The Royal Academy
of Engineering

# The heat beneath your feet: geothermal energy in the UK

Transcript of proceedings

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## Introduction

*Professor Nick Jenkins FREng*

Ladies and gentlemen, let’s start to make the best use of time. My name is Nick Jenkins. I’m from the Engineering Policy Committee of the Academy and I’ve been asked to chair the meeting. First, I should like to welcome you all, particularly our speakers, some of whom have come a long distance and we appreciate that very much.

We will hear 20 minute presentations, followed by five minutes of brief clarification questions. At the end, at 4.40, we have 50 minutes for a discussion. However, Michael Feliks, our first speaker, has to return to his duties, so we will have a slightly extended question time after his talk.

I will briefly remind you of the work of the Engineering Policy Committee of the Royal Academy. It is very broad, covering all aspects of engineering policy. I am particularly involved with our current energy challenges, which we all know are enormous. It is fair to say that our general policy is that we have an “and” approach to energy, rather than an “or” approach. We are looking for all the available approaches and technologies and it seemed to the Committee that the whole range of geothermal technologies were an untapped resource to which we were not devoting adequate attention and that were not falling precisely into the interests of any one of the particular learned societies that support the Academy. That was what led to this meeting.

At that point I will stop and hope that our expert speakers will paint the landscape for us. I think that the landscape is confusing; there are a number of different strands that fall under this broad topic of geothermal engineering or “The heat beneath our feet”, as it is described in our title. I look forward both to detailed clarification and also trying to put this whole area into context.

We move straight on to our first speaker, Dr Michael Feliks who is now from DECC. He was previously with various aspects of the Government, working on heat and energy and spent some years with the Treasury. He will address us on Government Policy on Renewal Heat.

## Government Policy on Renewable Heat

*Dr Michael Feliks, Department of Energy and Climate Change*

I'm from DECC, so I haven't come very far – just across the park. I work with the heat team in DECC. Previously it was the heat team in BERR, but now we have a shiny new department that does energy and climate change.

### Objectives for today

Today I want to put heat into its wider context and show you how it fits into the wider energy policy and try to focus on geothermal heat as well. This is about renewable heat, so to clarify first, much of this will apply to shallow geothermal heat. By coincidence I'm also supposed to be the leader on deep geothermal power as well, so I know a little bit about that. Mostly this will be about the ground source heat pump element of geothermal heat. I'll be looking at the present policy environment, what we are doing now on renewable heat and what we will be doing in the future. That is interesting since we have a large new policy coming down the pipeline called the Renewable Heat Incentive. I shall also be talking about removing the non-financial barriers to renewable heat, which is important. The biggest of those is probably simply ignorance about renewable heat. Very few people know what you are talking about; if you tell people at a party that you work in renewable heat you mainly get fairly blank looks. I will then talk a little bit about what the Government is up to next in this policy area.

### Heat policy is part of energy policy

As I said, heat policy is part of energy policy. We used to have four objectives for energy policy when I was a lad. Now, to meet our legal obligations, we have five and that makes good sense, for reasons I will set out in a minute. The four we did have were:

- affordability – reducing the cost of energy to businesses and consumers and a big policy issue for the Government is fuel poverty. I am sure that you have seen a lot about that in the news;
- mitigating climate change – reducing the greenhouse gases from the UK, which I think is self explanatory;
- energy security – which is increasingly important. For a long time the UK has not been dependent on imports of foreign energy fuels. That situation is changing and a big draw on our imported fuel demand is heat;
- maximising economic opportunities means a competitive energy market. I don't think that I'll touch much on that today. The UK is probably the most competitive energy market in the EU and the EU is committed to a very competitive energy market. We have probably taken that further than many others. From the point of view of heat, that is sometimes a good thing and sometimes a bad thing. Anyway that is the Government's objective.

### The UK's energy targets are challenging and legally binding

The next thing is meeting our legal obligations. That seems obvious, but recently that has taken on greater importance because we have adopted some challenging and legally binding targets that affect all of the UK energy sector. In the Climate Change Act of November last year we set out a legal framework that the UK has to stay within capped five year carbon budgets. The first one runs from 2008 to 2012 and the following one runs for 10 years after that. These are challenging and legally binding. Also part of the Climate Change Act is the commitment to reduce our greenhouse gases in the UK by 80% by 2050 and heat has to play a big role there. The thing that is driving the renewable heat sector at the moment more than anything else is the EU's 2020 target for renewable energy. The catch in this target is that it is 15% on total energy, not just renewable electricity as sometimes people think. Often in debates I notice people say "energy" and "electricity" and mean the same thing. This very definitely does not; it is total energy supply.

### Why does heat matter?

Why are we interested in heat? Is this a bit of a Cinderella policy? The answer is that it absolutely is not. We didn't think about it for a long time and in fact I remember when we started to think about heat at the Office of Climate Change where I worked it was a case of two or three people sitting in a room going, "Heat? What do we think about that?" Rapidly we have realised how important heat is and this pie chart explains exactly why. Despite the pre-eminence of renewable electricity in the public debate, in terms of final energy demand almost half in the UK comes from heat, including a big chunk of electrical heating, 38% transport and 12% electricity. A lot of people looking at that diagram would say, "That can't be right", but it is. What it tells you is that we simply can't ignore heat.

### Heat is half the battle

To meet the legally binding targets in the previous slide, we will have to think about the heat sector because it is half the battle. Not only is it 49% of our final energy consumed, it is 47% of our carbon emissions. If we want to reduce our carbon emissions by 80% or indeed by any significant amount, we have to think about heat. To a large extent that also means, at the moment anyway, renewable heat as the obvious way to take forward low carbon heat. For our 2020 and 2050 carbon targets we have to think about this. On the security of supply issue two-thirds of the gas we use in the UK is used for heat, so if you are worried about dependency on foreign gas imports, you need to worry about heat. It is far more central than its profile suggests.

### Why does heat matter?

I should also add at that point that heat is very important. We shouldn't downplay the importance of renewable electricity. There will be a big component of renewable electricity as a sector in which we are furthest along in building renewable capacity. Any technology that is renewable and can make a significant contribution in terms of the 15% doesn't need to dominate that graph. If it can make a reasonable contribution, it will be very welcome, depending on how much value for money it offers. That is where we might start talking about deep geothermal power.

### A closer look at the 2020 EU target

The EU target was agreed in 2007. The EU does not move quickly, but the overall target for the EU is 20%. The actual shares for individual member states, the burden of shares for meeting the target, were agreed late last year. Although the headline is 20% we have a target of 15%. Some people would say we have got off lightly, but the opposite is the case. Across the EU as a whole at the moment roughly 9% of final energy is from renewable sources. On average each member state needs to lift that 11% to get to 20%. We have to rise from 2% to 15%, which is obviously harder than adding 13% to a higher number. We also take on a little bit of a higher share because we are a richer country. There was a fantastically good graphic about this in the *Guardian* a few months back. For example, Sweden at the moment has 40%

renewable in its final energy demand, which is way ahead of the curve. They have to get to 49%, whereas Romania had to get from 18% to 26%, which is comparatively easy compared with us. Obviously this is a huge challenge.

Last summer we published the Renewable Energy Strategy consultation, which is a Government document saying, “We’ve got this target. We have some thoughts about how we might meet it. What do you think?” I’ll give you the web reference later in the talk. There was some analysis that supported that consultation; it was very much a first cut at how we might do this, but one particular scenario of how you get to 15% was 42% of electricity from renewables – an impressively large number – 14% renewable heat up from 0.6% and 10% from renewable transport. Transport is a special case. We assume the figure of 10%; I’m not an expert in this, but people tend to use 10% rather than a larger number, certainly at the moment. If you think back to the pie chart, that will place more of a burden on the heat and electricity sectors.

### How could the 14% break down?

Looking at the analysis in more detail, this was a breakdown of how people thought we might meet the 14%. A big chunk of biomass heat; if you can deploy it and get round all the other barriers such as sustainable supply, quality concerns and things like that, biomass heat is potentially the cheapest way of generating renewable heat. There aren’t that many other ways of generating. There aren’t many other technologies on the table – heat pumps are a large chunk and these two columns on the right are the cost of the different technologies. Biomass is strikingly cheap, despite being a big contribution; heat pumps are quite economical and commercial in relative terms. Solar is very expensive on this preliminary analysis; biogas is also quite expensive. I should stress that this is very much a first cut and I would be surprised if heat pumps didn’t move up the running order a bit as we move forward.

### Several technologies are available

There aren’t many renewable technologies; heat pumps, biomass, heat from waste, heat from the biogenic component of waste. You can also have deep geothermal heat. There is one very good example in this country in Southampton where there is a 1 km deep geothermal borehole providing hot water that runs into the Southampton district heating system. That’s great and it would be nice to see them spreading all over the country, but I’m not sure how much potential there is for that. I can’t emphasise too much that this is a preliminary analysis. We are trying to imagine the cost for all these technologies out to 2020 and that is a difficult thing to do. There are many variables that could affect things. For example, if the sustainable supply of biomass – and no one is suggesting that you could use anything other than sustainable biomass – turned out to be less than we think, heat pumps would need to take up a bigger share of the target.

The key message here is that the Government’s legal targets are such that whatever you think about renewable heat, they have no option but to push for a big amount of renewable heat. It is a very important component of delivering their legally binding target. Ground source heat pumps will certainly play a big role, but the question is how big.

### Policies that support renewable energy now

What policies do we have to make all this happen? We have the “Renewables Obligation”. That has been around for a while and it provides support for renewable electricity. From last week it has been banded, with some technologies getting a higher rate of support. It is not banded specifically by technology types, but rather classes such as established and innovative. Another two classes are well established. Deep geothermal electricity systems clearly count as innovative, since we don't have any yet. That would get two ROCs, which is pretty attractive financial support for a technology. There is a Renewable Transport Fuel Obligation supporting transport fuels and a range of grant programmes, which I won't go into in detail, some of them for biomass. The Low Carbon Buildings Programme covers micro-generation of various technologies. PV spend has been particularly high recently, as you may have seen in the newspapers, but it also covers biomass, ground source heat pumps and air source heat pumps. There is also a variety of regional grants. Because renewable heat tends to be most commercial off the gas grid where it isn't competing directly against gas central heating, it is more important for the devolved nations to look at renewable heat. They have a bigger proportion of people off the gas grid. In Scotland the figure for renewable heat is something like 3% rather than 0.6%, which is quite big. There is a lot of regional variation in the grants system.

### Government has acted: the Renewable Heat Incentive

You might spot a bit of a gap here because there is nothing on renewable heat. It is clear that these policies will not deliver the levels of renewable energy and heat in particular that we need to meet the 2020 targets. The Government has acted: there is a policy coming called the Renewable Heat Incentive, which was included in the Energy Act 2008 last November. Skipping a large chunk of the story, the Act had an amendment that included enabling powers to establish the Renewable Heat Incentive. That means that there are powers available allowing the Secretary of State for DECC to make regulations in a certain way, covering certain terms that will allow the establishment of this policy, which pays financial support to renewable heat. The interesting thing about this is that it came in at the same time as the feed-in tariff for small scale electricity, which people saw as the feed-in tariff for micro-generation. This isn't micro-generation; this is all the way up the scale. If you have a 100 megawatt heat biomass boiler, you will get support under the RHI. Heat from deep geothermal sources will certainly be covered at some level. It will be a big job to develop this incentive. For one thing we have a lot of policy and things such as the Renewables obligation and a lot of the legal framework on electricity and renewable electricity. If you want to do something in the electricity field you can build on the existing legislation. In heat we don't have that. We are going from zero in establishing laws and policies on heat for the first time. Even working as fast as we can we are expecting it to be in place in something like April 2011. When it is in place it will have huge potential; this can drive the entire sector on renewable heat and that is the intention.

### A closer look at a (possible) RHI

It is essentially a feed-in tariff for renewable heat. If you produce renewable heat, you will get a certain level of payment. In the consultation I mentioned earlier there was a straw man of our renewable heat incentive set out. We don't know how much it will pay; it is difficult to answer that question today and much water needs to flow under the bridge before we get to that point. Later this year there will be a consultation and people will be able to say how much they think we should get. The whole point here is that if you are off the gas grid – or on the gas grid for that matter – and as a business you are thinking of putting in a big oil- or gas-fired boiler, when the RHI is in place you will know that a renewable heat alternative, whatever that is, perhaps a big ground source heat pump or air source heat pump, will provide you with an extra income stream. That should take away a huge degree of uncertainty, increase uptake and reinforce the supply chain. More people will come here to sell renewable heat because there will be more people looking to install it. We would expect that it would be handed across the technologies; at the moment, as Professor Jenkins said, we are in an “and” rather than an “or” situation, so we hope to bring on as many renewable technologies and heat technologies as possible. There are varying distances from commercial at the moment, so some of the large scale technologies would expect to get less than some of the smaller scale micro-generation renewable heat technologies in terms of pounds per megawatt hour.

