The United Downs Deep Geothermal Power Project

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ABSTRACT

The United Downs Deep Geothermal Power project is the first geothermal power project in the United Kingdom. It is located near Redruth in west Cornwall, UK and is part-funded by the European Regional Development Fund and Cornwall Council. The project consists of two deviated wells; a production well to a target depth of 4,500m and an injection well to a depth of 2,500m. Both wells target a sub-vertical, inactive fault structure that is thought will provide enhanced permeability relative to the surrounding granitic rock, sufficient to support circulation of between 20 and 60l/s. Geothermal gradients in Cornwall are relatively good and the bottom hole temperature is expected to be in the region of 190^{O}C, allowing anticipated production to surface at greater than 175^{O}C, which should allow electricity generation of between 1 and 3WMe.

After funding agreements were signed in June 2017, a period of preparation and procurement followed, and drilling began in November 2018.

This paper places the project in the context of previous geothermal research carried out in Cornwall, summarises the concept and describes the site selection work carried out. It also outlines the microseismic and noise monitoring programmes implemented to protect the local community and describes the public outreach, education and research initiatives associated with the project. Finally, it sets out the forward programme and the aims for the future development of geothermal in Cornwall.

1. INTRODUCTION

It has been known for decades that the heat-producing granites of SW England represent a potential geothermal resource. Historical records and measurements made in deep tin and copper mines, and the first-hand experience of the miners, demonstrated elevated temperatures and they were confirmed by heat flow studies and geothermal assessments carried out in the 1970s and 1980s, e.g Francis (1980), Downing and Gray (1985). Heat flow in the Cornish granite is approximately double the UK average, at more than 120mW/m^2.

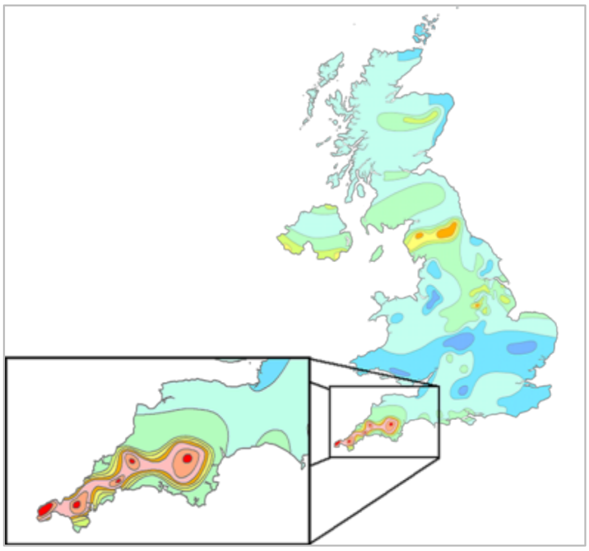

Figure 1: Heatflow distribution in the UK (© BGS (NERC)).

From the late 1970s until the early 1990s the Camborne School of Mines managed a Hot Dry Rock geothermal research programme at Rosemanowes Quarry, near Penryn in west Cornwall. This project made a significant contribution to the understanding of HDR reservoir development, in particular the importance of permeability enhancement by shear stimulation of favourably aligned natural joints and fractures.

Three wells were drilled during the first half of the 1980s; two to a depth of approximately 2,000m and a third to a depth of 2,600m. Numerous injection, production and circulation tests were carried out over a period of several years, alongside measurements of in-situ stress and fluid-rock chemical reactions. These experiments have been widely reported, e.g Parker (1989).

In the early 1990s European funding was withdrawn in favour of the Soultz HDR project and research in Cornwall stopped. For the next 15 years there was no interest in deep geothermal in the UK, either technically or from government, but by 2008 a number of companies and organisations had begun to take an interest in Cornwall again as a potential resource.

Because of the lack a regulatory framework for geothermal in the UK most companies dropped out, but

Geothermal Engineering Ltd decided to look in more detail into a potential commercial project.

2. CONCEPT DEVELOPMENT AND IDENTIFICATION OF POTENTIAL SITES

In 2009 a study was undertaken into potential geological targets and drilling sites within a data-rich 400km^2 area of west Cornwall that included the Carnmenellis granite outcrop, the original HDR research site and a large number of now-abandoned mines.

