Geothermal energy: technology and potential

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Contents

Introduction

In anticipation of a geothermal bill in 2011 the L&RS commissioned consultants (SLR Consulting Limited and Phillip Lee Solicitors) to work on a bills digest in 2010. As this bill has not yet been published we reproduce part their work in this *Spotlight*.

This *Spotlight* is intended to give Members an overview of geothermal energy, the technologies used to utilise this energy and their applications in Ireland. For ease of use we have included a glossary explaining technical terms.

Geothermal energy is a form of renewable energy and refers to heat energy stored in the ground. It has the potential to be a clean, cheap source of fuel and it would help Ireland met its targets under the Renewable Energy Directive of 40% of electricity consumption from renewable resources by 2020

There are already a number of geothermal projects in Ireland and these are discussed in this *Spotlight*. However, these tend to be small one-off projects and Ireland has a significant potential for much more widespread use of geothermal energy due to a number of geothermal 'hotspots'– such as the Lough Allen Basin.

A firm legislative basis for geothermal energy exploitation would probably increase the number of geothermal energy projects in Ireland.

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What is geothermal energy?

Geothermal energy is the energy stored in the form of heat below the earth's surface (definition adopted by the European Parliament 2009).

The hot core or centre of the earth is approximately 4,200˚C. Some of this heat is produced from the geological process which helped to form the earth 4.5 billion years ago, but most of this heat is provided from the decay of radioactive isotopes. The majority of this heat arrives at the surface of the earth at too low a temperature to be used for heating or power generation activities. This deep geothermal energy can only be accessed when it arrives at the earth's surface through geological processes such as through fault lines on the earth's crust (or areas of volcanic activity) or by drilling through the surface to access it. The second source of heat in the ground is from radiation from the sun. Solar thermal radiation is absorbed by the surface of the earth each day. This energy can be regarded as stored energy which stays relatively warm throughout the year (SEAI n.d.).

Some locations, like Iceland, Indonesia, New Zealand, USA, Italy and the Philippines, have elevated geothermal heat flow with temperatures of over 150ºC at 1km underground because they are located at geological plate boundaries (Fig. 1) which are generally also active volcanic zones. Most locations, like Ireland, have rock temperatures of around 35ºC at 1km underground.

A geothermal map of Ireland was completed using borehole data on warm springs and groundwater temperature. It was concluded that Ireland is very well suited for the utilization of ground source heat pumps (GSHPs), due to its temperate climate and rainfall levels that ensure good conductivity and year round rainfall recharge. There are a number of warm springs in Ireland and the two with the most potential are located in North Leinster and in Mallow, Cork.

Geothermal heat is used today for the supply of hot water for district heating schemes (houses, agriculture and horticulture, industrial applications) and to generate electricity. Geothermal-generated electricity was first produced at Larderello, Italy, in 1904. Modern geothermal electricity plants also produce large amounts of heat.

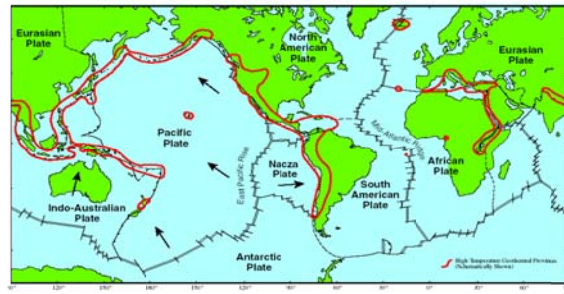

Figure 1. *A map showing the geological plate boundaries and the areas in red where high heat flow occurs along the plate boundaries. This explains why countries like Italy, Iceland, the Philippines and Western USA can produce electricity easily from geothermal heat (Source: Energy & Geoscience Institute, University of Utah, 2010).*

Different types of geothermal systems & associated technology

Shallow geothermal energy

Shallow (0-300m) geothermal energy is derived from both solar impact and heat from the centre of the earth. This heat is collected by plastic pipes in the ground or in vertical boreholes, concentrated by heat pumps and used to heat houses, offices, industrial units, etc. A 2009 study by Allen and Burgess reported that there are about 9,500 domestic heat pumps in Ireland (including at least 1,500 air source heat pumps) with a total capacity of 164MWH, representing 0.3% of heat demand

The larger systems require the use of multiple boreholes (borehole fields) or the use of high volume aquifers to reach the required energy output.

Ground source heat pumps (GSHPs), also known as geothermal heat pumps are a way of accessing the ambient heat in the ground and are used for space heating and cooling, as well as water heating. They operate on the fact that the earth beneath the surface remains at a constant temperature throughout the year, and that the ground acts as a heat source in winter and a heat sink in summer.

GSHPs transfer the heat stored in the earth or in groundwater to buildings in winter and the opposite in summer for cooling. Heat pumps work best in well insulated buildings with under floor heating or low temperature radiators. Through compression, heat pumps can 'pump up' heat at low temperature and release it at a higher temperature so that it may be used again. A heat pump looks similar and can perform the same functions as a conventional gas or oil boiler, i.e. space heating and sanitary hot water production. For every unit of electricity used to operate the heat pump, up to four units of heat are generated. Therefore for every unit of electricity used to pump the heat, 3-4 units of heat are produced (SEAI n.d.).