How it will be paid for is very important. It will be paid for by a levy on the suppliers of fossil fuels for heat. There is no need to go into that today, but the work to create that side of the RHI will be very big. Important for ground source heat pumps, certainly smaller ones, is this last point about dealing, so I will try to decode that. Rather than saying “You’ve put in a ground source heat pump and it will produce 10 megawatt hours a year; we will pay you £10 a megawatt hour, so every year we will pay you £100.”, it’s probably not worth your while to claim for that and for us to give it to you once you’ve added in the administration. But if we say, “It will probably last for 15 years, so we’ll give you £1,500 up front.”, that reduces our admin burden and yours and also helps to reduce one of the big barriers here. A lot of these technologies have high upfront capital costs. This makes the RHI look a bit like a grant and indeed it would be, except that once you have the RHI framework in place it is set up and will be running for a long time and the grants won’t run out. That is the key difference. Finally, the enabling powers are broad, so how exactly the Renewable Heat Incentive will look is difficult to say. I don’t think it will be too far away from how it looks there.

### Removing non-financial barriers

The thing I have been looking at most recently and focusing on is removing the non-financial barriers to renewable heat. It’s not enough to say, “Here’s some financial support for renewable heat.” There are many non-financial barriers. People don’t know about it, there can be planning problems and there can be supply chain problems, so we have to be smart about this and try to ensure that when the RHI does come in we have removed as many of these non-financial barriers as possible in parallel with the Renewables Obligation. The Renewables Obligation has brought on quite a lot of renewable electricity in the form onshore wind for example. If, three or four years ago or seven years ago when it was introduced, people had reviewed grid connection issues and made a big push on that, we might now have even more renewable electricity than we do at the moment. There is a lot here to be getting on with. If you try to install a large ground source heat pump and go along to your local authority to look for planning in two or three years’ time, we don’t want you to be met with blank faces. If you think you know what the big barriers to geothermal heat are and you think that I haven’t mentioned them, see me later and I’ll make a note.

### Who in Government does heat policy?

The headline here is that there is a big financial support policy coming. We are working on the non-financial barriers. Who is doing all this? The answer is us in the Department of Energy and Climate Change. There are some other parts of government that will lead on things like biomass sustainability for example and building regulations, which is obviously DCLG, but we will be leading on this. The heat team from BERR has moved today. It is the Distributed Energy and Heat Team. Hergen Haye is the head of the team and he is my boss. As I mentioned, at the moment we are also covering deep geothermal electricity.

The RHI itself is being developed by another team within DECC, the Renewables Financial Incentives team, which also covers the RO. We have several people working on that, one of whom is here today, because it is a big piece of work. We also have an energy innovation team leading on innovatory technologies. On the deep geothermal stuff I would expect them to play more of a role in future.

**The DECC Organisation**

Some of you might find this useful, but I don't propose to go through it here.

**What happens next?**

What will happen next? This is only part of the heat policy and of the renewable energy policy. In February we published the Heat and Energy Saving Strategy. You can view that there. Later in the year – early summer, I think – we will publish the Renewable Energy Strategy. This will show the 2020 target and how we propose to meet it, which is the natural follow-on from last year's consultation. Work will continue on the RHI. As I say, this is a big job and will need a statutory instrument although, crucially, because the powers were included in the Energy Act last year, it is secondary legislation and will not be held up by the parliamentary timetable. A big issue for us at the moment is that while the Renewable Incentive is good news it will not be here today, so what do we do with the market over the next two years? That is obviously quite a big issue, especially for people involved in the market. We are focused on that at the moment. The bottom line to all this is that heat is now a well established area within energy policy. It will be a while before we get past electricity, but the importance of heat is now well understood.

That's all, so thank you very much.

**Nick Jenkins**: Yes, absolutely. Can I now open the meeting to questions and contributions? Please remember to say who you are and where you are from for the transcription.

**Alan Powderham (Director, Mott MacDonald Ltd)**: Thanks for that comprehensive overview. Could you tell us first whether that presentation will be available and would those web addresses lead us to the same information? The second question is more specifically about getting the balance between the carrot and the stick, which you referred to. At the leading edge of trying to get innovation accepted in our industry there is a big constraint in the form of business as usual and natural resistance. If you are not getting the details on the legislation effective until 2011 and 2020 is the EU target, that is nine years in which to move pretty fast. An incentive is good, but that has a natural inertia to it. A stick may be better. How does it become legally binding over a period?

**Michael Feliks**: The legally binding bit is on the Government. That is our problem to worry about. I can see another difficult question coming. The RHI, as you correctly say, is a carrot. We are not particularly using the stick yet. If we had gone down the route of an obligation, that would have been the stick and the basic argument in the consultation, if you re-read it, is carrot versus stick. We have come down on the side of the carrot for now. We can do some things with some parts of the demand and the market that we do control. For example, in the public sector I would expect an increase in the uptake of renewable heat. We will try to drive that through government. Particularly over the next few years that could be an important stepping stone towards the RHI coming in.

Although the RHI is not an obligation, it will have the flexibility to set levels of support for renewable heat that can be changed. The way the levels can be changed will be entirely dependent on legislation. We have to bring on renewable heat. If we set the levels of support under the RHI in 2011 at a level that brings on hardly any renewable heat, we will have to rethink that.

As to the websites, we haven't got this presentation on the website, but I think that you will possibly find that it is available soon anyway.

**Xameerah Malik**: Yes. We will have the transcript of this meeting and the presentations on the website next week.

**Nick Jenkins**: Thank you. Another question?

**Robert Pine (University of Exeter, Cambourne School of Mines)**: I am an ex-hot-dry-rocker! On the 15% target for 2020, how does that relate to any savings you may make using systems such as combined heat and power and improved insulation?

**Michael Feliks**: I have not talked about that today, simply because I am here to talk about renewable heat. Everyone accepts the importance of reducing the energy demand, pushing energy efficiency and insulating where we can and of putting these technologies into situations where you are not simply producing renewable heat in a low carbon way, most of which is going through the roof because you haven't insulated it. So, yes, there is a huge victory to be won there if you make big progress in energy efficiency. In fact I should alter this to include energy efficiency to avoid accusations that we are not taking it seriously. The target is 15% of the total energy amount in 2020, so if you reduce that you need to deliver in absolute terms less energy from renewable sources.

**Peter Heath (Pro-.. International)**: I am interested in the carrots. You mentioned the Act coming into force some time in 2011. If a project started in, say, 2010, would that remove any hope of getting a grant? This applies to quite a lot of Government type sponsorship. Do we have to delay it?

**Michael Feliks**: I would hope you wouldn't, but it is difficult for me to say anything at the moment. I take your point and obviously that is the sort of thing that is being considered by those putting together the regulations. We would certainly not want you to delay.

**Peter Heath**: Secondly, do you have an inspired guess as to what the number might be behind the pound sign?

**Michael Feliks**: No, sorry.

**Nick Jenkins**: Is there one more question for Dr Feliks?

**Jonathan Teubner (Business Development Manager, Petratherm Ltd)**: In terms of geothermal, exploration for heat is similar to petroleum, yet currently there is no legislation available for exploration and production permit security in the UK although there is for petroleum. Is there any move to create that tenement security so that companies that explore for the heat to produce it have security of access to the resource?

**Michael Feliks**: I am aware of that as an issue. We have been having some thought about it. Ideally that would be the way you would go if you had a lot of time and resource and I am aware that in Australia you have such a system. It is work in progress for us at our end to think about this. The only thing I would say is that that would not be a particularly quick option if you wanted to do this.

**Nick Jenkins**: I would like to bring that section of our meeting to a close and thank Dr Feliks very much. I got the strong impression that policy was still being developed and I’m sure he would welcome contributions by email if anybody felt inclined. Thank you very much for your contribution.

We move on now to Dr John Garnish, who will address us on the development of hot dry rocks enhanced geothermal research in Europe. You have his biography in the attachment. He has been involved in the hot dry rocks EGS area for many years and is going to give us the benefit of his experience. John, thank you very much.

## The Development of HDR/EGS in Europe
*Dr John Garnish*

Thank you, Mr Chairman. Good afternoon everybody. I want to start with a quick definition of hot dry rock/EGS. The term “hot dry rock” was used for about 25 years as an all-embracing term for the technology of extracting heat from rocks that didn’t naturally contain water. It rapidly became clear though that virtually all rocks contain a certain amount of water and, as you might expect, what you are actually looking at is a complete spectrum from very low permeability crystalline rocks through to high permeability aquifers. We have gradually tried to move over from “hot dry rock” to the term “EGS”, which, depending on who you are talking to, stands for either “engineered” or “enhanced geothermal systems”. This describes any geothermal process that requires an active engineering intervention to produce commercial flows of energy.

### The Major Geothermal Power Producers

Unfortunately, geothermal energy is still a largely unknown topic to very large numbers of people, so I wanted to start by demonstrating that we are not talking about science fiction. There is a great deal of experience in conventional geothermal around the world. I have highlighted the major sites, which, as I think you will recognise, tend not surprisingly to be concentrated around the major plate boundary areas. Total installed capacity for electricity generation is currently around 10 gigawatts. The snag is that all the best sites or the majority are, as I say, around the plate boundary areas and, more or less by definition, the bulk of the land mass is remote from those. There is still plenty of heat there, but because the temperature gradients are lower, by the time you have got to a depth where the temperature is useful, the availability of water is much more restricted. Therefore the concept came about of trying to extract heat from those deeper formations.

### Heat in the subsurface

To give you a broad idea, if we take a cubic kilometre of rock, which might sound a lot, but is actually the characteristic scale of a geothermal reservoir, give or take the odd factor of 2, if you were to cool that by 1 degree Centigrade on average, that would be the equivalent of 80,000 tonnes of coal or having a coal seam somewhere between 2 and 5 metres thick across the whole area. To put it another way, the heat contained in the Cornish granites is equivalent to the whole of the coal deposits in the UK. That is a theoretical number and you could only ever hope to extract a tiny fraction of that. Even so it is very significant.

[***Slide – John Gardner 1885*]**

Just a little bit of history here. The earliest reference we have come across in Britain is from Starkie Gardner who was quite a remarkable character. Back in 1885 in the *Geological magazine* he wrote an article about the possible extraction of underground heat. You can see that he is saying that there are zones of considerable heat likely to be within a depth that might be practical. He was also quite far sighted in another way. He added at the end, “Our statesmen and others whom it may concern will then perhaps awake to the necessity of promoting experimental research … let us hope not too late to arrest a serious diminution of our national wealth.” Things don’t change much.

The next reference that we know of came from Sir Charles Parsons in a couple of Presidential addresses to the British Association in 1904 and 1919. He was talking about the practicality of sinking shafts to 20 miles depth. He reckoned it would take 85 years. I haven't been able to find published information about using those shafts for heat, but I'm told there was some private correspondence between him and, I think, the Falmouth estate that talked around the time of the First World War about multi megawatt power stations in Cornwall.

### Practical Mechanics, 1936

Somebody must have picked that up because the next reference that I've come across was in *Practical Mechanics* in 1936 where we had this diagram. Again we have the 20 mile shafts and they would be connected together "by some means or other". I think this comes under the heading, "at this point a miracle occurs". It's just worth mentioning that at this time in 1936 Italy was still the only country that was generating power from geothermal steam.

### Energy Paper 9 (1975)

I seem to have lost a slide, pity. The slide that I have lost was of the report I produced for what was then the Department of Energy in 1975 setting a case for doing geothermal research in the UK. Much of it, of course, was concerned with the possibilities of direct heat applications, the UK not being, generally speaking, well suited for power generation. I did comment on some work that had recently started in the US, which was in fact this project at Los Alamos.

### The Fenton Hill Project (Los Alamos National Laboratory, 1970)

In a paragraph that was less than perceptive, even by my standards, I wrote that there was no reason for us to do anything at this stage. We could sit back and watch the Americans. Within a few months we had the opportunity to send somebody to Los Alamos under the auspices of NATO CCMS. At that time the Los Alamos project, which, not surprisingly, spun off from their work on nuclear energy, looked at a way of disposing of radioactive liquids by injecting them into fractured rocks. Somebody came up with the idea that there was lots of heat down there and could we extract it. At that time, their concept was that these deep crystalline rocks were going to be impermeable and isotropic and so if you drilled into it and pumped hard enough with fluid, you would generate a single vertically oriented penny-shaped fracture. That fracture would be initiated and held open by the hydraulic pressure and you could then, in principle, intersect the fracture with another borehole, circulate water around the loop and the fracture surface provides the necessary heat transfer area to extract the heat. That was the original concept and they had been working on that for about five years when we had the opportunity to send somebody over there.

### Tony Batchelor's insights

The person that we sent over was a guy named Tony Batchelor, who at that time was a lecturer at Cambourne School of Mines interested in the problems of getting heat out of rock for the purposes of mine ventilation. Although he didn't spend very long at Los Alamos, he did recognise a couple of critical elements. The first was that the reservoir behaviour was dominated by the natural fracture system. These deep rocks were not isotropic, they were highly anisotropic and they were full of natural fractures that dominated the behaviour. In particular they were also subject to an anisotropic stress field. I will leave those other two points for a moment. I might add that these suggestions were pretty unpopular at the time, but when he came back here the Department of Energy agreed to set up a project in Cornwall which most of you will have heard of at a quarry called Rosemanowes. In fact several of Tony's team are here in the audience today, in particular Bob Pine, who was one of the original inhabitants. The reason we decided we would have a project in the UK was because at that time in the mid-1970s the American approach to research was to solve problems by throwing money at them. The Federal geothermal budget doubled every year for five years literally. I think that it was $160 million a year by the time they quit. Most of the problems at Los Alamos were actually centred on the sordid difficulty of running instruments down a hole at temperatures of 200 degrees Centigrade. It was nothing to do with the real problem. It was clear to us that within a few years the oil industry would solve that instrumentation problem. What we needed to do was to find a mechanism for concentrating on the rock mechanics without having the temperature problem. We decided to set up the problem in Cornwall on, as far as possible, full scale, but at temperatures low enough not to cause measurement problems. In fact the Cornish project was never designed as an energy producer. Subsequently we allowed the misapprehension to occur and as a result the project was severely criticised, but in fact it did achieve most of its objectives.