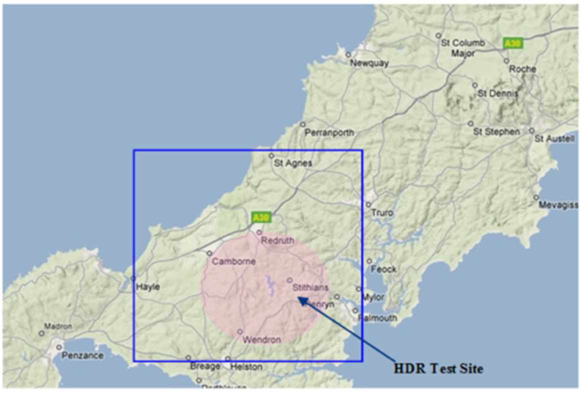

Figure 2: Study area for the 2009 geological and geothermal reconnaissance study into potential targets.

2.1 Study area for the 2009 geological and geothermal reconnaissance study into potential targets

From the outset it was assumed that the porosity and permeability of the rock matrix would be low to very low and that the viability of any geothermal reservoir would depend on the presence and efficiency of significant fracture-related and interconnected permeability. Furthermore this fracture system would need to have sufficient volume to host a commercial-scale circulation system and be deep enough to encounter economically viable temperatures, which meant it should be in the depth range 4,000 to 5,000m.

The study concluded that the best potential host for a geothermal reservoir was one of the northwest-southeast striking fault zones that are present throughout Cornwall. The target chosen was the Porthtowan Fault (referred to as the PTF), which extends from Porthtowan on the north coast to Falmouth on the south coast and is mapped along the northeast side of the Carnmenellis granite. It is a structural zone of significant length, and its linearity suggests that it is near-vertical and likely to persist to depth. It was observed in some of the mines.

The PTF is a >15km long NNW-SSE oriented complex strike-slip fault zone some 200m to 500m wide which may be thought of as a composite of several generally sub-parallel but anastomising fault strands. It belongs to a family of similar structures that helped accommodate oblique closure of the late Carboniferous Variscan orogenic belt in SW and southern England. Some of these faults are thought to have originated during the pre-orogenic Devonian extensional phase, subsequently undergoing phases of reactivation and possibly also acting as conduits for intrusion of the late to post-orogenic granitic melts which now form the Cornubian granitic batholith. The batholith is associated with high levels of polyphase metallic mineralisation including in and around the United Downs site. The area basically represents a major Early Permian geothermal complex whose rich mineral deposits became the focus of a world-leading mining industry.

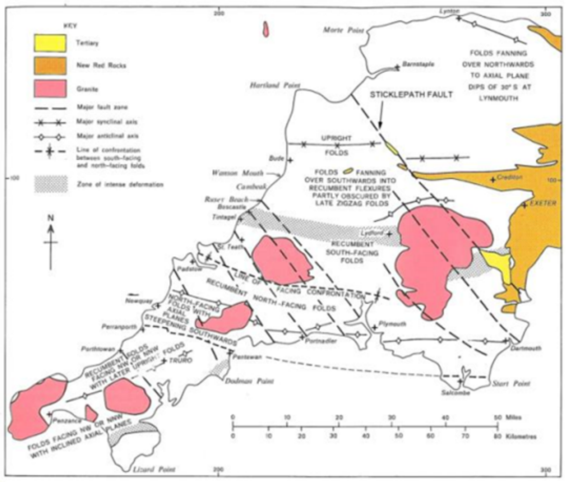

Figure 3: Selection of the larger NW-SE striking structures traversing Cornwall.

2.2 Potential drilling sites

The selection of potential drilling sites was focused not only on proximity to the granite but also on locations from which it would be possible to drill a deviated well into the PTF which, in practice, meant within 1km. Other important selection criteria included the availability of a site that could accommodate a large drilling rig, good road access, availability of a grid connection, sparse population, local authority planning policy and land ownership. Several sites were considered and the one chosen was a brownfield site within the United Downs Industrial Estate, close to the villages of Carharrack and St Day and about 2 miles east of the town of Redruth.