Deep geothermal energy

Deep geothermal energy is defined as those resources beneath 300m, but effectively they are usually below 1,000m, of the earth's surface. Deep geothermal resources are commonly subdivided into Hydrothermal and Engineered Geothermal Systems (EGS), the latter were formally known as Enhanced Geothermal Systems or Hot Dry Rock (HDR).

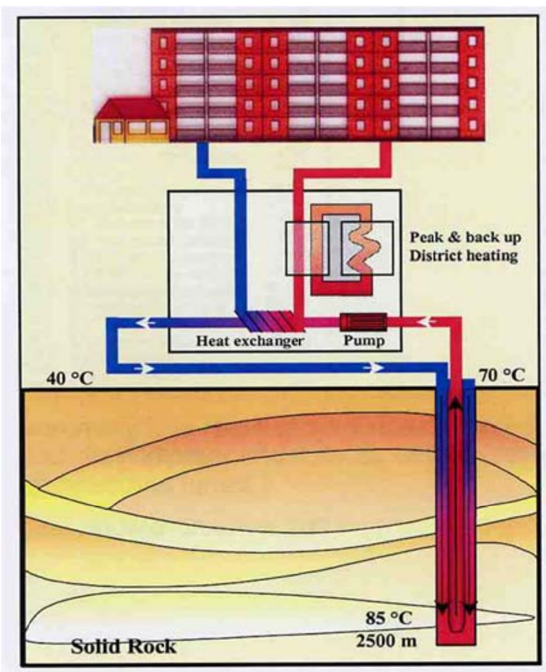

Figure 2. *A 2.5 km deep geothermal well in Germany combined with a geothermal heat exchanger located on the surface can cool and heat a building by means of a closed water cycle. Water at 2.5kms depth measuring 80ºC is recovered at 70º at the surface and passed through a heat exchanger where 30º is extracted to heat and cool buildings. The technology makes it possible to reduce the carbon dioxide emission rate by over 130 tonnes per year. With a peak capacity of 450 kW, the heat exchanger is able to provide the heat and cooling supply for about 200 single-family houses (Source: Super C Project, RWTH Aachen, Germany 2010).*

Hydrothermal: In Europe, hydrothermal resources are located in deep aquifers with enhanced temperatures where heat can be easily extracted due to the presence of water as a heat transfer medium. Open hydrothermal systems produce hot water from a production well and reinjection to the aquifer using an injection well. Closed hydrothermal systems use a closed loop heat transfer system contained within a single borehole (Fig. 2). Hydrothermal systems near Paris extract 73ºC geothermal heat from depths between 1800m and 3500m for district heating and in Southampton for the cogeneration of electricity with gas turbines (Combined Heat and Power or CHP).

***Figure 3**. Larderello standard unit of 20MW dry steam electricity generating power plant – Italy (Source: SLR unpublished 2010).*

Shallow geothermal and deep hydrothermal systems can also provide space cooling (air conditioning) which often provides an opportunity to return heat to the ground and improve the sustainability of the resource.

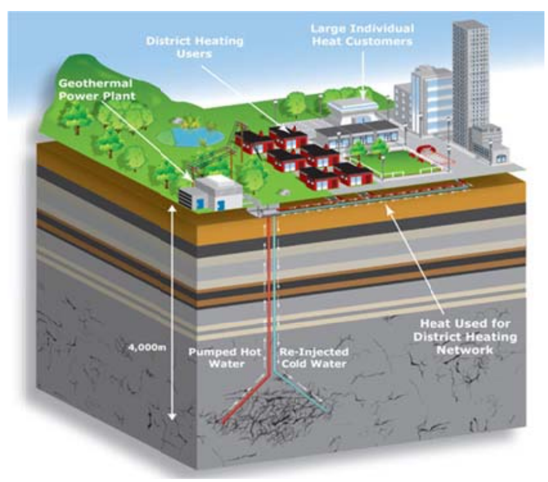

Figure 4. *Diagram showing an open hydrothermal system that delivers electricity and district heating (Source: GT Energy 2010).*

Engineered Geothermal Systems (EGS) extract deep (between 3500m and 5000m) geothermal heat, greater than 150°C, from impermeable rocks, such as granite, that lack significant naturally occurring water and a good natural fracture system. EGS systems artificially fracture the rock to allow injected water to circulate through the hot rock, extract the heat, and flow to the production wells and steam turbines to produce electricity (Fig. 5)[1]. In Australia's Cooper Basin GeoDynamics Ltd are currently working to develop and commission a 25MW EGS electricity power generation plant (Geodynamics n.d.).