It’s worth mentioning that just about this time of course the UK joined what was then the Common Market and this work was supported by the European Commission right from the beginning.

### Rosemanowes 1977-92 – a large-scale rock mechanics experiment

There is the Rosemanowes quarry in Cornwall. Eventually a total of three wells were drilled to a depth of 2,500 metres, maximum temperature around 80 degrees Centigrade. Here is a plan view and two wells essentially in the same vertical plane. The other ones curled around underneath to intersect this. What you are seeing here is the location of micro-seismic events; as these rocks shear under pressure you get micro-seismicity and that is in fact the only method one has of following what is happening underground. The third well was drilled through into there and a reservoir was established. Eventually there was something like four years’ circulation, including one year’s continuous circulation at more than 20 litres a second. A great deal was learned about the management of these fracture systems over the years of the project.

### Natural fractures

We ended up with this concept – essentially a system that was dominated by the natural fractures in an anisotropic stress field. The natural fractures are stimulated in shear. The fractures shear at pressures well below those necessary to generate a tensile fracture. You will have noticed in that previous slide I showed the micro-seismicity migrating downwards. At the time the received wisdom was that fractures would always go upwards and Cornwall must have got its measurements wrong. In fact it was a key paper by Tony Batchelor and Bob Pine that demonstrated the direction in which the fractures will grow depends entirely on the relative stress gradients in the rock and in many cases fractures will indeed grow downwards.

### Parameter analysis

Let’s have a look for a moment at how one sets about deciding what sort of targets we want. This is a very simplistic approach and there are lots of details to be filled in in between, but the principle is very simple. The designer of a hot dry rock EGS project only has two parameters under his control – the temperature he wants to achieve and the temperature drop before he puts the water back down the other hole. If you know the temperature for any given location, you know the depth and you know how much it will cost you to drill to that depth. Separately you have a pretty good idea of what the plant and O&M costs will be because there is so much experience of conventional geothermal elsewhere in the world. You also know what the value is of the energy you are going to extract. If you put all those together, the total cost tells you that in order to pay off the capital you know how much energy you have to extract from the system. That then allows you to work out the flow rate that you will need and therefore how big a heat transfer area to give you the lifetime of the reservoir and the rock volume you need to access in order to get that amount of heat out. This was all done very early on.

## Target parameters

The order of magnitude parameters that were obtained have not really changed in 30 years. They are still, broadly speaking, the targets you are looking at for a large scale project. Flow rate, 50-100 kilos a second; heat transfer area, 2 million square metres; rock volume 200 million cubic metres; impedance and water loss I'll come back to in a moment. These are the key ones. Heat transfer area and rock volume are not a problem; every project that's had a go at this has easily achieved that. Very few – none really – have achieved these sorts of flow rates for more than very brief periods. We are getting close to it, but we're not there yet. Resistance to flow is one of the key parameters. None of the projects has yet got down quite as low as that impedance, but, again, we're getting close to it. Those are the targets and that is what everybody was working towards.

## HDR/EGS Development in Europe

I say everybody because by the mid-1980s we knew – and I am talking specifically about Europe now – that there were a number of projects all working on aspects of the same problem. In France there was a project in the Massif Central at a relatively shallow depth of 300-800 metres by Francois Cornet trying to understand the behaviour of fracture systems, again, not as an energy extractor at this stage, although that is what he was working towards. Falkenberg in Germany, a similar shallow system, aimed at understanding the behaviour of a fracture. At Urach there was a deep borehole in which they were aiming to generate a single fracture and trying to use that on what's called a "huff-puff" basis as an energy extractor and, of course, there was the work at Rosemanowes. In principle, the sort of techniques you need to develop an EGS system shouldn't be particularly site specific.

These projects are very expensive and there are a limited number of people available to do them, so it made sense to pull all these people together onto one site in Europe and pool the resources. In the mid-1980s we did just that. I'm afraid I had to bang a lot of heads together because everybody said, "Oh what a good idea, as long as it's my site." Anyway they all ended up working on this site at Soultz, just north of Strasbourg in the Upper Rhine Valley. Initially it was a collaboration between France, Germany and the UK. Fairly soon after that, about 1989-90, the UK pulled out and various other countries – Italy and Switzerland in particular – joined in and we began to get industrial involvement.

By the mid-1990s we had a system at Soultz at 3,600 metres and, following a review by all the various players, we went on to build a deep system at 5,000 metres. Last year we generated the first power generation. By the end of the 1990s we started bringing in industrial players and gradually handed over control from public bodies to an industrial consortium. There's still a fair bit of public money in this project, but primarily EDF and Pfalzwerke are now running it.

### Soultz-sous-Forêts 1987-2009+

This is just a quick view of Soultz. Here was the original 3,500 metre reservoir between the first two wells. Subsequently that one was deepened and two others drilled with 600 metres separation at the bottom, 200 degrees Centigrade. That’s the concept: injector in the centre, production wells on either side.

### Soultz – main project achievements from 1987

I will run through these very quickly. The project started in the late 1980s drilling the first two wells in order to understand what was there, deepening the wells and finally a four month circulation test at 3,500 metres. This was the first time that a test had been carried out that had zero water loss for four months in a closed loop, which was one of the achievements. Following that the boreholes were deepened and the deep reservoir was stimulated. Hydraulic stimulation in itself was not proving quite sufficient to get the resistance to flow down. Occasionally, while you got thousands of micro-seismic events that could only be detected instrumentally, you got one that was felt at the surface. It was not enough to cause any technical damage, but enough to frighten the local population. Public perception is a major problem and something that we will have to watch. As a way of avoiding this, the hydraulic stimulation was followed up with chemical stimulation – basically an acid stimulation to remove some of the deposits in the fractures. That was very successful and got the resistance to flow down somewhere very close to the targets. As a result, in the past couple of years the first phase of the power plant has been built. Ultimately this reservoir should be able to support 5 MW.

### The European EGS plant at Soultz

Power plant tests, electricity production and this is the power plant. This generated power for a few days, for the benefit of the French Prime Minister last June. To follow up one of the questions that was asked earlier, it is shut down at the moment because the French Government are about to increase the subsidy from 12 to 20 Euro cents per kilowatt hour. If Soultz starts generating before that increase comes into effect, they will be locked into the old rate, so the project has been sitting there doing nothing for a year. Technical problems are not the major ones usually.

### Deep Heat Mining at Basel, Switzerland

The bad news is that down in Basel at the other end of the Rhine Valley, they started building an EGS system to provide district heating to Basel, which is why it is right in the centre of town. Unfortunately, they triggered two or three “felt” earthquakes; again, these were relatively small, magnitude 3, but enough to frighten the population. These are the sorts of headlines that that generated and as a result, the project was suspended and still is. We are hoping it will start up again fairly soon, but it is one of the problems of public perception.

### The geox GmbH Project in Landau

On the other hand, at Landau, just across the Rhine from Soultz and a little bit north, there is a very successful project that uses EGS techniques. It was built in a matter of a couple of years, came on stream last year and is generating 2.5 MW electrical and 6 MW of heat for the local district heating system.

**A vast European Resource**

Finally, this is a summary of the work that was done by Shell when they were part of this as a consortium at Soultz, just looking at the theoretical thermal resources in Europe. Essentially anything with the darker colours will be useful for power generation. The numbers they came out with was that if you cool 1 $km^3$ of rock $20^o$, that will support 10 MW(e) for 20 years. Even taking the best section of the resources, there are 12,500 $km^2$ 1 km thick, which would give you the output equivalent to that of the entire European nuclear capacity. The available resource in Europe is ten times that and that, again, is only in the best grade, more if you are prepared to accept a lower grade. Since this work was done getting on for 10 years ago now, as you can see, in September 2000, there has been a lot more experience with binary cycle turbines, which are beginning to generate economically at temperatures significantly below this.

That was all I wanted to say. Thank you for listening.

**Nick Jenkins**: I propose that we slip the programme 10 minutes, which allows us four minutes for questions and contributions to John. Can I invite comments and contributions now?

**Michael Feliks**: Can I ask about the geothermal heat potential in the UK?

**John Garnish**: Yes, what about it?

**Michael Feliks**: Can you say something about it? Not the electricity generation.

**John Garnish**: Obviously the Department of Energy’s exploration programme back in the 1970s and early 1980s was primarily focused on geothermal heat, which is where the Southampton project came from for instance. The problem we have, unlike the French, is that our warm aquifers tend, with rare exceptions, not to coincide with the centres of population. That is the real problem. The French have the Paris Basin right underneath them and so there are many district heating schemes there. As far as we are concerned, the Wessex Basin and Southampton is really the only good correlation, with possibly some around Humberside. I know there is some thinking up in the north east now about which I am not very familiar, but I think that you will be hearing about that later.

**Robin Curtis (Technical Director, Earth Energy Ltd)**: Given your vast experience, what would you like to see happen next in EGS? What should we focus on as our next stage of development?

**John Garnish**: I’ve said for many years – and it’s not a popular thing to say – that we actually need two or three pilot projects like Soultz, Landau and possibly one or two of the Australian projects, which will need to run for four or five years so that we can understand how these reservoirs evolve. They certainly will evolve and the question is whether they will get better or worse. Personally I am optimistic; they tend to get better, but who knows. We need that experience before I would feel comfortable about going to a company and saying, “Put your money into this.” We don’t necessarily need more research; we need two or three more pilots.

**Nick Jenkins**: Let’s bring that to a close and thank you very much. We will move on to our last speaker before the break, Dr Ernst Huenges, who is Director of the International Centre of Geothermal Research at the German Research Centre for

Geosciences. He will address us on geothermal deployments in Europe. Again, I suggest that we slip our break to 3.35 to give time for this contribution. Thank you.

## Geothermal Deployment in Europe

*Dr Ernst Huenges*

Thank you, Chairman, and good afternoon, ladies and gentlemen. I come from Germany, from the Research Centre for Geoscience of the Geothermal Group in Potsdam. We are also working on a pilot EGS plant in Gross Schönebeck close to Berlin, where we want to enhance a geothermal system in a sedimentary environment. This is what I would like to talk about, but I decided to talk about geothermal deployment.

This comes from my recent task of joining the IPPC group in generating a new report on renewable energies. There will be a geothermal chapter and I will be one of the authors of that. Therefore I will try to give my first thoughts about geothermal deployment, which comes very close to the previous presentation and also to what politicians have to decide. I will try to give you the view of a technology developer, which is what I am.

The Helmholtz Association is an association of huge research institutes in Germany that address challenges on energy. In this association I am the leader of geothermal research.

### Geothermal Deployment in Europe

The outline of my talk will address the technologies and I will speak about all technologies, especially my favourite in relation to geothermal, the product of geothermal, which is heat. Although it also produces electricity, heat is the most prominent part and therefore I will address technologies on this. I will speak about market penetration and the status quo at the moment and, of course, I will address the benefits of large scale deployment as part of the future renewable energy supply and as part of the $CO^2$ mitigation strategy by substituting fossil fuels. I will address the controlling factors of deployment from a technological point of view, an economic point of view and, of course, from the view of the politicians and bring this into some kind of decision matrix to address all these items to consider the starting conditions for each site in Europe and bring the risks and potential reactions together. I would like to end with the required actions.

### Technologies

Starting with technologies, coming from the surface and down the hole the first product can be derived by installing geothermal heat pumps. Usually you have a ground heat source, with wells going to several tens of metres and the essential part of the technology is a heat pump to lower the temperature and pump it with compression to a temperature for customer use.

The second technology is direct use of geothermal heat. For this we use deep wells going to an aquifer in the order of 2 kilometres. You need investment to do this and you provide the energy usually to district heating systems. The system itself is closed; you only take out the hot water with a pump and reinject it and you simply reduce the temperature of the system.

The third technology, enhanced or engineered geothermal systems, has already been presented by John. This is a picture of the three wells with the locations of the electricity, as has already been presented.

Last, but not least are conventional geothermal systems to provide electrical power, taking a mixture of steam and water at the surface, using the steam to drive turbines and reinject the water. Again, this is the conventional system which is in use.

### Geothermal Use, 2005-2007

John mentioned that it is already producing in the order of 10 GW at the moment, with a yearly production of 70 TWh distributed in 24 countries. He already also mentioned the new approach with binary schemes and organic ranking cycles in some places. Tomorrow there will be a new plant going into operation with the Kalina technology, which is another technology.

