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Induced Seismicity and the Viability of Enhanced Geothermal Systems

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Affidavit

I, **DARYL SLATTER**, hereby declare

1. that I am the sole author of the present Master's Thesis, "INDUCED SEISMICITY AND THE VIABILITY OF ENHANCED GEOTHERMAL SYSTEMS", 67 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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Abstract

This paper addresses the issue of induced seismicity by Enhanced Geothermal Systems and what this means in terms of its widespread commercial development. EGS promises to bring the potential of energy from geothermal systems to areas that do not have the naturally occurring reservoirs needed to produce heat and power from geothermal sources. There have been cases of individual EGS operations being disrupted by induced seismic events that have caused minor damage or have been felt by the public. The industry has reacted to these concerns and this paper analyses these reactions and assesses whether the seismic risk could be a problem for widespread use of EGS. It concludes that the perception of risk is important alongside the objective assessment of risk and that merely addressing the information gap may not be enough to allay the public concern.

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1. Introduction

This thesis is concerned with Enhanced Geothermal Systems (EGS) and their link to induced seismicity and what this in turn means for the development of this technology. EGS technology has been around since the 1970s but interest subsequently waned and it has only renewed since 2006. There have been a number of EGS projects, however most have not operated for long periods. Only the project at Soultz-sous-Forets (Soultz) in France has been operating for more than a few years (the EGS project at Soultz was established in 1987).

EGS has proven itself to be technically possible and able to produce electricity or heating in an environmentally sustainable manner. However, the technology has not yet shown itself ready for widespread commercialisation because of the economics. EGS needs to be competitive with other methods of energy production, especially other renewables, before it will be commercially viable.

This paper will briefly outline the current economic challenges faced by EGS. As a new technology EGS needs a positive story to tell to prospective investors to move it forward commercially. EGS requires significant upfront investment and has long return periods for a return on investment. This initial capital investment to find and develop a site is potentially at risk if the project is suspended or shutdown prematurely. A project may be affected if it induces or threatens to induce seismic events that the local population find concerning.

EGS has few environmental impacts. One issue of concern is its link to seismic events. EGS has not been linked to any large earthquakes but it has been linked to seismic events that in some cases have caused minor damage to buildings. Even if the seismic event is just felt and causes no damage it may be of concern to the local population and it may give locals legal redress to alter the operation. This paper draws on lessons from risk management and communication studies that show that the perception of risk is important alongside the traditional objective assessment of risk. The EGS industry has accepted that seismicity is an issue and has reacted by producing guidelines to mitigate the risk of seismic events. The focus of the reaction is mostly on educating and informing the public. This paper suggests that lessons from the risk management and communication field indicate that simply addressing the knowledge gap of the public is not in itself sufficient to allay public concern.

This paper is motivated by seeking to understand how the public sees the risk of a new technology that may hold great promise and what that can mean for the widespread use of that technology. As the paper will show EGS holds great promise but is still a niche technology that is yet to establish a firm foothold as an energy generating technology. This paper argues that to establish itself EGS will need to be perceived and accepted by the public (especially the public close to EGS operations) as a safe and acceptable technology. The issue is important as it addresses the fact that it is not just technical and economic barriers that can hold back new technologies that will help meet energy needs in a sustainable way.

If EGS does become economic the potential resource that becomes available is enormous. Even the conservative estimates for the United States (US) estimate that EGS would enable an additional 500 GWe to be accessed for geothermal. This is a conservative estimate and only for the US. The global resource for EGS could be as much as three terawatts. While this is based on a coarse estimate it does how large the potential resource that EGS could unlock is.

Public acceptance of new technologies is key to their success. This paper argues that this is especially true for EGS, as it still requires significant government support both for research and development, for establishing demonstration projects and for any early commercial projects. The EGS industry needs not only to establish that EGS is economically viable but that it can operate without causing unacceptable disturbance or risk to local communities. The EGS industry needs to draw on lessons from other fields and other industries that show perceived risk is just as worthy of consideration as objective risk and that simply trying to bridge a perceived knowledge gap is probably insufficient to gain public acceptance.

EGS operations release stress already present in the area. It does not introduce new stress to the field but has the potential to release stress that is naturally present.