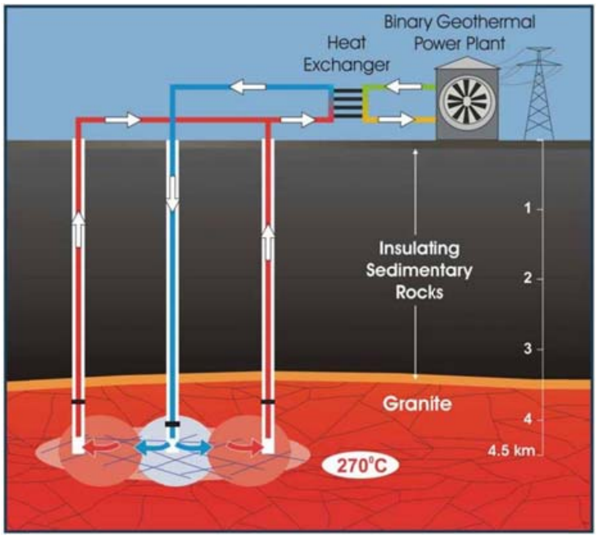

Figure 5. *Diagram showing an EGS that extracts geothermal heat from granite at depth to generate electricity at surface (Source: GeoDynamics Ltd. 2010).*

Generation of electricity

<u>Surface Plant Technology:</u> There are three basic technologies for generating electricity from geothermal energy (ABS Energy Research 2006).

Dry steam power plants use dry steam from the geothermal production well routed directly through turbine/generator units to produce electricity (Fig. 3).

Flash steam power plants are the most common type of geothermal power generation plants in operation today. They use water from the geothermal production well at temperatures greater than 182°C pumped under high pressure to the turbine where the pressure is suddenly reduced, allowing some of the hot water to convert or "flash" into steam which powers the turbine/generator units to produce electricity (Fig. 6).

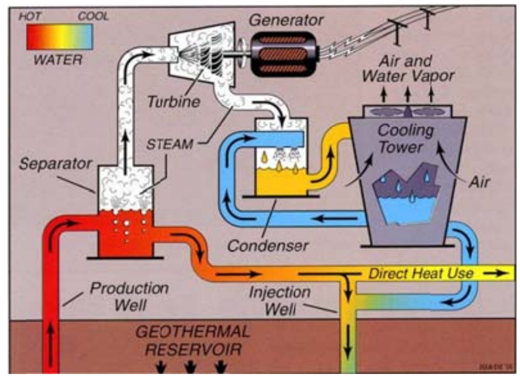

Figure 6*. Flash Steam Power Plant (Source: Energy & Geosciences Institute, University of Utah 2010).*

Binary cycle geothermal power generation plants differ from dry steam and flash steam systems in that the water or steam from the geothermal reservoir never comes in contact with the turbine/generator units but is used to heat another "working fluid" such as isopentane, which is vaporised and used to turn the turbine/generator units (Fig. 7).

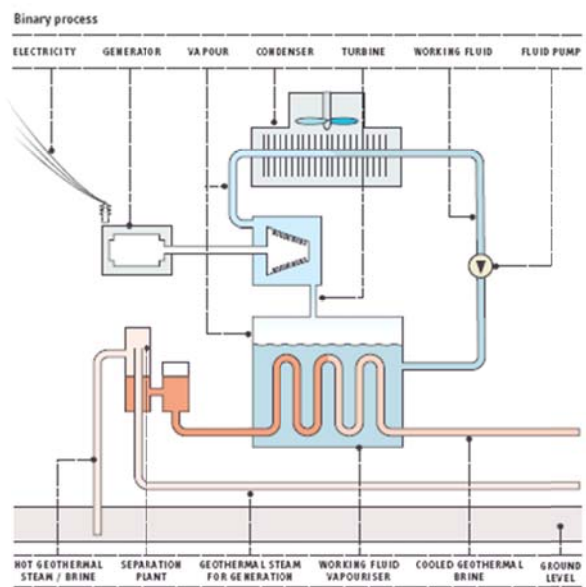

Figure 7. (right) The Wairakei Binary Cycle Power Station in New Zealand harnesses the power of 1,500 tonnes of steam and 3,500 tonnes of geothermal water per hour, allowing the generation of enough renewable electricity to power around 150,000 homes (Source: Contact Energy 2010).

District heating

District heating systems distribute hot water to multiple buildings from a single source such as a

[1] L&RS comment: while deep geothermal extraction has often proved safe occasionally there have been problems. The Swiss government shut a project in 2009 after several small earthquakes (*Quake Threat Leads Swiss To Close Geothermal Project* New York Times 11 December 2009).

geothermal plant, a cogeneration plant (CHP), waste heat from industry, or an incinerator. A typical district heating installation consists of a highly insulated "heat main" of flow and return pipes distributing hot water (or steam) to private residences, hospitals, schools, swimming pools, municipal libraries, apartment buildings and government offices. A junction point allows easy connection to each building, from which hot water can be taken from the main to a heat exchanger (heat substation) within each building. Heat from the hot water is transferred to hot water taps, air heating and radiant floor heating. The heating circuit within the building is isolated from the heat main and a heat meter allows the heat usage to be separately measured and billed to each building occupant. The cooled water then flows back to the original heating plant where it is reheated and re-circulated through the system. As with shallow geothermal and deep hydrothermal, space cooling can also be part of the cycle. There were nine major district heating systems operating at the end of 2008 (Ecoheat4eu, 2009) including the Heuston South Quarter system (Fig. 8).

Figure 8. *The Heuston South Quarter Development of 140,000 square metres of office space and 650 apartments was developed with district heating fuelled by its own 12MW energy centre supplied by a combination of wood pellet and gas boilers.*
If a geothermal heat source became available on economically attractive terms, this could provide the base load (Source: Architects Anthony Reddy Associates 2010; Building Services Arup Consulting Engineers 2010).