Detailed planning permission for a 3 well system on this site was obtained in 2010, together with outline planning permission for a 10MW power plant.

2.3 Temperature prediction

Simple heat flow modelling was carried out to predict a geothermal gradient in the region of United Downs. There was a high degree of confidence in these predictions, not only because of the earlier heat flow work but also because of the direct measurements made to a depth of 2,600m at the HDR research site, only 7km away. At a vertical depth of 4,500m the temperature was predicted to be between 180^{O}C and 220^{O}C, with 90% confidence.

3. FUNDING

Once planning permission had been granted GEL attempted to raise £12m to undertake Phase I of the project, comprising preparation of the site, and drilling and evaluation of the first well. Presentations were made to numerous energy companies, oil, gas and geothermal companies and investment funds. Grant applications to UK government were also made to part-fund the work if private match-funding could be secured. Despite considerable industry interest, no organization was willing to take the financial risk of drilling into an unproven geological and geothermal target.

Several potential investors indicated that they would be interested in developing deep geothermal in Cornwall once the proposed concept had been proved and the risks reduced. It therefore became apparent that public funding would be necessary to undertake some sort of demonstration project.

The local authority (Cornwall Council) and Local Enterprise Partnership were very receptive to geothermal proposals and supportive of the attempts to develop the resources of the county. Together, they were able to ring-fence funding from the European Regional Development Fund (ERDF), which Cornwall receives, to support a geothermal demonstration.

A call for ERDF funding was issued in early 2016 under Priority Axis 4, "supporting the shift towards a low carbon economy in all sectors", with specific reference to increasing the use of renewable energies. It called for a commercial-scale demonstration well to explore the deep geothermal resources in Cornwall. After a two-stage application process, GEL was successful in securing a £10.6m grant in June 2017. Together with a £2.4m grant from Cornwall Council and £5m from private sources, this enabled GEL to embark on an £18m three year programme to not only drill a single demonstration well, but also drill a second well, establish a circulating system and build a small (1MWe) power plant.

It is hoped that by developing a project plan that goes beyond the scope of the ERDF funding call, the technology will be proved more quickly and investment secured for further geothermal projects in the county.

4. CONCEPT

The UDDG concept is novel in several respects and relies on a number of key factors.

4.1 Large Well Spacing

Experience from HDR and EGS systems has shown that there are risks associated with engineering connections between wells because they necessarily have to be fairly close together, which increases the possibility of short-circuits and, as a result, poor long term temperature performance. On the other hand, systems that target fracture or fault systems with high natural permeability are able to support larger well spacing.

The United Downs Deep Geothermal Power (UDDGP) concept relies on establishing circulation over a large vertical distance through the natural fracture system within the Porthtowan Fault zone. If the permeability is high enough, the large well separation (2,000m) should enable sufficient flow rate and heat transfer area for commercial energy extraction.

4.2 Characteristics of the PTF

Establishing circulation between wells so far apart clearly depends on the presence of significant, connected, fracture permeability at great depth. Such permeability has been observed before in other places but in the UK it remains to be tested. This is the greatest uncertainty that has to be addressed in the UDDGP project. If the PTF proves not to contain such fracturing, the concept will fail. However, if it does contain such fractures, then the concept will not only succeed at United Downs but will also be repeatable at other locations in Cornwall, which is the ultimate goal.

Qualitative evidence from nearby mines, where hot inflows and underground springs were encountered, suggests the presence of fractures of the right type, and the 'crosscourses' encountered in many mines, which have the same strike as the PTF, were characterized by bad ground and water ingress.

No direct measurements exist of the fault characteristics at the target depth but, based on shallower observations and published analog information, average values were derived to make scoping estimates of permeability and transmissivity. Assuming a 200m true width for the PTF, with two fractures per metre, each with an aperture of 90µm, leads to the equivalent of 123mD within the whole zone, giving a transmissivity of approximately 25Dm.