This paper uses cases of EGS induced seismicity to show that, while no large damaging events have occurred, minor events have caused significant public backlash against individual EGS projects. This has caused one project to be prematurely ended and others to be delayed or to have limitations placed on operations. These cases are used to highlight the risk of failing to address the seismic issue and of the importance public perception plays in the story of EGS moving towards widespread development. Public concern has not moved on from concern with individual projects to the industry as a whole but as EGS is still only a niche technology tested in a few projects this does not mean it could not grow to a more general concern if the induced seismicity is not addressed.

While it is the economics of EGS that prevent it from being viable for widespread commercial development, the seismicity issue could upset the research and development of the technology and the policy framework that is developed around it. If not favourable, this could lead to false starts for the technology and discourage continued development or investment in it.

Furthermore, addressing the issue must include more than just a technical approach. The public must be aware of operators' limitations to predict and control seismic events and accept that any risk assessment takes into account their concerns. EGS as an innovation needs a positive story to show to the public, government and private investors at this early stage of its development to avoid false starts. EGS is also only one of several renewable technologies economies are able to pursue.

2. Literature Review

2.1. Enhanced Geothermal Systems and Induced Seismicity

Geothermal energy uses the heat underground for electricity production or for direct use in heating. Hydrothermal geothermal systems are limited to geographical areas that have naturally occurring concentrations of heat associated with water in permeable rocks. Geothermal power plants have therefore been limited to these geographic areas in the past. EGS technology offers the potential to create what is naturally occurring in these areas and make geothermal energy available outside the traditional geographic areas for geothermal power.

The principle of Enhanced Geothermal Systems (EGS) is to extract heat from deep underground for district heating and/or for power generation in areas that do not have a reservoir or where the permeability of rock is insufficient for a traditional geothermal system. The heat is transported to the surface via a heat transfer fluid that has been heated as it passes through the subsurface formation. A reservoir is artificially created. A network is created underground that is permeable enough to heat water economically. A network is stimulated that will connect the injection well to the production well (or wells). Cold water is injected into the fracture network and is heated as the water flows through the fracture network. It is then captured as hot water or steam by a production well. The steam or hot water is then brought to the surface and is then converted to electricity or used directly for district heating. The cooled water is then rejected into the reservoir. Ideally, a closed loop is created and water is not lost. In reality some water may be lost but the system is modelled to limit this. The stimulation of the reservoir involves the injection of large volumes of water at a high flow rate. This increases the pressure at the bottom of the well and this pressure induces shearing in the rock to create the fracture network.

EGS was first investigated in the 1970s. The US created the first EGS project (referred to as Hot Dry Rock then) at Fenton Hill, New Mexico. While this and other projects were created EGS remained largely absent from energy planning until two major studies were published. The first by scientists and engineers assembled by MIT (Tester et al., 2006) and another by the Geothermal Technologies Office (GTO) of the US Department of Energy (DOE) (GTO, 2007). The MIT study found that several challenges surrounding EGS were now manageable or have been resolved. The report concluded that there were no insurmountable problems with EGS becoming commercially viable and contributing significantly to the US achieving 100GWe from geothermal by 2050. The DOE report critically evaluated findings of the MIT study and largely supported the findings. DOE (2008) reached a higher estimate of potential and research and investment needed to bring EGS to commercial competitiveness.

In looking at the history of EGS it is necessary to understand the changes in terminology to describe the technology. Early projects referred to Hot Dry Rock (HDR) or Hot Wet Rock (HWR) to describe similar projects with differing reservoir characteristics. Subsequent terms include Hot Fractured Rock (HFR). Today, most of the literature and the industry building up around the technology tends to refer to Enhanced Geothermal System (EGS) (sometimes, although rarely, Enhanced is substituted with Engineered). EGS is an umbrella term that incorporates the various names of similar technologies. This seems particularly true since the term is used in the two reports that have led to a renewed interest in EGS (i.e. Tester et al., 2006 and GTO, 2007).

Commercial geothermal projects have been limited to particular geographical areas in the world where natural reservoirs with sufficient permeability exist and rock temperatures are sufficiently high. Conventional geothermal has therefore only represented a niche energy resource and geothermal power plants have been limit to areas where these natural conditions exist.

The concept of EGS originated at Los Alamos National Laboratory in the early 1970s, to exploit the heat contained regions of the subsurface that contain no fluids and thus are unsuitable for conventional geothermal exploitation. The EGS principle extends the possibility of exploiting the geothermal potential of the subsurface for power generation to far more areas than just those with natural hydrothermal resources.