Advantages & risks of using geothermal energy

Shallow Geothermal - the Pros and Cons

Shallow geothermal energy developments are clean, low risk projects. Once systems are properly designed they generally have negligible impact on the environment. GSHP systems are safe and with no exposed equipment outdoors, children or pets cannot injure themselves or damage exterior units. GSHPs have no open flame, flammable fuel or potentially dangerous fuel storage tanks. GSHP units are also quiet, providing a pleasant environment inside and outside of the home. Experience in Ireland and elsewhere shows that minor leaks of the working fluid (glycol) have occurred as a result of later construction activities over the site of the heat collector coils and therefore it is recommended that registers of the existence of these systems are kept for future use.

However, Eugster and Sanner (2007) argue that the increased popularity of GSHP has led to an increase of poorly planned and installed GSHP systems which has led to poor economic returns for many installations.

Deep Geothermal- the Pros and Cons

Deep geothermal energy provides constant heat supply and base load electricity when produced. See Table 1 for a comparison of the advantages and risks.

Table 1. Advantages and Drawbacks of DEEP **Geothermal Energy**

Advantages	Risks
• A renewable energy resource with virtually no limit to the amount of heat energy that flows towards the Earth's surface from the interior of the Earth. • A clean energy resource. Research shows that emissions of carbon dioxide and sulphur dioxide from geothermal power stations are less than 10 % of those emitted by coal-fired power stations. (In some geothermal	• The cost of exploration and developing a geothermal power station is quite large. Drilling exploration wells in particular is a very risky business - there is no guarantee that a suitable resource will be found. • The fracturing of hot rocks and injection of geothermal fluids (EGS) causes very small earthquakes to occur. Some of these can be felt on the surface.

plants, emissions are essentially zero.) • Being 'low-rise', geothermal plants blend into their surroundings. • The energy source for geothermal power stations is steady, which means that the plants are able to produce the same amount of electrical power 24 hours a day, 7 days a week. This means they can be relied upon to steadily supply basic daily energy requirements (known as the **base load**). This differs from other renewable sources of energy. For example, the power solar panels deliver depends on how much sunlight energy is available and the power wind turbines deliver depends on the wind strength. • Geothermal sources can be used in cooling applications	However, the vast majority of them cannot. • The energy efficiency of geothermal power stations depends largely on how hot the fluid is and how fast it can flow through the power plant. If the fluid is not very hot, such as only 90ºC, the efficiency is quite low. • Drilling problems during the development phase can significantly add to the costs. • Uncertainty about obtaining planning permission in certain areas is a risk. • Geothermal energy production plant sites are dictated by geology and not transferable.

Source: Kagel et al., (2007)

Environmental impacts

- Air emissions - geothermal plants emit only trace amounts of nitrogen oxides, almost no sulphur dioxide or particulate matter, and small amounts of carbon dioxide.
- Solid and liquid waste - solid wastes discharged from geothermal power plants are non-hazardous. The primary "waste" in geothermal operations is drilling cuttings, comprised primarily of rock chips and of bentonite, a naturally occurring clay.
- Noise pollution - Noise pollution from geothermal plants is confined to the well-drilling, testing and construction phase. The plant operation phase is quiet.
- Water quality and use - geothermal water is isolated during production, injected back into the geothermal reservoir, and separated from groundwater by thickly encased pipes, making a geothermal facility virtually free of water pollutants.
- Land use - geothermal power plants are designed to blend in to their surroundings; have a small aerial footprint and minimal visual impact when compared to a typical fossil-fuel power plant.
- Flora and fauna - geothermal power plants have minimal impact upon wildlife and vegetation: insulated pipes prevent thermal loss, power plants are fenced in so as to prevent wildlife access, spill containment systems are put in place.

Safety

- In rare cases where subsidence may be linked to geothermal reservoir pressure decline, injection is an effective mitigating technique.
- Most geothermal reservoirs are found deep underground, well below groundwater reservoirs and pose no negative impact on water quality and use.
- Geothermal production and injection operations have at times resulted in low-magnitude events known as micro-earthquakes. These events typically cannot be detected by humans.

Potential for geothermal energy exploitation in Ireland

Geothermal energy is a renewable source of energy. Ireland has set a national target of 40% of electricity consumption from renewable resources by 2020 and a target of 12% for renewable heat. The Renewable Energy Directive (2009/28/EC) requires member states to assess the necessity to build new infrastructure for district heating and cooling produced from renewable energy sources in order to achieve their renewable energy targets set under the Directive and, where relevant, to take steps to develop district heating infrastructure, including heating and cooling production from geothermal facilities.

The potential for the exploitation of shallow geothermal energy is seen by experience to be good throughout Ireland. This is largely as a result of our temperate climate and high rainfall which results in high average soil and shallow groundwater temperatures of between 9ºC and 12ºC. By the end of 2009 there was 164MB installed heat pump capacity in Ireland (Allen & Burgess 2010), present in domestic systems and in larger buildings such as offices, industrial units, colleges and residential blocks. The future potential continues to grow exponentially and should exceed 1000MW within the next ten years. The occurrence of 42 recorded warm springs (temperatures 15º-22ºC) are concentrated in two groups, in the southwest (Mallow area) and east (Dublin-Kildare) of the country. So far the only recent application of these warm springs has been the use of the Mallow spring to pre-heat the water for Mallow swimming pool.