This transmissivity value is on the low side for successful geothermal wells but it may be that these assumptions are slightly conservative. The 2,000m deep wells into the Dogger Limestone in Paris can have transmissivities of 50 to 75Dm and the shallow Eastgate Borehole in fractured granite in County Durham is reported to have had a transmissivity of 'over 2,000Dm'. A fracture zone of just these values would have a very low porosity but the faults are known to be weathered and vuggy. A porosity of 2% has been used with a water viscosity of ~0.0002Pa.s (0.2cP).

4.3 Well configuration

In the previous HDR research project in Cornwall, the injection well was originally beneath the production well, with the expectation that injected water would migrate upwards, and circulation was driven by injection pressure. One of the surprising outcomes of that work was that injected water migrated downwards by shear stimulation on favorably oriented joints and, as a result, a significant percentage of the injected water was lost. This was partially, but not fully, addressed by the drilling of a third well, below the original two.

Circulation in the UDDGP system will be driven by a downhole pump in the production well. This pump will create a pressure sink around the production well, drawing water towards it not only from the injection well, but also from the far-field. In this way it is hoped that the system can operate at a generally low pressure level and that 100% recovery will be achieved. Furthermore, it is predicted that the onset of shearing on some fractures will occur at pressures as low as 5MPa so that even moderate pressure around the injection well is likely to cause it, and it may well extend some distance into the natural fracture system. The stress regime at United Downs will be the same as at the Rosemanowes HDR site and, therefore, downward migration of this injected fluid is to be expected. It could also potentially be driven downwards by increasing the injection pressure temporarily. The injection well is therefore above the production well.

The combination of factors that allows the injection well to be much shallower than the production well also has a benefit in terms of the cost of drilling which is a significant factor in the proof of concept.

Based on temperature estimates and possible fracture characteristics, the project aims to produce water to surface at a target temperature of 175^{O}C and circulate at a flow rate between 20 and 60 l/s. This would produce between 1 and 3MWe.

4.4 Well Completions

The well centers are 8m apart at surface. Both are vertical initially but then deviated towards the southwest to intersect the target fault structure, approximately 700m away, at their target depths; 2,500m for the injection well and 4,500m for the production well. The Kick off point for the injection well will be at 1,110m, and for the production well at 3,400m. The wells are being drilled using standard rotary techniques using a modern, highly automated drilling rig designed for urban and noise-sensitive environments, manufactured by H. Anger's Sohne and operated jointly with Marriott Drilling.

Figure 4: The rig on site with team members and researchers

5. DRILLING PROGRESS

Drilling of the first well, UD-1, began on 8th November 2018. At the time of writing it has reached 4,000m depth. The geology has been highly variable, presenting both challenging and surprising drilling conditions. The top 210m was dominated by Killas, the local name for deep marine low grade metasediments of Devonian age containing a range of late intrusive hydrothermal bodies as well as ore-bearing structures. The ROP was very slow (typically 1-2m/hr) in this section, most likely as a result of persistent, steeply dipping quartz veins within the formation.

In addition, the presence of kaolinite in the upper granitic sections was unexpected and appears to have affected the performance of the 12 ¼" bits used, which were selected on the basis of more typical granite.

The 9 5/8" casing will shortly be run and cemented.

6. NOISE AND MICROSEISMIC MONITORING

6.1 Noise monitoring

The drilling site is located within an industrial estate which is noisy during the day but does not operate at night or at weekends. It is in a generally rural location and therefore otherwise quiet. There are private houses along the western, northern and eastern edges of the estate, as close as 300m to the site, and the village of Carharrack is less than 1km to the west. The planning consent for the drilling phase requires noise levels at any receptor to be kept below 65dB during the day and 45dB during the night.

During the drilling rig selection process, the noise signature was one of the most important criteria used and the rig selected is one of the quietest of its size in Europe. Additional noise mitigation and attenuation measures were also put in place around the site and background monitoring and predictive modelling was carried out to predict noise levels in the surrounding area.

Continuous noise monitoring is being carried out during the drilling operation with one monitor on site and three more in nearby locations. The monitors send automatic alerts if noise levels approach or exceed the preset limits so that action can be taken if appropriate. The public have access to live noise readings.