The promise of EGS is that it can create such systems artificially and will therefore not be limited by geography. Therefore, in theory, it would enable the establishment of geothermal power plants almost anywhere in the world. Various estimates are summarised in Table 1 below. The most detailed research has been done in the US. For some context, as of May 2012, approximately 11.2 gigawatt-electric (GWe) of geothermal power was online globally (DOE, 2008).

Table 1. Various Assessments of the Energy that may be Accessed with EGS

Source	Resource	Notes
United States		
Augustine, 2011	15,908 GWe (of Deep EGS Resource)	48 states consider, to a depth of 3-10km depth.
Tester et al., 2006	100 GWe target Resource base >13 million EJ Extractable portion ~>200,000 EJ	Target for development by 2050 not an estimate of resource. Extractable portion of 200,000 EJ represents about 2,000 times the annual consumption of primary energy in the US.
Petty and Porro, 2007	54.7 – 71.5 GW	
Williams et al., 2008	500 GWe (517,800 MWe) (addition from EGS)	Only 11 states considered, to a depth of 3-6 km.
GTO, 2007	15,908 GWe	The economically useful will be much smaller.
Germany		
Paschen and Oertel (2003)	EGS 1,100 EJ (c. 306,000 TWh)	Technical potential. Potential from all geothermal technologies:1,200EJ (c. 300,000 TWh).

Although estimates vary, they all conclude that there are very large geothermal resources that are made available by EGS technology. Even if only a very small proportion is exploited it still amounts to a large amount of energy.

Estimates of potential in the US vary. Most commonly cited for the US is the figure of 100 GWe in Tester et al. (2006). This was, however, presented not as an estimate of the resource in the report but as a target to achieve in the US by 2050. The DOE study (GTO, 2007) estimates EGS resource at 15,908 GWe (though the economically useful will be much smaller). This is more than the 500 GWe estimate reported in the US Geological Survey (USGS) 2008 geothermal assessment (Williams et al., 2008). The USGS study considered fewer states and to a shallower depth. It is also higher than the 100 GWe figure commonly cited from the MIT report (Tester et al., 2006). The MIT figure is a target for development not a resource estimate.

Geothermal energy has recently had more attention in Germany as EGS technology makes geothermal viable in places without naturally occurring geothermal reservoirs (Fischhoff, 1995). An assessment of the technical potential for geothermal in Germany concluded that there is a total potential of 1,200 EJ in Germany and 90 per cent (1,100 EJ) of that is only available with EGS technology (Leiss, 1996). From the report's findings it is clear that the potential of hydrothermal deposits in Germany can only be realised with EGS, illustrating the how important the development of EGS is to places that lack natural geothermal reservoirs.

EGS has one of the lowest adverse environmental impacts among electricity generating options. EGS is one of the few renewable energy resources that can provide continuous base-load power with minimal visual and other environmental impacts. Geothermal power plants may have less of an impact on the environment compared to than other options. A life cycle analysis of EGS by Lacirignola and Blanc (2013) found that it has comparable environmental performances to other renewable energies. Stephens and Jiusto (2010) and Tester et al. (2006) suggest that EGS might offer reliable power with lower environmental and health impacts than virtually all other electricity producing options, including other renewables. A study by Chatzimouratidis and Pilavachi (2008) of the impact on living standards of ten types of power plants ranked geothermal as the most favourable across a number of criteria. DiPippo (1991) however notes that geothermal operations may release carbon dioxide and hydrogen sulfide, and very small amounts of other gases such as methane, hydrogen and ammonia (DiPippo, 1991).

Sovacool (2009) claims that renewables are more visible than many conventional power generators that tend to be based in industrial areas and therefore blend in with other industrial activity. EGS has one of the lowest footprints of renewables. This could be another potential benefit of EGS over other renewables, in can be less visible than other renewables.

In 2005 MIT assembled an 18-member panel to evaluate the potential of geothermal energy becoming a major energy source for the United States. The panel's finding were published in 2006 as "The Future of Geothermal Energy Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century" (Tester et al., 2006). This was the first comprehensive assessment of EGS. The panel could not find any major barriers or limitations. Several workshops followed the publishing of the report that focussed on major aspects of EGS. The groups recommended that the MIT findings be used as the basis to define required research and development (R&D) activities and additional analyses required to enable the commercialisation of EGS (DOE, 2008 and GTO, 2007). In 2008 the US DOE largely confirmed the findings of the MIT panel's report and areas where additional research was required (DOE, 2008). These research categories have been further expanded and refined (for example, Snyder et al., 2009; Nathwani et al., 2011 and IEA, 2011). This has culminated in the most recent roadmap reports by Ziagos et al. (2013). The report includes a more detailed history of the development of the roadmap for EGS, including details of the various workshops.