In heat we have provision in the order of 30 GW worldwide production of 73 TW hours per year. This is well distributed and it is a fast growing market at the moment. For example, in Germany we increased direct use in the last five years from 20-30 MW to 180 MW, which is remarkable when you consider the effort, which involves drilling deep wells and so on. This is ongoing at the moment in countries other than the UK.

### Benefits of large scale deployment

Coming to the second part, these are the benefits of large scale deployment.

### Geothermal electricity production

First, looking back at the past 40 years you see the provision of geothermally produced electrical power is more or less a linear development. There is some kind of change here in the curve. We have other indications that the prognosis is now changing to a more dynamic exponential increase and the scenario where we agreed within the IPPC group that we can think about 140 GW in 2050. There are also other authors who think that there could be much more, but taking this number we are thinking about something in the order of 1,000 TW hours per year. We are probably on an exponentially increasing curve.

### Other Scenarios

I mentioned other authors and, for example, in this MIT study for the US alone there is a capacity of 100 GW in this curve with some idea of how to install the system. In Germany there are also studies talking about 35 GW of electrical power being possible. I don’t believe that, but it is important to mention the number. This means that we can think about multiples of 1000 TW hours per hour.

### $CO_2$ Emissions @ geothermal power production

What does this mean in terms of $CO_2$ mitigation? This study by Bloomfield and others compared $CO_2$ produced per provided electrical KW hour. Coal is more or less 1000 g, 1 kg per KW hour. I also checked other authors and this is plus or minus 100 g. Natural gas is 600, geothermal is in the order of 90 g of $CO_2$ per KW/hour. I have to mention that this is a conservative estimate, taking into account that in this open system there is still a release of natural $CO_2$ into the atmosphere. If you look at the EGS plants, which are usually closed systems, we have reinjection of the cooled water or steam and then we are speaking about numbers between 20 and 80 g of $CO_2$ per produced KW/hr.

### Geothermal electricity production - conventional

Bringing these numbers together, with this scenario of the 1000 KW/hrs of geothermally produced electricity, there is a mitigation potential of 1 gigatonne of $CO_2$ per year. This is remarkable if you take into account that all electrical power stations worldwide produce 13 gigatonnes nowadays. That means we can make a significant contribution to mitigating $CO_2$ by deploying geothermal energy.

### Geothermal heat provision

The same scenario can be calculated for heat provision. Taking these geothermal heat pumps, we are in the order of 4 EJ; in this scenario we have a mitigation of 200 million tonnes and while direct use does not produce so much energy, it is still a significant contribution to the mitigation scenario.

### Controlling factors of geothermal deployment – (i) technological

Turning to the controlling factors of deployment, I will take you into this matrix now with the four technologies – ground heat pumps, direct use, EGS and conventional geothermal systems. This is of course for heat provision or direct use; EGS is either heat provision, which for the UK is very interesting, and of course power provision; conventional is of course power provision. The technology is proven for ground source heat pumps for direct use. In the Paris basin, as we have already mentioned, we have a lot of plants in Germany and also with CGS, but restricted to specific areas, whereas EGS is still in the R&D stage. A further controlling factor is, of course, efficiency, which is poor for air based heat pumps, but ground pumps are interesting, needing only one part of electricity to produce four or five parts of heat.

The reliability of the system is important. You can use this in cascade use. It is important to have this in EGS to control the auxiliary energy to drive the pumps. You have to put energy into the system to take energy out and we have to work on this. In terms of reliability, corrosion and scaling is a technology factor that controls deployment. If you cannot control it, you will not achieve it.

Going on to underground issues, in red, you see mining risk and reservoir management; that means finding the reservoir and using the reservoir is a controlling factor. Sustainability is the strongest argument for geothermal energy. The geological factors are the stress field and the geological structure. John mentioned that, so there is no need to repeat it. Drilling, completion and induced seismicity have to be controlled.

Last, but not least, EGS has to be brought into a best practice situation. We need standardisation and this is a big challenge at the moment. Also in CGS there are some barriers preventing us from having larger deployment. Of course mining risk can be addressed with exploration, but also drilling has to find the reservoir without damage. We have reservoir damage in conventional plants, therefore we are working on methodologies with balanced drilling. We have to take into account the depletion of the system. To give one example, the ??... in the US are nearly depleted now because they don't have a reinjection programme. We have to think about reinjection not only of the water, as shown here, but also of the steam to keep the system balanced and this is a challenge.

### Controlling factors of geothermal deployment – (ii) economic factors

We have first to look at the potential. Ground heat pumps can be installed nearly everywhere. Direct use is restricted to hydrothermal reservoirs. EGS should be independent of site and this is restricted to hot hydrothermal. The customers are single houses and dwelling houses – very small units – and for this we need the larger systems of district heating. Without it there is no sense in drilling and it is the same for EGS, district heating or electrical grids to sell the power and some kind of base load requirement. This is the market for these technologies. What also drives the economics as shown here is what the industry can provide with skills, availability of consultancy and companies to operate the systems. Experience is the key to developing EGS. If you look at the conventional sites, you have geothermal energy already installed, which is still required for the other fields. Here, shown in blue, is a group of bankers who are needed to support this deployment. I put some numbers here that we can discuss later. We have between 4-10 cents per kilowatt/hour electrical power and EGS is slightly more expensive.  I didn't put numbers for heat because this is another product and I didn't want to have it on the same line, but you can keep in mind that this is one tenth of this number.

### Controlling factors of geothermal deployment – (iii) political

We heard in the talk by Dr Feliks about incentives for market penetration. In Germany we are very successful with feed-in tariffs, which are used a lot in electrical renewables and also in geothermal power. Our EGS plants are a product of these feed-in tariffs and these were a good thing. I also mention here an important item, which is incentives for technology transfer. We heard today the lessons learned at the Cambourne School of Mining. What I regret is that these products went into other industries, not the geothermal industry. For me that is a failure of politics; they have invented a lot of things, but it is no longer the leading group in geothermal provision. Public acceptance is important for EGS, as is, of course, research and development. This is most important in the engineered systems, but also the other technologies require research. Here it is the most prospective part.

### Decision matrix – (i) starting conditions

I went on to sort these items in another way; if you start deployment you must decide something. Somebody has to decide something and therefore I have made four categories here. The first is demand; do you have small customers or larger customers for heat and/or power? We have to be clear in which country we are living. Is this a developed country or a developing country? Is it a country, like the US, with laissez faire politics that let the market run or is it a more controlled market? In developing countries, of course, it is only possible with supported markets or with direct money from other countries. The geology also comes into this; do we have low enthalpy reservoirs, as in the UK? Are we still in the green field or can we add to existing systems or geothermal fields? The same in the high enthalpy fields; is it green or do we have existing wells? I will not suggest a way through this; this is up to you. I have simply identified these issues and we have to decide with the existing technologies how to address these. Of course a small customer will come to the heat pumps, but also it is possible to have larger areas and to develop district heating systems. District heating is, I think, the future, not only from the geothermal point of view, but also from other views. Energy requirements need larger systems.

### Decision matrix – (ii) risks and potential reactions (deep reservoirs)

Again, this is sorted by geology, technology and society. For geology the mining risk is the most important point; it requires reservoir assessment and, as was already mentioned before today, for this data needs to be shared. It is important that we find some ideas to share knowledge, taking into account, of course, the interests of the companies. For technology the risks are drilling and completion; I mentioned corrosion and operational risk. These can only be addressed through research and development and here also sharing expertise is necessary. Society has to give its acceptance and decide how to address its information policy. We always have to give people information and for society it is important to communicate the idea that there will be a long installation period. We are envisaging that it will be 2050 before these developments are completed. Last, but not least there are the requirements for capacity building, training programmes, sustainably financed projects and incentives for selling environmentally friendly clean energy.

### General options for actions

We require favourite frame conditions. We have to strengthen the industry, invest in research and co-operate internationally. I have also suggested that we have to wait for further increases in oil prices, but that is not the way to do things of course.

Thank you for your attention.

**Nick Jenkins**: Thank you very much, Ernst. Before we break for tea we will take two brief points.

**Alan Powderham (Director, Mott MacDonald Ltd)**: Just a quick question on your matrix of technologies. On GHP you observed that it was proven technology, but you restricted it to small customers and projects such as dwelling houses. However, it seems to me that they are applicable and have been used in major projects. For instance, we estimated 6 MW for a terminal building in an airport and I was curious to know why GHP is restricted to the domestic area.

**Ernst Huenges**: Why are you not happy with this?

**Alan Powderham**: You were saying on the other slide that it is restricted to small projects and customers, for instance dwelling houses, as opposed to major buildings and construction, which is also possible.

**Ernst Huenges**: Yes. The scale is between 10 KW of heat or 100 KW if required.

**Nick Jenkins**: If there are no further points at the moment, we will break for tea. Thank you very much for your contributions.

[*Resuming after break*]

**Nick Jenkins**: Shall we reconvene now, colleagues? We are something over 10 minutes behind schedule and my proposal is that we slip that and push it into our final discussion, which will start some time soon after 4.50. Our next speaker is David Banks, who will address us on Thermogeological Accumulator Ground Source Heating and Cooling in the UK. You have his short bio in front of you; I cannot resist reading the last sentence he has written. “He has worked in many exotic and challenging locations, including Tomsk, Kandahar, Somalia and Aylesbury.” We look forward to your contribution, David.

## Thermogeological Accumulator Ground Source Heating and Cooling in the UK

*David Banks*

I have worked for 25 years in geology; I am a bit of an imposter, because actually I am a chartered geologist.

### Many parts of the world suffer from a shortage of clean drinking water

For the first 15 years of my career I have been trying to solve one of mankind's fundamental needs and that is the supply of potable water, of which many parts of the world, including southern England, suffer a shortage. When I was young and naïve I decided that the existing means we used to supply water, i.e. take it out of the Thames and bung it through a few sand filters, was very old fashioned. I decided we needed a modern, industrial chemical process to produce large quantities of pure, clean new water. I developed a cunning and subtle plan and that was to use the world's reserves of fossil fuel and natural gas for something really useful, because, of course, when you burn propane you generate water. Fantastic! Patent pending and you are looking at me as if I were crazy. That was the reaction of most of my colleagues.

### But as a hydrogeologist I knew better

Then, of course I took a course in hydrogeology at Birmingham University and discovered why that was such a crazy idea. We don't need to burn fossil fuels to provide water because it is all around us. There is water in our rivers, streams, lakes, in rainfall and, most importantly, in the ground beneath our feet – right here, actually. If you drill down 30 or 40 metres you go into the chalk, which contains large reserves of potable ground water. Much of my career has been spent looking down holes like this, trying to catch the telltale glint of sunlight reflecting off the water table. I gradually came to appreciate that the ground is a kind of hydrogeological accumulator. It stores rainfall from times of excess in winter and spring when there is, quite frankly, more water than we can use, until times when we need it in droughts and the summer months, when we can pump it out of wells and put it into supply.

However, looking down that well there we can't always get at the ground water because it is too deep down. To be able to use it we need two things. One of them is obvious.

### We need –

We need a hole. We need a well, a borehole or even a horizontal opening like a tunnel or an adit. Even that is not enough; we need a device to lift the water from deep down in the water table up to a header tank or a water tower, from which it can be distributed. That device is, of course, a pump. A water pump simply employs a mechanical work input to move water up the gravitational or pressure energy gradient from a low pit to a high head.

[*Photos*] Here is one type of pump where the work input is manual and here's one where electrical energy is the input that does the work.

### Space heating is also a fundamental human need

The last 10 years of my career I spent trying to satisfy another fundamental human need – the need for space heating. Strangely, for hundreds of years we have used exactly the same cunning and subtle plan to provide space heating – we've burned hydrocarbons to produce heat. Nobody reacts to that being crazy, because we are all so used to it. But it is crazy because natural gas is a very high exergy fossil fuel that is better employed doing other things. It’s better employed doing mechanical work for one thing. Why burn fossil fuels to provide heat when there is heat all around us in the environment? There is heat in the air, in the sea, in our rivers, in our waste, in our sewage and, most importantly, in the ground and we call that ground source heat, which is simply environmental heat at the natural ambient temperature. In Britain that may be 10, 12 or 13 degrees Centigrade.

### As a thermogeologist I know that the earth is just a great big storage heater

As well as being a hydrogeologist I have now decided to call myself a thermogeologist, because I now understand that the earth is just one great big storage heater. A domestic storage heater is a box of aluminosilicate ceramics, popularly known as bricks,  which store heat from times of excess energy in the night time when electricity is cheap, build up a store of heat in those bricks, and release it during the day when there is a demand. The earth functions in exactly the same way. It is a big chunk of aluminosilicate minerals that stores heat from times of surplus, for example, the summer when the ground absorbs solar radiation or waste heat from cooling of buildings, and releases it at times of heat deficit in the winter when we have a demand for space heating.

### The ground is just a thermogeological accumulator

Just like ground water, in order to get at this thermogeological resource, this ground source heat, we need two things. We need a hole in the ground into which we can insert a heat exchanger. There is a hole in the ground with a heat exchanger – a very simple one. We can put it in a borehole as is the case there or simply in a trench if we’ve got lots of land. Of course the temperature of the heat in the ground is too low to use it directly for space heating in most circumstances. The ground is at 10 degrees Centigrade and our buildings are typically at 20 degrees Centigrade and we all know that heat doesn’t flow from a low temperature to a high temperature, unless of course we can think of some kind of device that can transfer heat up the temperature gradient. That device does exist, as I am sure you all know as engineers, and it’s called a heat pump. We need those two things. This is a heat pump; it is a humming white box that sits in the corner of a room and transfers heat from a low temperature environment to a high temperature one.