The large majority of alerts received since monitoring began have been caused by environmental noise, primarily the weather, trees, animals and traffic. Only a handful of alerts have been the result of drilling noise. An objective, fast and transparent procedure is in place to deal with complaints. Although some nearby residents have complained about being able to hear the drilling rig, even when the noise levels are below threshold, the number of complaints has been very low.

6.1 Microseismic monitoring

The microseismic monitoring networks installed at the original HDR project in Cornwall, and at other HDR and EGS sites since then, have provided valuable information about the distribution of injected water and the shape and size of the geothermal reservoir. There is therefore an 'engineering' imperative for installing such a system at UDDGP to understand how the reservoir develops within the PTF.

However, there is also an ‘environmental’ imperative to carry out monitoring because of public concern over induced seismicity. In the UK this concern began following the occurrence in 2011 of two induced events associated with shale gas exploration in Lancashire. They were very small events (magnitude 1.5 and 2.3) but were widely reported as earthquakes and contributed to very negative media reporting and the subsequent public objections to ‘Fracking’ projects.

Although UDDGP is not a Fracking project, there is still public concern and a degree of mistrust about any projects that involve deep drilling and the circulation of water through underground fractures. As a result the Local Authority included a requirement both for seismic monitoring and for a monitoring and control protocol in the planning consent for the project.

GEL is installing an integrated Microseismic Monitoring System (MMS) and Ground Vibration Monitoring System (GVMS) designed to detect events down to magnitude 0.0 at a depth of 5km within the immediate vicinity of the reservoir, and to magnitude 1 within a larger 10km by 10km area. Sufficient seismometers had been installed by May 2018 to begin background monitoring and several months of data were collected before drilling began. Detection and location of local quarry blasts and natural seismicity demonstrated that the system was working, noise levels were acceptably low and that events as low as magnitude 0 could be detected over a fairly wide area. The full system installation will be complete before the drilling of the first well is complete.

Data is transmitted from each station to the data acquisition and processing centre using the SEEDlink protocol and continuous data records are stored on a remotely hosted server, with a duplicate backup system in a separate location. The data acquisition system provides online event detection, processing and also remote database access and visualisation.

Data is transferred to, and then managed by, the British Geological Survey who maintain all seismic records for the UK and make them available to the public.

The monitoring and control protocol being put in place to manage any induced seismicity is based on both measured seismicity and surface ground vibration. Therefore, ground vibration motion sensors are also being installed as part of the monitoring system, in locations close to the site, within population centres and adjacent to sensitive structures. This data is acquired, transmitted, processed and stored in the same way as the seismic data.

The protocol is based on maintaining satisfactory magnitudes of ground vibration with respect to human response. It aims to minimise the ground vibrations that might be considered disturbing by the population in the area. In doing so it also aims to prevent any larger vibrations that might result in damage to buildings. The satisfactory magnitudes are defined in terms of the Peak Ground Velocity (PGV) measured at surface and are based on British Standard (BS) 6472-2:2008, which provides a guide to evaluation of human exposure to vibration in buildings. Cornwall Council already implements BS 6472 within the local planning framework to define the acceptable magnitude and frequency of vibrations due to mine and quarry blasting within Cornwall. This planning framework is the one under which the UDDGP operating permissions are issued.

It is generally considered that a PGV of 2mm/s is the threshold for human perception, but higher values are permissible before disturbance or cosmetic damage results. GEL is implementing a Traffic Light System (TLS) consisting of Green, Amber and Red zones, where each zone indicates a different level of ground vibration, operational intervention and reporting to Cornwall Council.

7. COMMUNITY OUTREACH

GEL has made a number of commitments to both the local and wider communities relating to information exchange, transparency, accessibility, protection of the environment, minimizing nuisance, addressing concerns and promoting cooperation. Work began on building relationships with the community while the project was still in the planning stage and since early 2018 a Community Liaison Manager has overseen interactions with local residents to ensure that any problems or concerns are addressed quickly and personally and that good neighbor relations are maintained.