The 2006 MIT report concluded that geothermal energy could provide 100 GWe or more in 50 years by using EGS. The report offers a good starting place for an understanding of the development of EGS since initial research into EGS began in the 1970s with the development of the Fenton Hill project in New Mexico, United States. The review offers a historical context on how EGS technology has developed and the lessons learned from these projects. The report reviewed several EGS research and development projects, which had been conducted since the 1970s. The major projects discussed in the report were: Fenton Hill, in the United States; Rosemanowes, in the United Kingdom; Soultz, in France; Cooper Basin, in Australia; and Hijiori and Ogachi, in Japan. It also discussed several smaller projects in Europe, the United States and Australia. The Appendices to the report discusses the current state of EGS technology, as it was in 2006. The report offers a general state of understanding of EGS reservoir technologies, as well as what remains to be researched or developed for commercial EGS operations to be viable. It identified a need for a robust research and development programme to realise the potential of EGS.

Overall, the report is optimistic about the role EGS can play in the United States' energy future. The panel concluded that, “Most of the key technical requirements to make EGS work economically over a wide area of the country [the United States] are in effect, with remaining goals easily within reach” (Tester et al., 2006, p. 1-3).

Brown (1995) states that during the years of research on EGS at Los Alamos National Laboratory, no technical obstacles were found that would preclude this becoming a major new energy source. A clear understanding of how to create such man-made geothermal systems was developed from the engineering and flow testing of two successive deep EGS reservoirs. Brown (2009) identified the most important lesson of the Laboratory’s work is that to create an effective EGS geothermal system, the stimulated region should be created from the initial borehole and then accessed by two production wells. To drill two boreholes and then try to connect them by hydraulic pressurization is almost impossible, according to Brown's observation of the Laboratory's experiences.

Brown (1995 and 2009) identified the principal remaining task is that of increasing the productivity of these reservoirs. The productivity of the reservoir is the most critical remaining issue related to the development of EGS.

GTO (2007) conclude that existing power plants are adequate for EGS development in its initial stages. Gurgenci et al. (2008) suggest improvements in power conversation technologies will make geothermal projects more competitive as they in effect increase the probable reward from a geothermal project, that is electricity to sell to the grid. The authors note that almost all R&D funding for geothermal over the past two decades has been directed towards subsurface issues. While this is considered of critical importance by the authors they also note that by improving the power generation efficiency more electricity will be available to sell from the same subsurface investment. If a breakthrough was made it would improve the economics of all geothermal systems (including EGS). This would require a breakthrough in the efficiency in power generation that is unlikely.

The hurdles that need to be overcome before EGS is considered commercially viable identified include significant improvements in current technology. A workshop in 2011 found that EGS to be commercially viable in the US it would require a 20 per cent reduction in drilling costs, an increase production flow rates to 80 kilograms per second and a 20 per cent increase in conversion efficiency (Gurgenci, 2011). Similarly, the 2006 MIT study concluded that a 200°C fluid flowing at 80 kilograms per second (equivalent to about 5 MWe) is needed for economic viability (Tester et al., 2006). The study also noted that no EGS project to date has attained flow rates in excess of about 25 kilograms per second. This is well below what is needed for an economical geothermal project.

Sanyal and Butler (2005) presented an analysis of the performance of EGS, focussing on the net electric power delivered by such a system over the long term. Sanyal (2009) also identifies steps that need to be taken to optimise the economics of EGS projects. The steps identified include: reducing costs (operation, maintenance and that of the power plant), choice of drilling site, a drilling depth that maximises power capacity per drilling cost rather than drilling for a maximum temperature, creating the largest possible stimulated volume per well, taking advantage advancements in pump technology, developing multiple EGS units to benefit from the economy of scale, and minimising the rate of decline in net generation with time. This paper presented certain steps that can be taken towards optimizing the economics of an EGS project.

Fridleifsson et al. (2008) identified one of the main future demonstration goals in EGS is to see whether and how the power plant size for EGS can be scaled up to several tens of MWe. A typical hydrothermal plant is 30-50 MWe and smaller plants are difficult to make economical because of the high cost.