### The Compression Expansion Cycle

It works, as I’m sure you all realise, on a compression expansion cycle of refrigerants. There are other types, but the most common type works in this manner. One side of the heat pump is coupled to the ground in some way via a heat exchanger. There are a number of different ways of doing this, but this is a popular one. Heat is sucked out of the ground at, maybe, 10 degrees Centigrade and delivered as space heating on the other side. However, it isn’t a free ride. To get this to work we need an input of energy to drive a compressor and usually that energy input is electricity. It turns out that to heat a small domestic house for example we may only need to use 1.5 KW of electrical input and that could be sufficient to suck 4.5 KW of ground source heat out of our borehole. The energy, ideally, is conserved and we deliver 4.5 KW plus 1.5 KW, equalling 6 KW of useable space heating to our house. For 1.5 KW of electrical energy in we get 6 KW of heat out. It sounds too good to be true, but that’s the great attraction of ground source heat pumps. If we compare ground source heat pumps with an electrical bar oven, for example, we reduce our costs by a factor of four approximately and we reduce our carbon emissions by a factor of four, compared with electricity.

### Types of ground source heat: open loop systems

How do we couple the ground up to our heat pump? Again, there are a number of ways of doing it and we tend to subdivide them into two main categories. The first is an open loop system where we have a water well from which we suck warm ground water at 10, 12 or 13 degrees Centigrade. The ground water is pumped up to the surface, goes into the evaporator of the heat pump, heat is sucked out of the ground water flow, delivered as space heating and we are left with a stream of cold ground water to dispose of.

### And what does it look like?

This is what it looks like and this is the great trouble with ground source heat; it doesn't advertise itself very well because, frankly, there's nothing very much to see. There's a white box – this one is really exciting because it's blue – and that is an 80 KW heat pump at the Ecocentre on the south bank of the Tyne in Jarrow. It's sourced by a water well drilled into the coal measure sandstones 60 metres deep. I don't know how much water it pumps, but I'm guessing 2-3 litres a second – 3 litres a second maybe. The heat pump takes the heat out of that ground water, delivers it as underfloor heating to the Ecocentre and the cold stream of ground water goes out into the Tyne.

### Types of Ground Source Heat: Closed Loop Systems

Of course, to use that type of system, you need to be sitting on a ground water reservoir, an aquifer, a body of rock that stores and transmits ground water. That is not the case everywhere in Britain, but fortunately there is another type of system called a closed loop system that works almost anywhere, irrespective of geology. With this type of system we aren't actually sucking any ground water out of the ground at all. We are simply circulating water through a closed heat exchange pipe, so we send cold water down our borehole, it absorbs heat from the ground, becomes a little bit warmer, goes back up to the surface into the heat pump. The heat pump sucks the heat out and we're left with a cold water flow going down the borehole again to suck out a new load of heat. The collector pipe is usually high density polyethylene and although I described the fluid in the pipe as water, normally we add a little bit of antifreeze to stop it freezing. That antifreeze can be a solution of glycol, alcohol or different salts.

### Closed Loop Systems

The way in which the heat exchanger is installed in the ground can take many forms. If we are lucky enough to have a really big garden or a paddock, we can simply install the heat exchanger in a series of trenches. Again, we are typically using 20-40 metre polyethylene pipe buried at somewhere between 1.2 and 1.5 metres depth. The moister and more compact the soil is, typically the better. We can lay the pipes either as coiled "slinkies", as simple straight pipes or in different geometric configurations. There are a number of ways of doing it.
[*Photo*]

Here is one example of quite a large scheme, which is run off heat exchangers buried as "slinkies" within trenches. This is a building called the Green House, a new development at Anfield Plain in County Durham and that is an 80 KW system.

### Closed loop systems – pond loops

If we are fortunate enough to have not just a paddock, but a pond or lake in our back garden, we can simply bung the heat exchange coils in there. If it is an existing lake they can be floated out in a raft, filled with our antifreeze and sunk to the bottom of the lake. Of course if we are building the pond as a feature from scratch, they can be installed on weighted anchors on or below the base of the pond. Here is a 60 KW reversible scheme just being installed.

### Closed loop systems – vertical boreholes

If we're normal folk who don't have a paddock or an ornamental lake, the only way to go is down and we can install a heat exchanger in a borehole. There is a typical heat exchange pipe, a U-tube installed in a series of Jurassic clays, with no aquifer in sight, we don't need one. Here is a rather messy photo of a U-tube being installed down a borehole. For some reason boreholes are often around 100 metres deep. There's no reason for that at all. It simply seems to be a habit that drillers have fallen into in Britain. They feel confident down to depths of around 100 metres and the pipe is typically 32 mm or 40 mm OD high density polyethylene.

### Britain was a pioneer in ground source heat and pump technologies

The title of this talk was Ground Source Heating and Cooling in the UK and all of this has been rather general stuff, so let's have a look at Britain's role in ground source heat pump technology. If we go back far enough we find that Britain and Ireland were heavily involved in the development of this technology. If we go back to 1929 we find Mr Richard Trevithick and there is a certain amount of evidence to suggest that he toyed with the idea of steam powered heat pumps for maritime refrigeration that year. The first compression expansion heat pump was built in London by John Hague and Jacob Perkins in 1834. Thermogeological hero, William Thomson, or Lord Kelvin, who was actually born in Northern Ireland, although most people think of him as Scottish, was the first person to propose using a heat pump for space heating rather than refrigeration. He proposed it in the context of providing heating to Queen's University Belfast in 1852. Of course he was very involved in measuring the thermal parameters of the earth to try to measure its rate of cooling and, thus, its age, so I think that he can lay claim to being the first hydrogeologist. The Scotsman, Horatio Scott Carslaw devised many of the fundamental mathematical solutions that are now used to solve heat transfer problems in ground source heat pump technology. Mr Haldane built some small experimental heat pumps in Scotland in the 1920s. He didn't actually use the ground as a source; he found a much cheaper source. He simply sucked heat out of mains water being supplied to his house. That's an interesting one. Then of course another big hero was John Sumner who built probably the first full scale ground source heat pump systems in the UK in the 1940s and 1950s, being funded in part by Lord Nuffield.

### 1945: John Sumner – River Wensum, Norwich

Here is one of his first systems, which was a large operational heat pump system heating a building in Norwich and taking heat out of the river Wensum. If you ask me where the heat pump is and you are looking for a little white box in the corner somewhere, you will be looking a long time because that room is the heat pump. Rumour has it that some of the parts from that were war salvage and that there are bits of German U-boat stuck in there somewhere, but it worked apparently quite well.

He published a very good paper on that subject and gave to the Institution of Mechanical Engineers in 1946-7, which is well worth digging out.

## The Oil Crisis in the 1970s stimulated renewed interest in North America and Mainland Europe

It took the oil crisis in the 1970s to stimulate serious interest in ground source heat pumps in North America and mainland Europe. Sweden was one of the first European countries off the mark. Between 1980 and 1986 they installed around 50,000 ground source heat pumps, apparently with a total output of half a gigawatt. In the 1990s, 30,000 ground source heat pumps were going in every year in Canada and in 1996, 50,000 a year in the There is an incredible statistic, which I've tried to verify several times and my Swedish colleagues assure me that it is approximately true. In 2002 apparently 90% of new homes had some form of space heating via a heat pump, of which three quarters were ground source heat pumps. I've put question marks after it because I can't quite believe it. I am assured it's true. How many are there in the world today? In 2002 there were probably between half a million and one million ground source heat pumps systems installed and almost certainly more today of course. That is difficult to verify, so those are guestimates. With a total installed ground source heat pump capacity in 2002 of probably over 10 gigawatts and over 50% of that capacity is in the USA, which says something about the economic viability under the right circumstances of ground source heat pump schemes.

## Meanwhile, back in Blighty

Back in Britain, a survey in 1999 by Rosemary Rawlings and Sykulski was able to find 10 ground source heat pump systems. There may have been more, but that was all they could find and document. It was very definitely an alternative technology, not mainstream. There is a very lucid article in this magazine called *Undercurrents* where it is ranked along sci-fi, home grown food and this kind of stuff. There is nothing wrong with that, but it was definitely not regarded as of mainstream interest. The market really took off in, I would guess, 2000 and 2001. In 2001 there were 150 ground source heat pumps going in each year and the market was growing at over 100% a year. Currently, how many ground source heat pump systems are there in the UK? Nobody knows because, rather surprisingly, there is no register of them. There is no obligation to report them or get permission to install them from anybody. My best guess is probably around 6,000, but that really is a guess.

## Challenge 1 - thermogeology

I have listed three challenges for the future. The first is to place thermogeology on a sound scientific footing. The ground is not a black hole from which infinite amounts of water and heat can be extracted. It has both a heat and a water budget and we can draw it up in simple terms. Let's take a block of earth that stores and transmits heat. If we were talking about a block of earth that stores and transmits water we would call it an aquifer, so let's call this block of heat storage medium an "aestifer" from the Latin "aestus" and "ferre". It will have an influx of thermal heat from below – a few tens of milliwatts per square metre, almost nothing; it will have an influx of solar and atmospheric energy from the surface. There are lots of very complicated heat transfer processes going on up there, but it may be several tens of watts/$m^2$, much larger than the geothermal heat flux. There will be a flux of ground water going through our block of rock, which will also have a cargo of heat that we have to think about. Then, of course, we come along and start drilling and taking out ground source heat, which is another element of the heat budget. In very broad terms, if we take out more heat than is going in, the ground will cool down. Hopefully at some point it will establish a new equilibrium with the surface and ground water heat transfer processes, but at a lower temperature.

Interestingly, we can also use heat pumps in reverse to take heat out of buildings in the summer and dump it into the ground – yet another element in the heat transfer budget. Of course, if we put more heat into the ground than is going out, the ground will warm up and, if it is designed correctly, hopefully it will establish itself at a new equilibrium at a higher temperature.

How do we do all of this? Of course it gets mathematical, but fortunately the maths have been known for decades, the fundamental equations you are all familiar with. There is Fourier's Law, which describes heat conduction. It is very simple and has been known for donkeys' years. Heat transfer with water flux, advectional heat transfer, is also a very simple equation. Radial heat flow towards a well, developed by Carslaw and Ingersoll, is a more complex equation because it's got an infinite polynomial expansion in it, but you are engineers and you can deal with that. The tools are there to solve all these problems, but we don't necessarily tend to think in terms of that scientific framework when we design ground source heat pump systems.

## Challenge 2 – Interdisciplinary Respect

The second challenge is interdisciplinary respect. I'm a geologist, many of you are engineers and we all know that traditionally we hate each other, but to get a ground source heat pump system to work, we actually need to co-operate. I'm going to grit my teeth here and say that actually to design a ground source heat pump scheme we need at least one engineer and probably more. We need building services and HVAC engineers, electrical engineers and, increasingly I am coming to realise, we actually need hydraulic engineers to design efficient flow for all these loops we are putting through the ground. You do need a geologist; in fact in many cases for large projects you probably need a sympathetic architect and you need a competent driller and installer who understands the scenario. No one skill is sufficient, at least for large schemes.

## Challenge 3 – Imagination (1)

The third challenge is imagination. We are in a strange situation where we have hundreds of thousands or maybe millions living in so called fuel poverty in Britain and yet in the centre of London and our other big cities, the big problem is businesses trying to get rid of waste heat. They've got nowhere to dump it – the London Underground, big hotels and big offices want to get rid of waste heat. That is crazy. The heat shouldn't be waste; it should be a resource, provided we can store that surplus heat from summer to winter, when we can use it, or provided we can transfer that heat from loads of surplus, i.e. the London Underground, big hotels and offices, to points where it can actually be used, maybe out in the suburbs in domestic properties. Fortunately the ground can provide both storage and transport of heat.

## Challenge 3 – Imagination (2)

Here's a little ground source heat pump scenario. Let's say we've got a big office block sitting on top of this ground, with a heat pump. In the summer it will be taking cold ground water out of an aquifer in the London chalk and dumping waste heat to it, reinjecting that heat back into the ground, creating an area of warm rock around the reinjection site. Come the winter, the building can simply reverse the polarity of the wells and start pumping pre-warmed ground water out of this well, putting it through the heat pump and providing heat to the building, then dumping chilled water back into the other well. Come the next summer, reverse the polarities again and you pump out pre-chilled water for cooling and so on. The ground can act as a store, a thermogeological accumulator.

### Challenge 3 – Imagination (3)

What about the geographic problem, the fact that the buildings that generate waste heat – the hotels, big offices and so on – are all in the centre of cities whereas the residential properties that need that heat tend to be out in the suburbs? How do we solve that problem? We are thinking real blue sky here. Maybe we should reject the idea of such a strict zoning of different types of property. Maybe we should get used to the fact that residential areas ought to be in closer proximity to commercial zones and linked by heat distribution networks, so that waste heat from the big buildings can be used by the smaller buildings. Maybe we could even use existing infrastructure to transfer waste heat from large buildings with a cooling demand in the city centre out towards residential areas. Could we actually use water mains to do that? That's existing infrastructure and anything that transmits fluid can also be used to transmit heat. I don't think the water companies are going to like that, but why not? Or even sewage mains?