A Community Liaison Group has been established, comprising Parish and County councilors, local residents and businesses and representatives of other interested agencies. Regular meetings give stakeholders direct access to GEL staff and an opportunity to raise any concerns that they, or members of the public whom they represent, may have.

GEL has developed a number of resources to share information with the public. These include a visitor centre at the drilling site with information panels and a viewing platform, flyers and leaflets, exhibition material, and a number of information videos containing interviews with members of staff at key stages of the project. Project staff have attended numerous public events in the surrounding community with a mobile information booth. Regular drop-in sessions are held at the site facility and provide an opportunity for people to come and talk to the project staff and see the drilling rig up close.

The project website contains detailed information about the project and is regularly updated with news on drilling progress and public events. Social Media also plays an integral part in GEL’s communication strategy with regular posts contributing to the project’s active Facebook and Twitter feeds.

Regular interaction between the project and the local community has resulted in growing interest, enthusiasm and support for UDDGP. As a result of these initiatives it enjoys good relations with the community and GEL strongly believes that, in order for geothermal energy to grow as an industry in Cornwall, the importance of extensive community outreach cannot be overestimated.

8. EDUCATION PROGRAMMES

GEL has developed a diverse and inclusive education programme covering both deep geothermal and wider environmental issues, suitable for different levels of learning from primary school to Degree level, with appropriate dedicated material created for each age group. During 2018 the programme directly reached more than 2,000 local students.

8.1 Primary School (ages 7-11)

The primary school education package combines indoor and outdoor elements to create a memorable learning experience. GEL staff attend the school and begin with a classroom session explaining which members of staff are present and what they do. The children are then shown an animation written and directed by GEL which features ‘Miss Molecule’; a water molecule who carries heat from the reservoir, up the production well and into the heat exchanger to create electricity. After a Q&A session, the session moves outside where the group splits into teams to complete ‘Miss Molecule’s Mission’; a continuous relay obstacle course depicting each stage in the process of creating electricity from deep geothermal energy (Figure 10). Work sheets, based on both the animation and the game are then handed out to complete in the classroom.

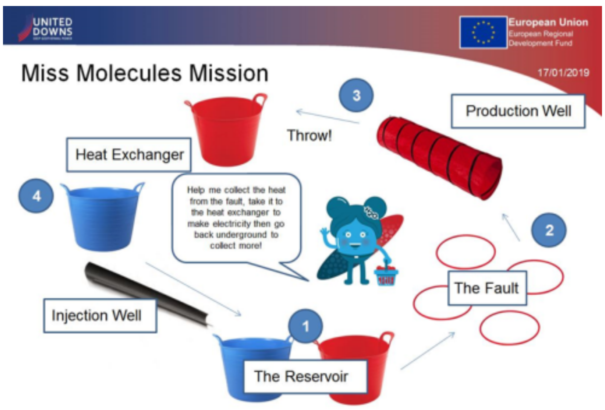

Figure 5: Miss Molecule’s Mission continuous relay.

8.2 Secondary School (ages 11-16)

Several staff members from GEL have become ‘STEM’ (Science, Technology, Engineering and Maths) Ambassadors, and participated in Cornwall Council initiatives within schools, helping them to bridge the gap between industry and academia. GEL’s involvement with the Council’s ‘STEM Discovery Project’, which focused on energy, showcased UDDGP to a range of both students and teachers throughout 2018.

Site visits for secondary school students involve a presentation, an explanation of the drilling rig from the viewing platform and interactive learning activities. They also see an animation giving an overview of geothermal energy and the project;

GEL has also set up a ‘seismicity for schools’ programme, installing simple ‘Raspberry Shake’ seismometers in nine local secondary schools and connecting them to a global network of stations, allowing students to study seismicity on both a global and local scale. This aspect of the education programme provides a link between the national curriculum and the project and gives local students a chance to get involved directly.

8.3 Further Education (ages 16-18)

Engagement with pupils in further education is largely focused around careers. GEL has been involved with career fairs and “speed networking” events with a strong emphasis on encouraging more females into geologically-based careers. Site visits are available for A-level geology and geography students and involve a presentation by the project geologist, a discussion of the chippings derived from drilling, and an explanation of the drilling rig from the viewing platform.