The US DOE has done considerable work researching EGS for use in the United States or providing funding for studies into EGS (for example Tester et al., 2006; DOE, 2008; and Salmon, 2011.) A DOE 2008 report evaluated technology relevant to EGS that is currently used in the conventional geothermal industry and related industries. Much of the information was produced through workshops attended by experts from the geothermal and related industries. The DOE strategy is to leverage and build on current geothermal technologies and resources to develop the advanced technologies required for EGS. The DOE has identified that this will require a systematic and sustained research and development effort by the United States government, industry and academia to ensure full development of EGS.

The DOE (2008) identified three critical assumptions about EGS technology that require thorough evaluation and testing before the economic viability of EGS can be confirmed: the demonstration of a commercial-scale reservoir, sustained reservoir production at economically viable levels (the DOE cite the MIT 2006 study findings), and the replication of EGS reservoir performance at a commercial scale over a range of sites with different geologic characteristics. According to the DOE these assumptions can be tested with multiple EGS reservoir demonstrations using current technology. The key technology requirements for immediate development stemming from the DOE evaluation (2008) include: temperature-hardened submersible pumps, zonal isolation tools, smart tracers, monitoring and logging tools, and coupled models to predict reservoir development and performance. The DOE state that experience from the conventional geothermal and petroleum industries provides a solid foundation from which to make technology improvements. In the long-term, significant reduction in drilling costs will be necessary to access deeper resources, and the cost of conversion of the energy into electricity must be reduced. The DOE identified that these improvements will move EGS forward as an economically viable means of tapping the geothermal resources of the United States.

An Intergovernmental Panel on Climate Change report on the possible role of geothermal energy in carbon dioxide mitigation identified that once operational, EGS can be expected to have great environmental benefits but that this impact cannot yet be satisfactorily quantified (Fridleifsson et al., 2008). This report saw widespread deployment of geothermal as having a positive impact on energy security, the environment, and on global economic health. It also noted that while there is an inherent limitation on the scale of conventional geothermal resources, EGS could make it possible to exploit geothermal energy in areas unsuitable for conventional geothermal power generation, that is, where geothermal energy is characterised by high temperature but low permeability and lack of natural fluid circulation.

An evaluation of the cost of electric power from EGS was presented by Sanyal et al. (2007). It reiterated what seems to have become a common claim (for example see Tester et al., 2006) that with “adequate” research, development and demonstration, EGS power should be commercially competitive by 2050. The total capital cost of hypothetical EGS projects is higher than for conventional geothermal projects. The Sanyal et al. (2007) paper identified improvements in geothermal pump technology (that would increase the pumping rate) as key to reducing the cost of power generation in EGS projects. Lowering the cost of EGS is key to its commercial viability as the price of power is unlikely to rise significantly enough for this alone to make EGS commercially viable. Government subsidies would ease the challenge of commercialisation. According to the report, the absence of this effort combined with potential increases in drilling cost due to market forces may undermine the prospects for commercial EGS power.

Baria and Petty (2008) note that funding is limited for research and development and so it must be focused toward making the EGS cost competitive. However, according to the authors there is no EGS project that has operated over a long enough period to enable the quantification of all variables to assess commercial viability. They claim, however, that there is enough experience according to show that certain aspects (such as the size of the heat exchanger and the pressure drop) need to be part of the economic assessment in proposing a commercial EGS project. The authors suggest the achieving particular milestones in the cost variables will contribute to the commercial viability of EGS and should be targets for further work. These other variables, however, are likely to be very small compared to the cost of drilling the wells.

Ledru et al. (2006) discuss the establishment of the ENhanced Geothermal Innovative Network for Europe (ENGINE), the purpose of which was to define, organise and manage joint and common initiatives. The ENGINE Project was a co-ordination action supported by the 6th Research and Development framework of the European Union. Its main objective was to coordinate research and development initiatives for EGS from resource investigation to exploitation through socio-economics impacts assessment. From the November 2005 to April 2008, the ENGINE co-ordination action gathered 35 partners from 16 European and 3 non-European countries including 8 private companies. The project has ended but the results of the coordination action are at http://engine.brgm.fr/. Two publications of importance came out of the ENGINE co-ordination action: a best practice handbook and a definition of research areas for EGS.