### Regional groundwater flow

Could we even use natural groundwater flow to transfer heat from nodes of heat surplus in the city centre to nodes of heat demand in the suburbs? Let's say we have an aquifer, looking in plan, with a regional groundwater flow from west to east. Let's say we have a suburb of residential properties with a heating demand out in the east and a city centre with lots of big buildings with a cooling demand and a need to get rid of waste heat in the city centre. If they reinject the heat into the ground, they create a plume of warm groundwater that, over the years, will migrate down gradients and eventually you will have warm ground water beneath the suburbs from which the heat can be extracted.

### Challenges: Imagination

Finally, let's be more imaginative about some of the pollution that we have to deal with in Britain. I don't know if any of you recognise this, but this is a coal mine water treatment plant. Down here, of course, it's not a big problem, but up in the east Midlands and the north east where David and I come from, it is a big challenge. When the coal mines were abandoned they flooded, filled with water and started to overflow at the surface, leaching out iron, manganese, sulphates and stuff into surface water courses. As a consequence, the coal authority based in Mansfield has had to take ownership of all those polluted coal mine discharges and treat them. Currently they are treating about 3000 litres a second of polluted orange water from abandoned coal mines. Some of this water is quite warm; it's coming from depths of several hundred metres and it's a heat resource. If you really wanted to, you could take tens of megawatts of heat from that 3,000 litres of polluted water, provided that there is a demand for it in the area. Of course many of the old colliery sites are being redeveloped as commercial and industrial parks. So the final challenge is to change orange mine water into green renewable energy.

A technology that started off to some extent in Britain and Ireland was commandeered by continental Europe, but I hope that we are beginning to reclaim some of that technology and use it for our benefit here in Britain.

Thank you.

**Nick Jenkins**: Do we have one or two contributions in respect to David's talk please?

**Bob Pine**: That was a very good talk; I enjoyed it very much. The last time I looked at my utility bills, the cost of electricity was something like three times per kilowatt hour the cost of per kilowatt hour of gas, so the cost of the pumping starts to look significant. I am guessing that the big uptake in Sweden of ground source heat pumps is probably because they have hydroelectric power as their main source of electrical energy and are not burning fossil fuels. I could be wrong there. I am interested also in the source of electrical power in the USA where, as you pointed out, they have a lot of ground source heat pumps. Theirs is a hard-nosed economic system; what is the storyline there on the source of energy for the pumping?

**David Banks**: You are absolutely correct. I haven't touched on the economics of this, but I did foresee your question so I brought along this slide, which compares the prices of common heating fuels based on the standard assessment procedure from 2005, so these prices are quite out of date. You are absolutely right that the standard price for electricity is around three or even four – according to that – the cost of mains gas. For running heat pumps off electricity, where is the benefit? If we use a heat pump with a coefficient performance of four, we cut the cost of the electricity by four, so we come down to a cost that, using standard electricity tariffs, is comparable to mains gas. However, we have also cut the carbon dioxide emission by a factor of 50%. Of course we all know that there is any number of tariffs for electricity and if you can somehow get a cheap electricity tariff, that figure becomes a lot more favourable. I would agree with you that the savings compared with mains gas are quite small year on year. On a residential scale, if you are competing against mains gas, I struggle to put my hand on my heart and make the argument to a householder that a ground source heat pump will save them money. I am not sure that is actually true. However, there is a scale factor and the cost of installing the heat pumps, boreholes and so on per installed kilowatt decreases the larger the scale of the project. With large scale school, hospital and university projects for instance, you are much more likely to get a realistic pay back period. On a small residential scale, if you are competing against mains gas, it's a bit dodgy.

Sweden's source of electricity, last time I looked, which was admittedly quite a long time ago, was, as you said, imported hydroelectric from Norway, their own hydroelectric and nuclear. They had a very strong motivation, not having their own fossil fuels, to go for ground source heat.

In the States there is probably a complex mix of power; I don't know about that. Somebody here may know. It is also true that in the States you don't have such a dense population with a mains gas network that stretches everywhere. Also a lot of properties are much more used to using heat pumps for cooling as well as heating, which is an extra incentive to save costs.

**John Garnish**: Thank you, David. I wanted to add that it's not purely that cost comparison. I can't remember the details, but there is certainly one example in the States of a big US army base with, I think, 4,000 houses, where they put in a large ground source heat pump system. They reckon that paid for itself in reduced maintenance costs alone within two or three years, even without worrying about the running costs, so that is another parameter.

**Robin Curtis**: The usual comprehensive coverage there, David – very good. I have a couple of contributions and comments. The largest uptake in social housing in the UK is in the off gas areas where we are addressing affordable warmth and fuel poverty. That is where we are not competing against mains gas. It is a difficult challenge to deliver affordable warmth off the mains gas grid in the UK now. There is actually legislation compelling the RSLs to deliver. They are between a rock and a hard place.

Your blue sky stuff is not so blue skies. Your water mains distribution system is actually used in New York these days. People thought it was blue skies and it was done on a very small scale, then a major utility took it up in New York. You asked why the US became such a large user. This was because of something we haven’t even started to think about in the UK. Mainland Europe has, but demand side management; the big uptake of ground source heat pumps in the US was by the rural electric co-operatives to reduce their peak demands. They were then effectively subsidising the installations to get their peak demands down. We are not even beginning to start thinking about that. Europe is much better, but we are already in trouble here. We are trying to get the utilities to be able to turn the heat pumps off at peak times and we have utility barriers at this point.

Thank you very much.

**Nick Jenkins**: Thank you for that contribution. Let us move on swiftly in the interests of time. Our last paper is from Professor David Manning, another geologist. This seems to be an after tea geology session. He will talk to us about an experimental demonstration initiative that they took up in the north east on deep geothermal.

## Deep Geothermal in the UK

*Professor David Manning*

Thank you very much for this opportunity to speak. This is a bit of team work. I want to describe to you some work that has been done by me with Paul Younger, who wasn't able to come today – we are both from the University of Newcastle – along with Daniel Dufton from PB Power, which, of course, is Parsons Brinckerhoff, which Charles Parsons set up so long ago.

### Acknowledgements

We have taken advantage of an opportunity created by the demolition of this cement works in Weardale, which was taken over within the last few years by LaFarge. It was taken out of commission and is in the process of being demolished. That led to the loss of 300 jobs and the requirement for some kind of recompense for the community in the area. The Wear Valley Task Force has led the project for redeveloping this site. It is made up of Wear Valley District Council, which no longer exists with effect from 1 April this year, LaFarge – which of course does exist – and One North East, our regional development agency who have provided a lot of the funding for this. The purpose of the exercise has been to come up with a plan for a mixed use development at the site that will lead to employment, tourism and other activities, probably a bright hope, given the current economic crisis.

### UK Deep Geothermal Prospects

We have already talked about the deep geothermal prospects in the UK and I apologise for these slides duplicating some of the others that we saw earlier, which were more elegant. The key thing is that the survey work carried out in the UK has highlighted Weardale as well as Cornwall as being a location where there are things called hot rocks – high heat production granites. The available energy is 70 milliwatts/m$^2$ and this area with the granite has been shown to be the one to go for. We were in the middle of that area in terms of the physical location and available geology.

### Deep Geothermal Energy in the UK

Looking at geothermal energy history in the UK, we had the Cornish experiments that John Garnish has talked about and the geothermal aquifers in the Mesozoic basins. I want to spend a little bit of time talking about the Southampton experience.

### Reasons to be cheerful about geothermal energy in the UK

We heard earlier a little bit about this, the point being that geothermal now actually only plays a minor part in that, but still has numerous benefits that will help us go forward in thinking about how the geothermal prospectus might pan out. We need to take into account the experience of the Southampton Geothermal Heating Company and consider the changing world climate, which is very different from what it was 20 years ago, not just in terms of CO$^2$ in the atmosphere, but in terms of our awareness of it and the political driving forces that you have heard about. We need to bear in mind technical innovations; heat pump technology and borehole heat exchangers have come on. Our perspective at Weardale has also changed. In the 1980s when I was working on these particular rocks it was to look at them from the point of view of the mineralisation and how that was brought into being. Now, of course, we can go back into it and have a look at how those same water circulation systems that gave us the mineral deposits with which we are familiar and for which the region is famous might be useful in hydrothermal.

### The Southampton Geothermal Heating Company

It is very interesting to visit Southampton and to find out about the Geothermal Company there. It is a combined heat and power system. You've got the CHP station at this point here; in the middle of the Toys R Us car park there is a borehole, which deprives the shoppers of two parking spaces, but the water goes into a combined heat and power system that furnishes water through the entire city with schools, hospitals, the civic centre, luxury flats, social housing and a huge shopping centre. It is run in a very ship shape way. The borehole is here in this car park; there are heat exchangers in the centre in a tiny building. The footprint of the building is remarkably small. For the housing where this has taken place, particularly the social housing, one of the advantages of the scheme is that you don't have a boiler. You simply have a set of valves and thermostats in each house, which, again, gives you a great reduction in the cost of maintenance. There is far less that someone can break here and far less in the way of hazards from moving gas around. The Southampton experience is important for us.

### Lessons from Southampton

The resources from geothermal inputs are really small now; they are less than 5% of the energy going round that system, but they reckon that they are saving 10,000 tonnes a year in carbon emissions from a few years ago now. More importantly, the benefit has been that the high visibility of geothermal energy there has made it much easier for energy savings measures to be introduced in Southampton. It is important to bear in mind that the benefits go far beyond the numerical benefit of energy and carbon saving costs. They have found from experience there that retrofitting has worked out well. It has often been cheaper than other alternatives and they reckon that the experience has given them something like £250,000 a year savings compared with fossil fuel sourced energy for the systems that are sourcing their energy from the city centre system. There are many lessons to be learned from Southampton that take us down the route of wanting to do much more with geothermal energy.

### The Eastgate Geothermal Exploration Project

Now I will move on to the Eastgate geothermal exploration project. This is an opportunity that we were brought into and an adventure in which we participated. All this has gone now.

### High temperature geothermal prospects in the North East

We were asked to explore this as a geothermal prospect. The reason is that the geothermal energy prospects in north east England are potentially more significant than might at first appear, as much as anything because we know a huge amount about the subsurface geology. We have a long record of mining. There is coal mining, lead, fluorspar and zinc mining in the north east, so in this area we know a lot about what is under the ground and that is useful.

### But what's so special about Tyneside and County Durham?

There is something special about Tyneside, which runs along here, and County Durham to the south of Tyneside. That is that there is a major fault that divides two geological areas. North of the fault there is a deep trough, as it is called; a sedimentary basin is filled with something like 4.5 kilometres of sedimentary rocks.

**Stublick – 90 Fm Fault System**

That behaves very differently from what is south of this Stublick 90 fathom fault system. South of the fault we have what are called basement rocks very close to the surface, the Weardale granite in particular. A number of investigations of coal mine waters throughout County Durham and into Tyneside have shown that it is easy to encounter mineralised waters in some of these mines at shallow depths of less than one kilometre. The chemistry of these waters indicates that they have equilibrated with basement rock at rather higher temperatures than are currently found. They are warm anyway, but the geochemistry tells you that they may have seen temperatures of as much as 120 degrees Centigrade at depth.

**Mine waters with chemistries indicative of highest temperatures**

This is British Geological Survey map overprinted with a number of sites where mine water chemistry is available, including Eastgate and a few in Northumberland. This is an example of how you can get an MSc student in a project to do something really simple and come up with some very good answers. I don’t think that Orla Fitzpatrick, who did this, has any idea how useful this map has been. It has enabled us to highlight wells, springs or coal mine waters that have a chemistry showing that they have that high temperature history. That gave us more confidence in looking at Eastgate.

**Cue the redevelopment project**

The closure of the Blue Circle Cement Works as it was – LaFarge is the owner at present and there is a history there, of course – means that there is a development plan for regeneration as a model renewable village. They want to make sure that this patch of land that supported the cement works is there with buildings and structures supported by renewable energy as far as possible. We have to remember that in this part of the world, the only energies available are fossil fuels, brought in by road. There is no gas mains supply here at all. We were looking at the geothermal prospect beneath the site and you have to remember as well that what we did was cheap and cheerful. We had less than £500,000 to spend and 90% of what we had went on the borehole, as you can imagine. This has been done at a tenth of the annual income available to Soultz and some of the other prospects and it was a one-off payment. You will have to forgive me that some of what I will be telling you about might be deemed to be a bit too cheap and cheerful and would not have happened in a properly funded exercise.

**The target: Slitt Vein (Cambokeels Mine)**

Our target was a Slitt Vein in the former Cambokeels Mine. The mineral vein has been taken out and this is a cross-section to the north of the site. The river Wear is here. In the 1980s I was lucky enough to go underground to some of these places, where I was showered by warm water. It was like taking a bath where the water was coming in to this mineral vein – okay, it was 16 degree Centigrade, but we like cold baths in the north.