8.4 Higher Education (18 years and over)

Work experience students and interns are an integral and highly valued part of the project. In 2018, two 17 year old work experience students were given placements and three internships were awarded to students at various stages in their careers. This personal approach to engaging older students benefits both the project and the students and will be continued in 2019.

9. RESEARCH INTO PUBLIC ATTITUDES AND ACCEPTANCE

In parallel with the work on the United Downs site, the Sustainable Earth Institute at the University of Plymouth has been conducting a series of studies focusing on the perceptions, attitudes and communication techniques of the resident communities around the site and other stakeholders, such as Cornwall Council, local renewable energy advocates and local businesses. The studies fall into three broad disciplines (psychology, sociology and communications) but they all combine to form an interdisciplinary approach to the study of the public’s perceptions of deep geothermal power at United Downs.

Due to the way that geoscientific subjects are normally communicated, with a focus on factual data and the ideas of the expert, the first study explores how expert and non-expert geoscientists visualise the geothermal environment and how the gaps between the two forms of conceptualisation influence effective communication from a science communication perspective. This study uses data drawn from a combination of focus groups and individual interview data from a diverse group of experts and non-experts to identify key trends and values that are useful in framing conversations around deep geothermal.

For the second study, the way in which the media reporting of geothermal energy projects and the choices about what information is presented, how, and by whom, can have a critical effect upon public awareness. This study investigates the media framing and sentiments around geothermal technology, using a holistic conceptualisation of the media; with data drawn from both digital and non-digital platforms, regional and national, and journalistic and user-generated content.

The third study investigates the social processes that influence community acceptance of energy technologies and how a novel technology for the UK such as deep geothermal fits into the cost-benefit analysis performed by those individuals considering their attitudes towards renewable energies. Using a series of focus groups, this study aims to investigate the influence that social and cultural factors have on the acceptance of geothermal energy in the resident communities in Cornwall. By exploring community perceptions of renewable energy, culture, communications and language, this research is working to reveal some of the key messages to use when engaging with a resident community about a new geothermal power plant. Central to the data is the importance of culturally relevant concerns; highlighting that whilst broad lessons of framing geothermal power in a community context apply in all cases, it is vital that specific local narratives are included in any geothermal development. UDDGP is providing examples of several key narratives that can be used when engaging with resident populations, as well as suggestions for inclusive methods that can be deployed to engage with diverse and concerned audiences.

10. CONCLUSIONS AND FUTURE PROGRAMME

Drilling of the two wells is due to be completed by June 2019. At the completion of each well short term injection and production tests, lasting a few days, will be carried out to make an initial assessment of the characteristics of the PTF. A full suite of wireline geophysical logs will also be run in each well, and wireline cores will be taken.

Following demobilisation of the rig more prolonged testing will be carried out to fully characterize the system and estimate the sustainable energy extraction that will be possible. Multi-rate injection and production tests will be carried out and circulation will be established and maintained. Fluid samples will be collected and analysed and cross-hole tracer testing will be used to estimate the size of the circulating system. This period of testing will last through the second half of 2019 and probably into the first quarter of 2020.

Assuming that this testing demonstrates adequate performance, the design of a 1-3MWe power plant will be finalized. It will have been designed and procured on a preliminary basis before the end of 2019, based on the results of drilling, logging and short term tests. GEL aims to commission the power plant during the second half of 2020.

The UDDGP project is intended a proof of concept, in terms of both the geological and geothermal settings, and of the well design and completion strategy. If the concept proves successful, it will be possible to replicate at other locations in Cornwall which will encourage the investment required to develop further projects and unlock the county's geothermal potential. Therefore, as part of this programme, GEL will begin searching for target areas where future projects might be located. This search will begin with the geological and geothermal elements to establish areas of interest. These will be refined by GIS studies based on many other site selection criteria, consideration of potential heat loads, and discussions with the local authority, power utility, land and mineral rights holders.

It is hoped that this will be the next phase in a long term strategy to develop a sustainable geothermal industry in the county and make a significant contribution to Cornwall Council's ambition to generate 100% of the county's electricity from renewable sources by 2030.

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