While there are currently estimated to be 9,500 domestic systems in place in Ireland, over 60 larger and more innovative systems have been installed in the last ten years generally in new small offices, the retrofit of public buildings and in swimming pools (Fig. 9). As outlined above, emphasis has been on using low temperature resources for space heating, employing heat pump technology (Allen & Burgess 2010).

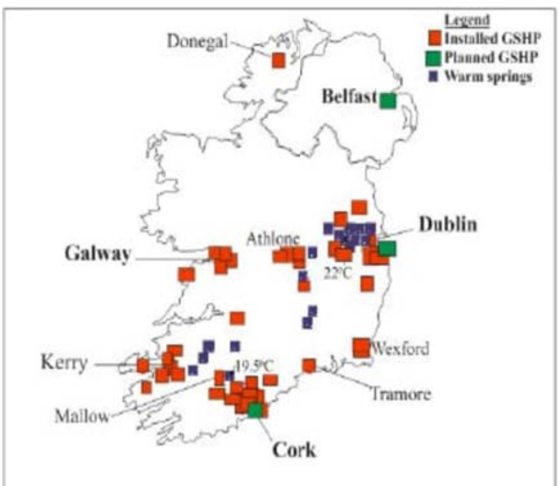

Figure 9*. Locations of large (over 15kW) or innovative geo-thermal systems in Ireland (Allen & Burgess 2010) (temperatures are maxima for the warm springs in each area).*

In the case of the deeper resources the 2,500m depth geothermal resource map of Ireland (Goodman *et al.* 2004) indicates potential for hydrothermal resources for direct use in district heating/cooling schemes using temperatures in the 65ºC to 80ºC range, assuming adequate aquifer capacity is present. The 5,000m depth geothermal resource map (Fig. 10) indicates that there is significant potential for electricity generation in a number of potential 'hot-spots' with values of 115ºC - 165ºC in the Lough Allen Basin, 115ºC – to 150ºC in the Larne - Lough Neagh Basins and a potential 180ºC in the Rathlin Basin (Fig. 9). The potential for deep geothermal energy exploitation is evaluated by combining the heat resource map (Fig.10) with the geothermal exploration map (Fig. 11). Continuing improvements in the use of lower temperature resources (80ºC – 110ºC) will allow electricity generation from an expanding spectrum of geothermal resources in future.

Regarding deeper geothermal resources, the first deep drilling project to investigate warmer water at depth for potential district heating and low temperature electricity generation has been initiated with a trial well drilled to over 1.4km in Newcastle area of South County Dublin. Under this proposed project, the developer, GT Energy aims to produce at least 10MW heat and 3.6MW electricity (see text box).

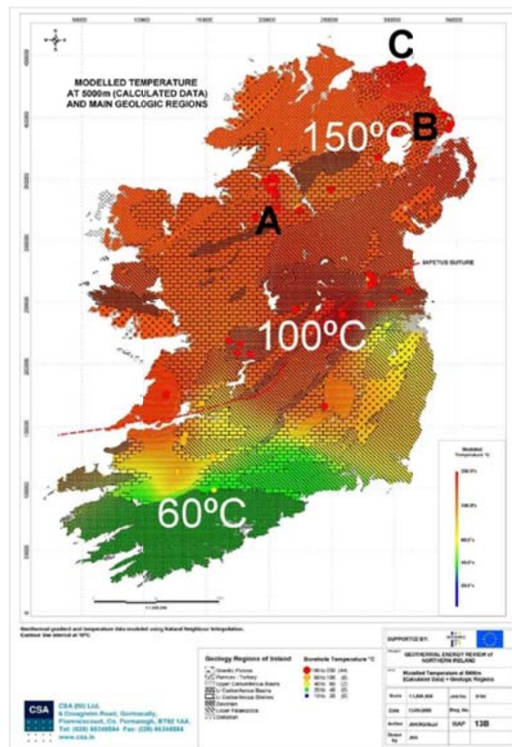

Figure 10. **Regional Modelled Temperature at 5km Depth (from Goodman et al 2004)* – *note that locally these temperatures may be significantly different.
A = Lough Allen Basin; B = Larne - Lough Neagh Basin; C = Rathlin Basin

These new developments will require geological expertise using existing data exemplified by the resource map (Fig. 10) and the exploration risk map (Fig. 11), followed by new research and surveys, including geophysical and borehole exploration, to obtain the optimum position for the plant. It is envisaged that this will result in small electrical power plants, producing stable base-load current, up to ten times as much heat (i.e. a 1MW electricity plant could produce up to 10MW of heat), and with a negligible environmental impact, will be possible throughout the country depending on local geology and a suitable market.