The ENGINE partners defined the best practises for EGS conception, exploration, site development and production in correlation with risk analyses and public acceptance in the “Best Practice Handbook for the development of Unconventional Geothermal Resources with a focus on Enhanced Geothermal System” (ENGINE, 2008a). The EGS life cycle is covered from best practices for such things as the location of a geothermal site, process from drilling of wells to reservoir preparation for exploitation, it presents plant configurations and technologies for power production and heat supply and discusses environmental impacts of EGS. The report claims that the Soultz-sous-Forêts project has proven the technical feasibility of EGS exploitation and further research should be directed towards reducing the costs of EGS plants. The report concludes that a European research and demonstration project proving the economical feasibility of EGS plants is necessary in order to stimulate large scale development of EGS in Europe. **[refer to idea in discussion]**

The ENGINE group also defined research priorities for EGS in “Propositions for the definition of Research Areas on Enhanced Geothermal Systems” (ENGINE, 2008b). The ENGINE co-ordination action's ultimate goal was the development of a technology to produce electricity and/or heat from the internal heat of the Earth in an economically viable manner, independent of site conditions. To this end, it defined priorities for research investment in the EGS field. The report highlights the importance for coordinated research for technology improvement and for a continued reduction in cost through R&D developments. The report stated the state-of-the -art for various stages of EGS projects and developed priorities covering four main research areas for future investment were defined (ENGINE, 2008b).

Ledru et al. (2006) broke the challenges widespread EGS development faces into several different areas: the scientific challenge of understanding the processes involved, a technological and economic challenge to make EGS commercially viable, a communication challenge to rally the support of policy makers and investors and increase the social acceptance of EGS, and a challenge to integrate the different research and development paths that currently exist.

Genter et al. (2009) looked at the pilot EGS project at Soultz, France. The paper reports on the project to develop an EGS reservoir in Europe and presents the main milestones in the project. A scientific and technical monitoring of the power plant started in 2009 focussed on the evolution of the reservoir and that of the different technologies used.

One of the main constraints on geothermal project development is the ability to secure capital. The 2006 MIT report found that significant progress has been achieved in recent tests carried out at Soultz, France, under European Union sponsorship and in Australia, under largely private sponsorship. Salmon et al (2011) makes particular note of the rapid growth of EGS investment in Australia due to strong government investment and the Australian Stock Exchange, which is more familiar and comfortable than other stock exchanges with resource development risks because of the considerable number of mining companies traded on that exchange.

A recent EGS concept has been gathering interest, although it is yet to progress beyond laboratory experiments and numerical modelling. Brown (2000) proposed that the concept of heat mining using supercritical carbon dioxide for both reservoir creation and heat extraction. Brown concludes that this concept, built on the research and development work conducted by Los Alamos National Laboratory at Fenton Hill, appears to have considerable advantages in a power-producing man-made HDR geothermal system.

Pruess (2007a) summarised the research to date into operating EGS with carbon dioxide. The paper noted that modelling studies indicate that carbon dioxide would achieve more favourable heat extraction than aqueous fluids. However, it is also noted that quantitative assessment of this in the early stages and an integrated research programme of model development, laboratory work and field studies is needed to fully evaluate the potential of EGS with carbon dioxide. The paper concluded that for a realistic assessment practical tests in the field will be necessary.

Numerical simulation results presented in Pruess (2007b) claim to confirm the advantage of carbon dioxide over water as heat transmission fluid for EGS, predicting larger energy extraction rates for carbon dioxide for the same applied pressures in injection and production wells. The study focussed on the energy extraction aspects of using carbon dioxide and acknowledges that future work must be done to address the issue of carbon dioxide losses and whether this will remain contained safely and securely.

Pruess and Azaroual (2006) suggested combining EGS with carbon dioxide storage could provide an additional revenue stream that would improve the economics of

EGS. They found that carbon dioxide is roughly comparable to water in its ability to mine heat from hot fractured rock and that it has certain advantages compared to water. carbon dioxide appears to offer advantages that may lead to reduced power consumption for maintaining fluid circulation. Fluid losses are an unavoidable aspect of engineered geothermal systems. Whereas the loss of water in a conventional operation would be unfavourable and costly, fluid loss in a system using carbon dioxide would offer storage of carbon dioxide underground. Such storage may provide economic benefits and incentives in future carbon management scenarios. Combining EGS with carbon dioxide storage could provide an additional revenue stream that would improve the economics of EGS.