### Slitt Vein, Cambokeels Mine

This was our target, with the warm water coming in, very highly mineralised. We published on that in the context of the mineral deposits and, importantly, this mineral vein goes through the land near the cement works.

### Slitt Vein at Eastgate

This is the projected line of the mineral vein, the cement works is up here and this is where we decided to put the borehole.

### Borehole concept

The concept for this was that the borehole would follow the mineral vein down. Mineral veins are not simple straightforward fractures; they have bits coming off them here and there and the idea was that we were going to set fractured ground all the way to the bottom of the borehole and use the mineral vein as a conduit that we would tap into.

### Prospecting programme

We did the desk study work, the shallow site investigations and went on to the deep drilling programme, which went down to the depth of 1 km. This was a drill that started off as a hammer, but a tri-cone roller, 8.5 inches at its final diameter, so it is a big hole, casing off through the Carboniferous sequence and into the Weardale granite. Our plan was to seal off all this part here at the top so that any water we were getting out was coming from the granite. Then we did the geophysical logging, pumping trials and we are still working on some of the results that came out.

### Shallow, inclined boreholes

Finding a mineral vein is not easy, so we had drillers to help us find it. It was only 8 metres wide – the width of this room – and someone had to decide where to put the pin for the big drilling rig to come in. The big drilling rig was furnished by Foraco, a French contractor; we centred it on the vein and started off at 17.5 inches diameter, going to 12.5 until it got into the granite, then once it was in the granite, 8.5 inches diameter.

### Deep exploration borehole

I want to talk about the groundwater, geothermal resource and pump test findings.

### Deep exploration borehole: water strikes and casing

Importantly, we had high rates of ground water coming in through the Carboniferous, so we had to case those off. We cased down to about 403 metres depth, where we were about 130 metres into the granite to get rid of all those shallow feeders. The prospect on the rig was that we were going to carry on and granite is a fairly dry hole. However, within 8 metres, at 411 metres, we hit a major fissure so that the drilling bit and all the drill string above it dropped half a metre, the pressure gauge jumped to 23 bars and then over 30 bars and went off the scale. This was the point at which the men started running away from the rig. Had we got a blow out? That is not something that you would expect in the granite, but certainly this was what was happening here. We hit a water strike that was giving us something like 60 cubic metres an hour – 1 cubic metre a minute – which is truly remarkable for a granite. As we progressed down, we hit other water bearing fractures.

### Deep exploration borehole: water quality

The chemistry of this water is consistent with a very deep origin, rich in calcium, nearly 10,000 mg/l sodium and nearly 30,000 mg/l chloride, so these are very salty waters, but they show it is not a polluted water of the type that David Banks was talking about earlier.

### Changes in conductivity and temperature of groundwater air lifted from borehole

As we go down, this is a change in the electrical conductivity of that water. This is where we hit the granite and that facture at 411 metres, very salty water and a temperature spike coming in there at 26 degrees. The water in the hole stayed at 26 to the bottom, which is reflecting mixing of water in the hole, rather than anything else.

### Where does all the heat come from?

This is our power station; this is the mineral biotite in the thin section about half a metre in length. There is the mineral reserve column, which has uranium and thorium in it, with radiation damage around it. It is a mini-nuclear power station that is giving us heat. That is the origin of the heat in granite of this type. We have to bear in mind that that is what is doing all the work by dispersing and giving us a substantial energy output aggregated.

### Geothermometric evaluation of water composition

This is the geothermometric evaluation of the water composition. We have used a number of geothermometers and these can be interpreted in different ways. The important thing is that in two places, the mine at Cambokeels and at Eastgate, we are getting more or less identical results. That told us that we had intercepted the right water system that was there in the mine and that I had encountered personally in the 1980s.

### Comparison with Southampton CHP

If we compare with Southampton, the Southampton CHP has a 2 km deep hole with a bottom hole temperature of 76 Centigrade. Our bottom temperature is 46 Centigrade, so if we had gone down two kilometres we would easily be at the Southampton 76-80 Centigrade. In terms of temperature the Eastgate prospect is on a par with Southampton. The yield we are getting is similar to the Southampton yield, so that is reassuring, but we are a lot less salty. The water has about one third of the salinity of Southampton. We cannot estimate what the power might be. There are 2 MW of thermal energy coming out of Southampton, but it all depends on the design, getting the engineers to do the calculations and the team that David mentioned pulling together a figure to replace that question mark. We can’t do that at this stage.

### Deep exploration borehole: Geothermal Findings – I

We’re very encouraged by all this and 46 Centigrade at a 1,000 metres is far greater than would be expected for the normal geothermal gradients in this country, which are around 25 degrees Centigrade per kilometre depth, so we have a high geothermal gradient that we can exploit, all being well.

### Deep exploration borehole: Geothermal Findings - II

We would like think about whether there could be another hole put down to nearly two kilometres depth, where the temperature would be around 78, but we have to have heat exchange of fresh water because this water is highly salty and will have to go back down in a closed loop system. We couldn't discharge this into the river Wear – we would be prosecuted straightaway for that – but, importantly, we have a very large volume at Eastgate and the rest water level in the borehole is only 14 metres below ground level, so the water is welled up. That means that the lifting costs are very low. Southampton has to lift its water from 150 metres depth. We think it has been a great success and has given us a resource that is different from what might normally be expected.

### Pump tests: with and without a packer to isolate the 411 metre fissure

When we moved in to do the pumping trials we had a concept like this where we'd got the water in the column and got it cased off, with the 411 metre fracture and a packer that we could put in to isolate that and pump from below it and above it, depending where we put the packer. That is the packer there and that piece of kit cost about £10,000 to build. It had to be built especially for the drillers. There is the well head and we had to get this down there, blow it up and the cost of the thing was such that the drillers didn't want to push it down there and possibly wreck it when they knew that there were fractures down there. We ran downhole cameras to see what would happen and let's see what that looked like. [*Showing clip.*] It's very dark down there. Can you see these fractures? This is an 8.5 diameter hole, so those fractures are a few centimetres. (I have two hours of riveting footage!) You are amongst a very small number of people who have actually seen what the Weardale granite looks like at depth. It is amazing to see how fractured it is from the point of view of how it might behave as a reservoir material. That is a real issue for us and it is something that opens up the door to a new type of geothermal prospect, looking at these granites that are highly fissured naturally. Of course, that is something that was not there in the original concept when we began the exercise.

### Results of Pump tests were remarkable

The pumping tests were quite remarkable. We have lost some data here, but the important thing about these graphs is how horizontal they are. Normally you would see the level of water and the ability to deliver water decreasing with time, but what we found was that the water level in the hole actually rose. We have a 1 km deep hole, thermal expansion in the hole and the water level actually rising, which is remarkable. Pumping at 37 $m^3$/hour gave us no effective draw down of any significance; in fact it was rising. At 22 $m^3$/hour, again we are keeping horizontal levels of water, so this is a truly remarkable source of water. In terms of yields of water, we are getting on for 1,000 $m^3$ a day for the entire hole.

### Pumping trial results were remarkable for a basement granite

There are very large values of permeability and transmissivity of the rock, which again was quite unexpected, although granites are known to be well fissured and this is something else that we have been able to document in this particular case.

## What can be done with this resource?

What can be done with this resource? First, it would be possible to have a Southampton style CHP system where there are a lot of other sources of energy coming into it as well. On the site they want to be able to have new and refurbished buildings, they want to have a spar to compete with Bath – and I want to be one of the first to jump in; they want a swimming pool, a leisure centre, a new school, housing, commercial premises, a railway station and a visitor centre – lots of different things. We are at a stage now where the outline planning is being looked at and the developers are looking at what might or might not be possible. What is unknown, of course, is the possibility of electricity generation for local use and that awaits technical developments. This all subject to what the planners and developers require for the site, so we still have a long way to go.

## For the future elsewhere in the North East?

If we think about the future in the north east of England, one of the things we want to bear in mind is that we are down here, but the geological structures we are after are heading in the same direction as this major fault up here. We are interested in having a look at the possibility of getting hold of geothermal energy somewhere in the city of Newcastle itself. Of all the urban centres that we have had described, this is one where we think the geology is actually very good from the point of view of looking for an urban geothermal resource. There will be others, but we know from the history of the mining activity in this area that there is scope for success.

Thank you.

**Nick Jenkins**: Thank you, David. Are there any comments or contributions on David's presentation before we move to our final discussion?

**Peter Ledingham (Operations Director, GeoScience Ltd)**: I didn't catch the scale on the figure you showed where you had the holes showing fluid samples that had been at 120 Centigrade. How far away from that was your borehole drill?

**David Manning**: About 100 metres.

**Peter Ledingham**: What is your interpretation of what's going on with those fluids that have evidently been much hotter than they are now and were much hotter than any of the fluids you encountered in the hole?

**David Manning**: the Slitt Vein is the largest mineral vein in the north Pennines. The working hypothesis for the conceptual model is that that vein penetrates down to maybe 5 km depth or more, given that it is about 20 km longer, if not longer. Thinking about the aspect ratio of faults and veins, that would take it down to that sort of depth. However, the pathway by which that water has risen is another matter and, indeed, one of the things to bear in mind is that the fissuring shown in the downhole TV show is not really related to that mineral vein. That's fissuring related to weathering and the original weathering that happened before the granite was buried under the Carboniferous sediment, so there is actually a lot of horizontal water movement going on there. It is actually a much more complicated system than I have made out in the talk, but we haven't been able to develop that in the sense of doing the work required to define what the shape and geometry of that flow system is. That still needs to be done.

**Peter Ledingham**: But if you were trying to drill a deeper well into a resource, would you that as target?

**David Manning**: Yes.

**Charles Jones (Principal Hydrogeologist, Mott MacDonald Ltd)**: With that very fissured system in separate layers, were you conscious, having done the logging, that there might be some sort of natural circulation system pre-existing, which, by putting the borehole down, you have actually interrupted quite a lot?

**David Manning**: That is an interesting question. It is very much a stratified system and the water chemistry does change systematically as you go down the hole. The water in the granite is different from that in the overlying sedimentary rocks. We believe that there is little connection between those water systems. Indeed the sequence of the Carboniferous rocks there is a mudstone dominated system, so most of the movement of water is horizontal in aquifers within the limestones in particular and in the dolerite of the Whin Sill, which is equally fissured. We see lateral movement and quite discreet step changes in the chemistry as we go through each aquifer as we go down the hole.

Within the granite itself I don’t know what scope there is for us to have made a difference to the groundwater system through our own well, given that the response to the pumping test was so little. If we had seen a major response to the pumping test we would have then perhaps seen evidence of water being drawn in from different levels, but we see consistency and constancy of chemical composition during the 24 hour pumping test. I think that on the evidence we’ve got there is relatively little to say that we had disturbed what was down there. I’m quite sure we disturbed things down there in other ways though.

**Theresa Cory (Technical officer, Ground Water and Contaminated Land, Environment Agency)**: I’m from the Environment Agency and we liked your comment about not putting hot water back into the river. Thanks for that! What do you propose to do with the warmed up water and what do you think the loss will be for the amount of water that you are using? Are you hoping to have a non-consumptive process?

**David Manning**: The ideal solution is to make sure that everything we take out is injected back into the granite underneath. That is very much driven by the chemistry of the water, not just the heat of the water. We definitely want to make sure that that is controlled and disposed of – if that is the right way of describing it – by being put back and used as part of a recirculating fluid. The ultimate design of that remains to be seen.

**Nick Jenkins**: Thank you very much, David. We will bring that to a close now.

## Discussion

**Nick Jenkins**: I would like to move on now and we will be bringing the meeting to a close at 5.30. Can I invite all the speakers to come and join me and I hope that we can have 25 minutes of useful dialogue.

The ambitions of the Academy are to see where what we have heard so far fits in to the challenges that the UK faces in terms of energy. That is my ambition for the next 25 minutes, but I throw it open to you for any contributions. Otherwise we will go through the Academy's agenda.

**Sreebhusan Ghosh (Principal Policy Advisor, AT Consultancy)**: I wish to put a broad question. I am a civil engineer, but in the view of the panel is it better to invest in geothermal energy than wind power, which seems to stay still when it is most needed.

**Nick Jenkins**: I think the question was, is it better to invest in geothermal energy than wind farms. We will certainly take your question sir, but I think that our general policy is "and" rather than "or". However, in the interests of debate, let us take the "or" question.

**Ernst Huenges**: I will answer with an example. I have been to the United Arabian Emirates and the people there told me they don't want to have wind in their country and are starting to think about geothermal. The answer is that it depends on the site and the frame conditions. There are sometimes frame conditions that are favourable for geothermal, but usually, if you look at the development of wind from less than 1 GB to now in the order of 12-14 GB, as installed in Germany, it would have been a good thing to invest in wind five years ago. Now it is separated into onshore and offshore and the market will go offshore, but there are a lot of problems to be solved. The problems are similar to those to be solved for the EGS challenges. In future these will be equal. But, yes, invest in geothermal, of course.

**Sreebhusan Ghosh**: The reason I ask is that last February we had snow fall and the amount of power from wind was virtually nil, because all the wind turbines became still. On the other hand I see the potential of geothermal energy as a base load station equivalent, available throughout the period, whereas wind power only seems to be available at the whims of nature.