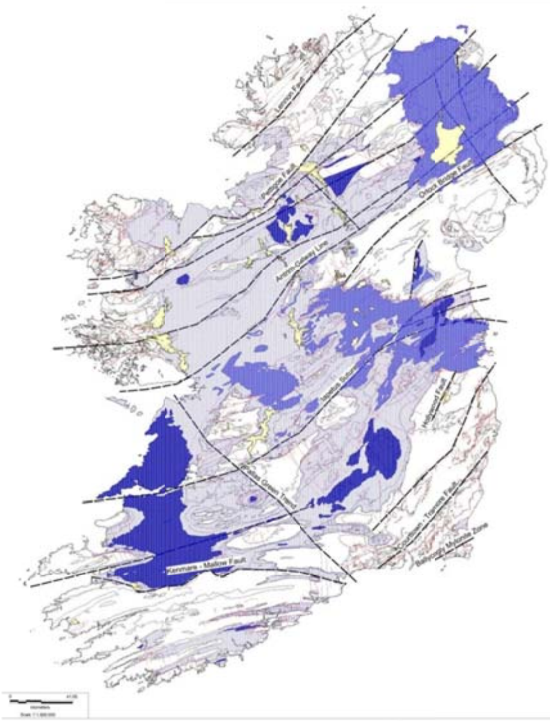

Figure 11. Geothermal exploration risk in the Carboniferous Basins of Ireland. The area in dark and medium blue indicate potential lower risk because of the presence of insulating shales and possible deep fractures providing transmissivity (Source SLR in prep.)

Text box: GT Energy Ltd. Newcastle Project

GT Energy Ltd., a leading Irish company specialising in harnessing deep geothermal energy, is in the process of obtaining planning permission for a geothermal electricity generation plant at Greenogue Business Park, Newcastle, County South Dublin. It is the only geothermal energy system under development in Ireland at present. Over €2.1m has been spent on the investigation, exploration and quantification of the geothermal resource to date.

The overall Capital Expenditure (CAPEX) is estimated at €35m. The development site is based on an optimum geological location identified in a geothermal resource study commissioned by SEI (Goodman et al. 2004).

The new geothermal power plant will be capable of generating up to 3.6 megawatts (MW) of electricity which will be fed into the national electricity grid. The drilling of production wells is planned for 2011 and the plant is scheduled to be operational and connected to the national grid in late 2012.

The Environmental Impact Assessment concluded that the development has minimal environmental impact during drilling and operation.

The system is also intended to meet the equivalent heat demand requirements of up to 280,000 houses and provide consumers with an alternative to fossil fuel energy at cheaper prices.

Figure 12: The drilling rig. (Conodate unpublished 2009).

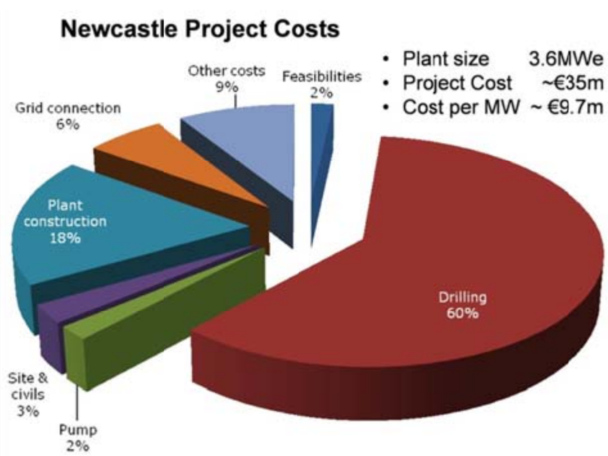

Figure 13: Newcastle Project Costs (GT Energy, 2010).

GT Energy has entered into a Technology Partnership Agreement with ESB International (ESBI), whereby GT Energy will generate up to 50MW of electricity using geothermal energy by

Costs associated with exploiting geothermal energy

2020, and ESBI will assist the company with the design of the generating equipment and grid connection design work. The two companies will work together to share information, expertise and resources to support GT Energy's plans to develop a number of deep geothermal electricity projects across the Island of Ireland.

Information from GT Energy press releases 23/09/2010 and 31/05/2010.

Shallow geothermal energy costs are modest. A system for a single house is likely to cost about €8-10,000 and the payback is about 6-7 years (Goodman & Jones 2007). Large scale systems have proved to be efficient and economic (Figs. 14 & 15).

Figure 14 *(Source: Conodate unpublished 2009)**.** Glucksman Art Gallery, UCC with a floor area of 2,350m^2. A 15°C single well, open loop system provides 190kW of heating and 130kW of cooling (Source: Kondwani et al. 2010).*

Geothermal power projects are characterised by high capital investment for exploration, drilling wells and installation of plant, but low operating costs because of the low marginal cost of fuel. Worldwide costs for geothermal projects are highly variable depending on uncertainties of the local geology, which may affect the costs of drilling, the temperature of the reservoir and the volume of water production (plant construction, grid connection and other costs are well defined).

Figure 15. *IKEA, Dublin (Source: IKEA website 2010). €1.75 million, 158 closed loop borehole field heats 31,500m^2 floor space. The TCS Group designed and installed the Aermec heat pump supplied by Mitsubishi which provides space heating of 884,018 kWh/yr (27.6 kWh/m^2/yr), and cooling of 207,194 kWh/yr (6.5 kWh/m^2/yr). It delivers a 65% reduction in carbon emissions (Source: Hearns 2010).*

About 75% of the costs of geothermal energy are the capital costs including well drilling and plant construction. The cost per megawatt thermal (MWth) installed capacity for heat generation is, in regions with average temperature gradients, in the range of €0.8 to €1.5M per MWth. Most direct-use deep geothermal projects have a thermal capacity over 4MWth and the investment costs of the distribution can be factors higher (up to five times for new district heating grids in densely populated urban areas). The electricity power production cost from geothermal plants ranges between €0.17 and €0.36 per kWh in Germany (Fig. 16). Costs in Ireland may be similar to or higher than for the North German Basin where the level of geological uncertainty is similar.