Xu et al. (2008) discussed the impact on reservoir growth and longevity of carbon dioxide which may have important ramifications for sustaining energy recovery, for estimating carbon dioxide loss rates, and for figuring trade-offs between power generation and geologic storage of carbon dioxide based on simulations. The paper suggested that sensitivity studies on different rock mineralogies should be performed in the future. A major finding from the simulation suggested that carbon dioxide could be fixed through precipitation of carbonate minerals, which can offer geologic storage of carbon as an ancillary benefit.

2.2. Induced Seismicity

Induced seismicity is not well understood (Majer et al., 2007 and ENGINE, 2008a). In the 1980s there was some reluctance by engineers to accept the significance of induced seismicity (Simpson, 1986). The issue of EGS-induced seismicity is described by Majer et al. (2007) as “uncharted territory”, as there have been no long-term projects. EGS operations to date support this as there have been no large seismic events associated with EGS projects that have caused major damage or injury. However, there have been several examples of seismic events associated with nearby EGS operations that have been felt and/or have caused minor damage (minor meaning cracks in paint for example). There are a number of examples of induced earthquakes from EGS operations. Cases prior to 2007 are discussed in Majer et al. (2007). It includes events at The Geyers, USA; Cooper Basin, Australia; Berlin, El Salvador; Soultz-sous-Forets, France and Basel, Switzerland. EGS projects generally are discussed in McGarr, Simpson, and Seeber (2002), Tester et al. (2006), McClure and Horne (2012) and Ziagos et al. (2013) and include the induced seismicity issue. Evans et al. (2012) discusses examples of induced seismicity in response to fluid injection, including EGS examples. Cladouhos et al. (2010) also discusses cases of induced seismicity.

There is also a body of work that deals with cases individually. The cases of seismicity associated with the Basel EGS project are analysed and reported in Baisch et al. (2009) and Secanell et al. (2009) and Asanuma et al. (2007). The results of the Basel project are discussed in Häring et al. (2007) and details of its development are provided by Häring (2004). Baer et al. (2007) covers earthquakes in Switzerland in 2006, including the events at Basel. Technical descriptions of the events are provided by Mukuhira et al. (2008); and Mukuhira et al. (2009); Bachmann et al. (2011); Wiemer, Woessner, and Hainzl (2011); and Mukuhira et al. (2013)

Seismic events caused by operations at Soultz and the disruption to the project are covered by Majer and Baria (2006) and Charlety et al. (2007). An assessment of ten years' of the project is provided in Genter et al (2000). A technical description of the stress field of the area is given in Dorbath et al. (2010). That injection operations at the Geysers was faced with local opposition is described in Majer and Baria (2006). This was partially abated by and improved communication process. An evaluation of events in South Australia is discussed in Morelli (2009) and Hunt and Morelli (2006).

According to Majer et al. (2007) it is likely that both injection and production operations contributed to induced seismicity at the Geysers. While the small earthquakes that are not felt on the surface benefit EGS projects, larger, felt seismic events are a hazard and detrimental to EGS projects.

While the connection between injection and seismicity is established the relationship is only understood qualitatively (Häring, 2007). The calculation of a probability needs be done statistically for modelled but reliable statistics require large data sets, which are not available for induced seismicity events caused by human activity. There is insufficient knowledge on the assessment and prediction of induced seismic events and the effect of seismic events on people and infrastructure.

The estimation of seismic risk has become one of the central themes of EGS. There have been a number of workshops specifically related to the issue and in the GEA roadmap for EGS technology it is defined as a research category. International expert groups have been established to look at the issue and national agencies and scientists are co-operating. This co-operation is described in Majer and Baria (2006) and Baria et al. (2006), including a description of cases of induced seismicity around the world.

EGS research and development needs to continue to develop methods that can, with sufficient probability, avoid EGS activities inducing seismicity that results in damage to nearby populations or infrastructure. Arguably it is less of an issue to induce seismicity in sparsely populated areas.

According to Bendall et al. (2012), hydraulic stimulation rarely constitutes a significant hazard because the forces involved are relatively small. Majer et al. (2007) study of induced seismicity and EGS concluded that more project experience and further study into the issue was needed. If further projects are needed to demonstrate not only the viability of EGS but also to understand the induced seismicity issue, avoiding induced events that have a detrimental effect on projects will be important. Majer et al. (2007) ‘s study therefore also concluded that best practice guidelines were needed to avoid this issue hindering the wide spread acceptance of EGS. The events at Soultz, Basel and Landau have shown that although no damage may occur the public perception of EGS as safe technology may be affected. This will impede the development of future EGS projects that further understanding will be built on. (Majer et al., 2007) suggests this is a risk if the public is not properly informed about the benefits of EGS balanced against the inconvenience of minor, occasional ground movements.