**John Costyne (Renewable Financial Incentives, Department of Energy and Climate Change)**: I am working on developing the renewable heat incentives. I hope that won't make me too popular at drinks time! The question of the ground as a heat reservoir with heat going in and out is obviously a useful one. How close are we to any particular limit there might be? If we were to incentivise, for example, all of the major detached houses in the outskirts of London and all of the business parks and things like that to put in ground source heat pumps, how close would we be getting to the limits that the ground could deliver to heat those buildings?

A related question is that if you can get coefficient of performance of four or so from the ground as it is, how much better would performance be if you could ship out some of the waste heat from the centre of the city? Would you be able to get order of magnitude changes, or is it really not worth the effort if you can already get a COP of four?

**David Banks**: The first part of the question was related to the overall density of ground source heat pump schemes you can install. Clearly there is a limit, but we are nowhere near approaching it yet. All I can do is to offer you some rough figures. If you have two boreholes that are adjacent to each other, both taking out heat, you probably won't get too much interference between those two boreholes if they are 15-20 metres apart. If they are closer than that, they will eventually begin to interfere with each other. That doesn't mean they are going to fall over or fail overnight, but over the long term you may see a decline in performance. If you are talking about overall heat densities, which I am a little bit reluctant to do, taking 10 watts/$m^2$ as a sustainable heat extraction density I think that the Germans have done quite a bit of work on this and come up with some guidelines. There are some ballpark figures out there, but, of course, as soon as you start putting heat back in the ground – waste heat from buildings – and re-extracting it in winter, you are automatically forcing the replenishment of the reservoir and you can get away with a much greater heat extraction and rejection density.

The second part of the question was on the coefficient of performance. I took 4 as a figure because the maths are easy to do with that. It could be anything between 3 and 4.5. the coefficient of performance improves, the hotter the source is. For some of my crazy ideas about thinking long term and trying to develop some of our aquifers as geothermal resources and encouraging the migration of heat with ground water flow, you are probably only talking about a temperature change of 1 or 2 degrees at the centre of a heat plume in groundwater. For a single property you probably wouldn't notice the difference in terms of the coefficient of performance to brutally honest, but given enough people using that heat plume, maybe it would add up to something significant. This is just something I've thought of while having a bath and I haven't sat down and worked out how feasible it is. I developed that idea to try to counter some trains of thought within the Environment Agency. I have encountered the opinion that any discharge of heat to an aquifer is pollution. I developed that little slide to try to turn that on its head and show that there is another way of looking at it. We can regard disposal of heat to an aquifer as creation of a new resource, if we use it again. Putting waste water into a river or aquifer isn't automatically pollution. It depends on how it will be used downstream. It can be a resource as well.

**Brian Simpson (Director, Arup Geotechnics)**: If we put together the picture we have heard this afternoon, the systems are currently contributing a tiny amount of our energy resource in heat or electricity and are more expensive than fossil fuel alternatives at present. If the price of fossil fuel rises, they become more competitive and we are able to use the different systems we have heard about. The price could rise because we run out of oil or because politicians take the hard decision of making it rise through taxation or whatever. Is there a clear view as to how much the price would need to rise for the systems we have to become competitive and then how much energy they could provide? What a politician would need to know, I suppose, is if the price of fossil fuel is forced upwards, can we replace it and how much of that energy resource can we replace by the systems we are talking about here?

**Ernst Huenges**: I can tell you a story. We had a drilling project of a 4-5 km well just at the time when the oil price rose from 20 to 150. I got some money to have a deep well and during this time the cost for drilling rose in the same order; for us it was a factor of three in 2005/2006 compared with 2002. That means that the whole system is scuppered. A rise in oil price leads to much more exploitation in hydrocarbon and to higher prices for services. This coupling is bad news. The good news is that in Germany people have started to develop new drilling rigs for geothermal applications. That means there is something going against this trend and now we have several drill rigs available for geothermal work and the price for drilling has decreased. For the long term perspective it will become compatible, but in the short term view it is complicated and not very clear. In the long term of course the market will regulate itself.

**John Garnish**: I'd like to add a couple of things to that. There is no one answer to that question. It will be country specific if not site specific. There are countries in the world where geothermal is already a commercially competitive proposition – in New Zealand, for example, 11% of electricity is geothermal. France is a good example if you are trying to look at the possibilities in the UK. Over 40 district heating schemes were built in the Paris basin in the 1970s and early 1980s. It fell out of favour because Paris suddenly got cheap natural gas and expensive interest rates. One of the problems with geothermal is high upfront costs. Now that natural gas has become more expensive and interest rates have gone down, they are building geothermal schemes again.

Ernst mentioned the problem of drilling rigs. Drilling is about half the capital cost of a geothermal scheme, so you are very dependent on the demand for rigs at any given time. That, in turn, depends on the oil price.

**David Kenning (Visiting Professor, Brunel University, School of Engineering and Design)**: First, I'd like to say thank you very much to all the speakers for being very educational, which I needed, because I don't know anything about geology. My background is in heat transfer. If I ask a silly question now, I'll blame the educators! One of the things that struck me was the emphasis in this morning's talks on developing huge areas for heat transfer and then this afternoon when David Banks was describing his system we had what looked like to me an incredibly inefficient heat exchanger with very little surface area that wouldn't work well if it depended only on conduction in the soil around it. However, there has been great emphasis this afternoon on ground water movement, which I suspect is the key to a lot of this. This relates to some of the things that have been said before. The other impression I have gathered is that in the UK there seems to be a limited number of sites on which we might have large scale applications, so does the future lie with the very small scale multiple applications that Dr Banks was talking about?

If you do that, the question of interference between installations starts to become important. I wonder to what extent at the moment we have the sort of information about groundwater movement at small depths below the surface where there is likely to be interference from foundations, buildings, underground tunnels and the rest. This seems to be an important question if we are to move towards having large numbers of small scale installations.

**Nick Jenkins**: Who would like to take that? If I could re-interpret it, do we see the future for the UK – which we all know is extremely challenging in the energy domain – as being large scale or small scale or both? How do we move the UK forward using this technology.

**David Banks**: I will pass on the first part of the question because for me the future is inscrutable. To the more concrete second part about interference between systems, I am guessing that your comment applies particularly to those systems that are installed in aquifers and particularly to open loop systems, where you are directly recharging warm or chilled water. Clearly in that case there is a potential for a plume of warm or cold water to migrate away from the reinjection point down gradient and affect another heat pump scheme. Of course that effect can be positive or it can be negative, depending on whether the down gradient scheme is doing heating or cooling. It is not necessarily a problem; it could actually also be a benefit.

As to how much we know about ground water flow in Britain and in Britain's main aquifers, the answer is actually quite a lot. We have at least a couple of people here from the Environment Agency who will be familiar with the maps of groundwater levels that have been compiled for the chalk beneath London, for example, on the basis of thousands of well records. If you look at a map of the wells drilled in central London, it looks like a Swiss cheese, there is so much information there. We have a lot of information about how ground water moves in the main UK aquifers and we also have the numerical modelling tools to simulate heat transport in those aquifers. I think that the Environment Agency has reached the stage where they are beginning to think seriously about policies for regulating some of the larger, potentially more problematic ground source heat schemes. I don't think that the small scale residential ones are a problem, but in some of the large ones, when you get up to tens or hundreds of kilowatts you can imagine scenarios where there could be interference between schemes and other aquifer users.

**David Manning**: Could I say a few words about the deep geothermal prospects; one of the points that needs to be made there is that they are extremely expensive in terms of the investment that is required to carry out what is an exploration process, let along a production process. The hole we put down in Weardale was clearly exploration and probably another hole will need to be put down to turn it into a production well. We would never get that done within the budgets that we were given to start with. The experience of the exercise shows that much more money will be required to make it work. Incentives will be needed and we heard some talk about that from Dr Feliks in the first presentation. One of the key issues that needs to be addressed is who owns those resources in the sense that if you are looking at a major exploration project for thermal energy that will cost many millions of pounds, you want to know that you have the sole right to extract that energy for whatever purpose. You don't want to have someone coming along in a field a few kilometres away and drilling into the same aquifer and heat source, so there is a risk associated with that. There are possibly ways around that, but within current legislation it is not readily obvious how it can be done. It will be interesting to see what incentives come out of the Government as a consequence of the deliberations that are going on this year.

Looking at the Southampton experience as a case study of something that has worked rather well and at the way a number of cities are considering their energy balance internally – and the city of Newcastle is one that wants to become a carbon neutral city in the future, an aspiration that may or may not be possible – it means that they are looking at combined heating systems that cover large districts within the city where, of course, we have major public bodies and institutions that interconnect one way or another. There is scope there for a structure to be exploited and used. In the context of that, what is needed is an opportunity to revisit the geothermal prospects as heat energy sources at depth, rather than as sources of electrical energy, which is what perhaps came into people's minds at first when we started in Weardale. The one thing we can say that we might have achieved in our Eastgate adventure is to be able say that there is heat down there and that it is worth thinking about some of the new exploration prospects and geological concepts that come out of that work to enable people to have confidence to plan to put holes down in other places.

**Ernst Huenges**: I would like to add that it is sometimes misunderstand that the former HDR research was focused on power provision, but the new thinking on any geothermal system must not have power as the end product, but also heat provision can be the purpose of this research. For the UK and for your geology, the future of deep geothermal is enhanced geothermal systems for heating purposes. The potential is huge and the technologies are close to being applied. This is for deep; of course for shallow systems, I agree that decentralised systems are okay. Heat storage and chill storage is also an option. We have done it in Germany for the houses of parliament very successfully. All the politicians are heated with geothermal heat and it’s not so bad for bringing this into society.

**John Garnish**: Just a comment. Ernst said that current thinking is looking at heat from EGS systems almost as an alternative to electricity for power generation. I have always taken a different view. If you are going deep enough to be able to generate electricity in these areas of northern Europe, the capital costs are such that you have to produce a lot of energy in order to pay it back. In Switzerland, which is probably more developed in that respect than anywhere else, there are only two district heating systems big enough to absorb the thermal energy from an EGS system. The problem is that while on paper you can sell lots of heat and make the project look very attractive, in practice there are not many sites in Europe where you can actually dispose of all that heat. I always take the line that you have to make the system pay from electricity sales and if you can sell some heat as well, that’s a bonus.

**Unidentified speaker**: I just wanted to come back to the competition that inevitably comes up with wind power and the negatives of wind power are never adequately covered. The aesthetics are the first, but the main one is load factor. You have to have 100% back up for any wind power system with some conventional power generation because the wind is rarely convenient. Tidal power is similar.

**Nick Jenkins**: In the four minutes remaining, discussing the intermittency question is probably not a good use of time.

**Duncan Nicholson (Director, Arup Geotechnics)**: Looking at the map of contours of ground temperature, it seemed that Cornwall had a dark colour, indicating a high potential for geothermal. I didn’t quite see the contouring. How does that compare with, say, the systems that are working in the Germany in terms of the intensity of the contours or type of heat in the granites in Cornwall? I was trying to make a comparison between different plants in northern Europe. There seems to be quite a lot of money tied up in the boreholes; I would be interested in the cost of drilling a borehole from the experience in Germany. Also it seems to me that the technology relies quite a lot on not getting down there and finding a dry hole. It seems to me you need to be able to fracture it, you need to be able to make sure that you don’t get one fracture that does all the work and make sure that you have control of that technology. I guess that is all a function of in situ stresses in the ground and how that works.

**Nick Jenkins**: Could we pick something from that smorgasbord and respond to it briefly because we must let Ernst get off for his plane?

**Ernst Huenges**: Just to say how far we are with these simulation techniques, which are applied in several locations also in Germany. Based on what John told us from his understanding of the rock mechanics and the geology, with the simulation techniques we are somewhere between trial and error and best practice. We know what the controlling factors are and so on and that means you can think of such projects again. You can revisit Rosemanowes, go deeper and use this technique and have some kind of planned approaches. We do that in Germany. We have good frame conditions for this and we are drilling 4 or 5 km very close to some kind of economics, due to the good frame conditions. If you want to do that, you have the chance in the UK as well.

**David Manning**: We drilled down to 1 km depth and that was probably the limit that a rig of the type we had would be able to reach. It was able to be done rather more cheaply than could be done for a much deeper hole. I am sure that John can comment on that shortly. One point to bear in mind with the target that we had was that we were looking at natural fissures, so there was never any indication in our concepts that we would need to go for artificial fracturing.

**John Garnish**: Two quick comments. We went to Soultz originally because it looked at the time, on the basis of the shallow data we had, that the temperatures at depth would be higher than in Cornwall. As it now turns out, it looks as though temperatures in Cornwall at 5,000 metres, 200 Centigrade, will be pretty identical to Soultz and the upper Rhine Valley generally, so Cornwall is looking a good bet again.

The other quick answer is that a 5,000 metre hole in granite at the moment is coming out around 7-8 million Euros per hole.

**Nick Jenkins**: On that note, let me bring the proceedings to an end. I would like to thank Xameerah, who has organised this meeting for us. Thank you very much. I need to thank Professor Pine, who I think is still here, and Professor Younger, who gave very useful support and input to the structure of the meeting. Finally I would like you to thank our speakers in the normal way and we will then draw the meeting to a close.