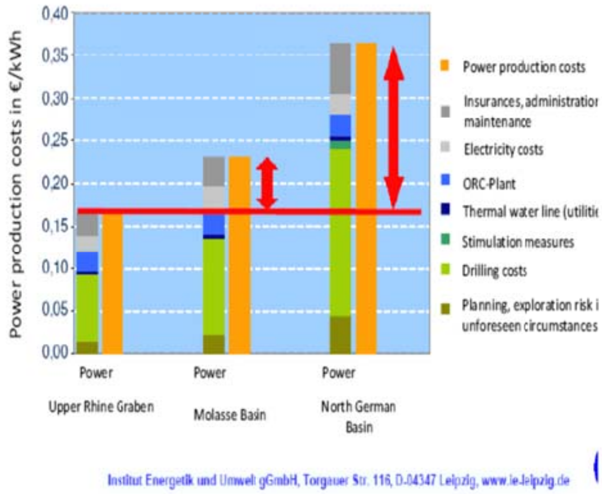

Figure 16. *Power production costs from geothermal energy in Germany (Leipzig Institute for Energy, 2010) - the red arrows indicate where at that time the cost of development exceeded the feed-in tariff – this feed-in tariff has been increased in more recent times for projects of higher risk and where the available heat is being utilized in addition to the electrical output*

L&RS Conclusion

Ireland is well suited to the utilisation of geothermal energy. If we continue to increase our share of geothermal energy production this will help Ireland reach our national and international carbon emissions reduction and renewable energy targets.

Proponents claim that geothermal is a clean and renewable source of energy which offers a secure and uninterrupted supply of heating and/or electricity.

Environmental impacts are (usually) negligible in comparison to conventional fossil fuel type power plants and although initial costs are high, operational costs are significantly less due to the low marginal cost of fuel. Evidence exists that there have been some problems associated with very deep geothermal projects. An understanding of the difference in the technologies employed and the risks associated with each is essential.

A more immediate problem is that the legislative basis for geothermal exploration and exploitation is hazy. It was on this basis that the last government and the present government have promised to introduce the Geothermal Energy Development Bill. This bill aims to provide a legislative framework for the vesting, licensing and regulation of the development of geothermal energy. It is due in late 2012.

Several other governments have put in place incentives for geothermal energy, once the legislative basis is in place, incentive might be one way to help meet Irelands commitments to increase the amount of energy from renewable targets.

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Glossary

Aquifer: As defined by EU Water Framework Directive 2000/60, “means a subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater".

Baseload: The lowest level of power production needed during a season or year.

Binary-Cycle Plant: A geothermal electricity generating plant employing a closed-loop heat exchange system in which the heat of the geothermal fluid (the "primary fluid") is transferred to a lower-boiling-point fluid (the "secondary" or "working" fluid), which is thereby vaporized and used to drive a turbine/generator set.

Capacity: The amount of electric power delivered or required by a generator, turbine, transformer, transmission circuit, station, or system that is rated by the manufacturer.

Closed Loop Horizontal System: Ground source heat pumps (GSHPs) are the most common type of geothermal system currently installed in Ireland. These systems consist of a closed circuit of pipes in shallow soil or other collector source where the circulating fluid warms to the ambient temperature and then is circulated through a heat pump where heat is extracted. As the temperature of shallow soil and sediment throughout Ireland varies between 9ºC and 11ºC, these systems have proven to be highly suitable to Irish conditions as the space required for the collector is usually readily available. A closed-loop heat-pump system contains a water and glycol antifreeze fluid. A 15.5kW output heat pump requires a 3.5kW pump.

Closed Loop Borehole System: Consist of a closed circuit of pipes usually placed in boreholes to a maximum of 150m. These are commonly used where there is very little space or flat ground in which to place a horizontal collector, such as in cities, e.g. the Green Building, Temple Bar, Dublin. Deeper boreholes can be used in the same manner, though the scale of the heat recharge required needs to be accurately modelled to ensure economic viability.

Co-efficient of performance: (COP) is the ratio between the energy required to run the system and the output of the system. COP values of 3-4 are normal for most efficient systems. COP = Kilowatts of heat out / Kilowatts of electricity in.

Combined Heat and Power (CHP) or cogeneration: The production of electricity and thermal energy in a single integrated power plant.

Deep Geothermal Resources: Usually referred to as those below 300m (depending on the jurisdiction). Practically most international development occurs from 1000m to a maximum of 6000m with temperatures varying from 50ºC to 150ºC and higher depending on location and local geology.

Direct Use: Use of geothermal heat without first converting it to electricity, such as for space heating and cooling, food preparation, industrial processes, etc.

District Heating Systems: Distribution systems of hot water from a single source to multiple buildings.

Dry Steam: Very hot steam in the absence of liquid.

Earth’s Crust: The upper layer of the earth (25 – 32km thick) which forms the mountains and underlies the oceans.

Easements: A right enjoyed by the owner of land over the land of another, e.g. a right of way.