Similarly, Bendall et al. (2012) argues that concern over induced seismic events is the result of a lack of knowledge or a misunderstanding of the situation which can be overcome with the right tools and communication between stakeholders. This requires that effort is invested in developing the tools to predict and map the stimulation of the reservoir and show that they can do so reliably.

Induced seismicity can be useful for EGS development. During fluid injection the additional hydraulic pressure produced small stress fractures that in turn triggered a large number of small earthquakes (Baisch et al., 2009). Tracing the small earthquakes maps the dominant path of the fluid.

Seismic risk is generally understood as some function of the probability of a particular level of seismic event occurring and the vulnerability of people, buildings and infrastructure to injury or damage from such an event (Bommer et al., 2006).

When considering induced seismicity there is the issue of disturbing or distressing nearby populations (Bommer et al., 2006 and Cypser and Davis, 1998). Cypser and Davis (1998) looked at the issue of liability under US law for induced seismicity. While the study looks at only US law but the authors note that because of similarities and connections to a common tradition concepts may also exist in countries whose legal systems descend from English common law or Roman civil law. It gives us an insight into the issue of liability for inducing seismic events beyond the issue of who should pay for damage caused but also the issue of the feeling vibrations. Earthquakes are usually considered to be “acts of God” and therefore there is no question of liability. However, if the seismicity is created by human activity it is not considered to be an “act of God” and the question of liability can be raised. The study suggests that the concept of “creating” seismic covers activities that trigger or induce seismic events by releasing stress that is naturally present in the geological formation. In this sense EGS operations that release naturally present stress and cause a seismic event may be considered to have “created” it. The study concludes that induced seismicity does not need to cause damage to create a legal issue. The seismicity may be considered a nuisance if it interferes with someone’s use or enjoyment of their land. If the interference is minor but reoccurs frequently is it is likely to be considered a nuisance. They also note that vibrations from human activity are sometimes viewed as analogous to a physical invasion (i.e. trespass).

There has not been a long-term EGS project. Although the idea was first looked at in the 1970s all previous projects have run out of funds after a few years of running (GTO, 2008a).

Some cases of induced seismicity have received more attention than others. The Basel incident is widely covered while the Landau induced seismicity has received very little coverage in the English literature. The final report is only available in German (Keilen et al., 2010) and the case is not discussed to the extent that the Basel example is.

Ground shaking is not the only impact geothermal operations can have. Subsidence has been an issue with some hydrothermal operations. Subsidence at the Wairakei geothermal field in New Zealand was due to the development of the geothermal field there and caused damage to nearby infrastructure (Allis, 2000). At Staufen in Germany, a geothermal operation caused subsidence that caused damage in the nearby town. The public were concerned as repair work could not be done until the subsidence stopped (Pancevski, 2008).

The risk analysis of the seismicity caused by the EGS project in Basel found that most of the damage reported consisted of small cracks in walls. Of the buildings that were damaged most were built prior to 1950 using building methods and construction material less favourable to seismic events (Secanell et al., 2009). The nature of the buildings in the surrounding area may therefore also be an important factor in determining the likely damage from a particular magnitude event. Making the local assessment of the risk important and underlining the importance of gathering seismic evidence from EGS projects in a range of locations not just defined by geological criteria or population densities.

2.3. Risk Communication and Assessment

Classically risk has been defined as a function of probability of an event occurring and the magnitude of that event over a period of time (Rayner and Cantor, 1987). In this conception of risk, risks are assessed as: Risk = (Probability x Magnitude) / Time.

Fischhoff (1995) organises the history of risk communication into several stages. Each stage builds on the previous and carries forward the lessons learnt as to the effectiveness of the previous strategy to communicating risk to the public. The following stage does not replace its predecessor. Weakness of each drives the evolution forward (Leiss, 1996). Sandman (2012) divides the activities of risk communication between alerting people to the risk and reassuring them.

Table 2. Developmental Stages in Risk Management

All we have to do is get the numbers right	Focus on developing technology and controlling risk. Experts may dismiss the risk.
All we have to do is tell them the numbers	Information about technology made public (often in the form produced for experts). Accuracy depends on experts mastery of technology. