufficient to do this. Perhaps the Scottish Government could address this by supporting a deep geothermal demonstrator (innovation platform) at the GGEFRS involving Scottish academics and innovative Scottish technologies. Perhaps the Wave Energy Scotland model could be considered to drive innovation. Another option is for Scottish Enterprise to join the ERA-NET on geothermal energy (GEOTHERMICA), which involves 14 European countries that are co-funding research & innovation projects (these are not restricted to EU Member States so could still be an option post-Brexit).

7 Recommendations

The study has identified a significant number of companies in Scotland (around 80) that already are, or have the potential to be, active in the geothermal energy sector. These, and the reasons for inclusion, are tabulated in Appendix B. Some of the more active were consulted both on their potential use of the GGERFS and the wider issues that are inhibiting opportunities. This report provides an overview of survey responses, analysis of those responses and conclusions regarding the potential use of the GGERFS by Scottish companies.

It is clear that Scotland has an underexploited opportunity to generate renewable heat energy from the disused mine workings in the former coal mining communities from Ayrshire to Fife. This is being considered by some Local Authorities that have the aspiration to encourage investment in renewable heat networks for new housing/commercial developments but there are a number of barriers including the lack of demonstrators and appropriate funding instruments. This aspiration is driven by Scottish Government policy and targets, related to Climate Change, but it is not yet sufficient to create a 'lead market' for innovative Scottish companies.

Clearly, there is evidence of market failure and so the presence of the GGERFS is Scotland, and the adjacent Clyde Gateway 5th generation district heating network, could be an opportunity to create a platform for collaborative action that will maximise benefits to Scottish companies, provide the evidence for wider replication and attract key players from other countries.

Whilst the mine energy opportunity is the most obvious way forward there is also a wider opportunity to support innovative new technologies that have the potential to reduce the costs and risk of extracting deep geothermal resources and/or utilise these for energy storage.

We have therefore segmented our recommendations into two main opportunity statements:

1. Create a focal point for mine energy innovation around the GGERFS
2. Incentivise innovative oil & gas industry companies to demonstrate new technologies to unlock Scotland's deep geothermal energy resources

These are both elaborated below.

7.1 Create a focal point for mine energy innovation around the GGERFS

The GGERFS is a unique asset that will generate international interest and scientific evidence on the potential to utilise warm water from disused coal mines as a practical source of renewable heat. This will, of course, not be realised in the short term and so there is a degree of impatience amongst industrial stakeholders. This could be addressed by developing a complementary innovation action (mine energy innovation platform) that builds on this scientific infrastructure and the aspirations of Clyde Gateway to be a leader in advanced renewable energy networks. We have attempted to summarise the main areas for such an innovation platform in Appendix C based on consultation feedback. This includes five thematic areas including subsurface characterisation, instrumentation & control systems, mine water reservoir characterisation, water quality & treatment and heat load. For each of these we have highlighted the main technical challenges and potential opportunities for GGERFS action.

We would therefore recommend the following way forward to build on the unique GGERFS asset and the complementary heat network being developed by Clyde Gateway.

1. Secure commitment from BGS and Clyde Gateway to create, or host, a ***Mine Energy Innovation Hub*** around the GGERFS. This should be aimed at helping aspirational public sector stakeholders, developers and innovative Scottish companies to reduce the real and perceived risks. One potential physical location is the Red Tree Magenta building on Magenta Building Park in Shawfield, which will be powered by the new heat network. This could start with a ***Workshop*** to update stakeholders on both the GGERFS and the Shawfield heating network and initiate discussion on a programme of activities that would help them to overcome the barriers. It may be that there is scope to establish a ***Scottish Renewable Heat Supply Chain Group*** as this would have broader scope in terms of companies and align better with an important policy challenge.
2. Convene an ***Expert Group*** to discuss and refine our 1st draft synthesis of thematic issues and opportunities for a ***Mine Energy Innovation Platform*** (Appendix C) around the site and the adjacent Shawfield heat network. This should also involve the Coal Authority, which has a strong interest in innovation and some of the leading academics. The outcome of this could be the specification an ***Integrated R&D Programme*** involving Scottish companies and academics.
3. Host a meeting of the public sector ***Energy Managers Group*** in Scotland to make them aware of both the geothermal energy opportunity and the CAN DO Innovation Challenge Fund that could be used to identify innovative solutions for renewable heating networks either at a community level or at locations where there is high demand for heating energy.

The overall aim of these activities is to encourage a clustering effect around the location of the GGERFS and the development of collaborative demonstration projects.

7.2 Incentivise innovative oil & gas industry companies to demonstrate new technologies that could unlock Scotland's deep geothermal energy resources

Clearly, the GGEFRS will be focussed, at least in the short term, on the mine energy opportunity and so it is unlikely that there will be any opportunities to address the technical and financial barriers to deep geothermal projects. Also, whilst there are indications from the consultations of some novel technologies being developed in the oil & gas industry it appears that the geothermal market is not sufficiently attractive at present. This suggests that there is a need for both R&D incentives and innovative financing instruments to support the practical demonstration of such technologies for the exploitation of deep geothermal resources in a country like Scotland. This could include using deep geothermal resources for either the extraction and/or the storage of heat energy.

We would therefore recommend the following to encourage cross-sectoral collaboration between innovative oil & gas technology companies and the geothermal energy development companies

4. Explore the option for an ***equivalent of the Wave Energy Scotland model***, which uses a competitive procurement programme to attract innovative solutions to technical challenges.
5. Explore the option for Scottish Enterprise to participate in the joint calls of the ***deep geothermal ERA-NET*** (GEOTHERMICA), which would give innovative Scottish companies the opportunity to engage in European-level R&D projects (n.b. the ERA-NET model is not restricted to EU Member States and so this could still be possible post-Brexit).
6. Carry out a review of ***business and financial models*** used in other countries to support the development of geothermal energy markets and the supply chain to identify transferrable lessons for Scotland

The overall aim of these activities is to address the commercial funding barriers to the development of innovative demonstration projects.

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Economic Development

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