Efficiency: The ratio of the useful energy delivered by a dynamic system (such as a machine, engine, or motor) to the energy supplied to it over the same period or cycle of operation. The ratio is usually determined under specific test conditions.

Engineered Geothermal System (EGS): A geothermal resource created when impermeable, subsurface rock structures, typically granite rock 4000 metres or more below the Earth’s surface, are heated by geothermal energy. The resource is being investigated as a source of energy production. EGS is also sometimes called Hot Dry Rock.

Enthalpy: Used to express the heat (thermal energy) content of fluids, and gives a rough idea of their 'value'. The resources are divided into low, medium and high enthalpy (or temperature) resources, according to criteria that are generally based on the energy content of the fluids and their potential forms of utilization.

Fault: A fracture in rock with an observable amount of displacement.

Flash Steam: Steam produced when the pressure on a geothermal liquid is reduced. Also called flashing.

Fracture: A break in rock generally without displacement.

Geothermal Energy: As defined by Renewable Energy Directive 2009/28/EC on the Promotion of the use of energy from renewable sources this is “energy stored in the form of heat beneath the solid surface of the earth".

Geothermal Reservoir: A natural underground container of liquids, such as water or steam

Geothermal Resource: A region identified containing geothermal resources. Geothermal resources are divided generally into Shallow and Deep.

Geothermal Steam: Steam drawn from deep within the Earth.

Geothermal gradient: Also referred to as 'heat gradient'. Rate of increase of temperature with depth in the earth's crust. Average gradient in the earth is 30ºC/km.

Geothermal: Heat produced within the earths crust by convection from the deeper high temperature areas and through radioactive decay.

Glycol: Ethylene glycol ($C_2H_6O_2$) is used as an antifreeze and solvent, also as the heat transporting fluid in heat pumps.

Granite: A coarse grained igneous rock consisting of quartz (20 – 40%) and other minerals (Feldspar, Mica, Apatite, Zircon, Magnetite).

Heat Exchanger / **Heat pump:** A device for transferring thermal energy from one fluid to another.

Heat Flow: The rate at which heat is lost from the inner zones of the Earth to the atmosphere.

'**Hot spot':** An area with a higher temperature than surrounding areas.

Hydrogeology: The study of the geological factors relating to ground-water.

Hydrothermal Resource: Underground systems of hot water and/or steam.

Igneous: Rocks derived from a molten source (either Extrusive Volcanic or Intrusive Plutonic rocks).

Injection: The process of returning spent geothermal fluids to the subsurface. Sometimes referred to as reinjection.

Isopentane, C_5H_{12}, also called methylbutane or 2-methylbutane, is a branched-chain alkane with five carbon atoms. Isopentane is an extremely volatile and extremely flammable liquid at room temperature and pressure. The normal boiling point is just a few degrees above room temperature and isopentane will readily boil and evaporate away on a warm day..

Open Loop System: These systems use groundwater or surface water as the heat carrying medium. These systems can use drillholes to depths of 50-150m to access groundwater or alternatively can use lake, river or sea water. Water is taken from the source, cycled through a heat pump and the cooled water is returned to the source by reinjection to the aquifer (in the case of boreholes) or downstream at some distance from the extraction point in the case of surface water.

Renewable Energy: "As defined by Renewable Energy Directive 2009/28/EC on the promotion of the use of energy from renewable sources - renewable energy means energy from renewable non-fossil sources, namely wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases."

Shallow Geothermal Resources: These are usually soils, lake/river sediments, warm springs, gravel and rock aquifers at depths from 0 – 300m. Soil and shallow sediment temperatures in Ireland are in the 9º
C – 11ºC range and horizontal closed loop heat collector pipes can be installed with a depth of emplacement of 0.6 – 2m. Warm springs occur occasionally in Ireland with temperatures elevated between 3ºC and 12ºC above the average groundwater of the surrounding areas. These changes are subtle and result in cool to warm springs with temperatures from 15ºC – 22ºC. Gravel aquifers and fractured surface rock have temperatures of 9ºC – 13ºC but can have high ground water flows at depths of 0-30m. Closed and open loop systems can be installed in boreholes to extract geothermal heat from warm spring and shallow aquifer resources.

Solar Impact: Radiation from the sun that hits and is absorbed by the ground.

Thermal Conductivity: The ability of heat to pass through rocks, measured in $Wm^{-1}K^{-1}$ or Watts per metre per degree Kelvin.

Turbine: A machine for generating rotary mechanical power from the energy of a stream of fluid (such as water, steam, or hot gas).

Watt: The electrical unit of power. The rate of energy transfer equivalent to 1 ampere flowing under a pressure of 1 volt at unity power factor. Kilowatt (kW): One thousand watts. Megawatt (MW): One thousand kilowatts (1,000 kW) or one million (1,000,000) watts. Gigawatt (GW): One billion watts. One megawatt is enough energy to power 1,000 average homes.

Watt-hour (Wh): An electrical energy unit equal to 1 watt of power supplied to, or taken from, an electric circuit steadily for 1 hour. Kilowatt-hour (kWh): One thousand watt-hours. Megawatt-hour (MWh): One million watt-hours. Gigawatt-hour (GWh): One billion watt-hours.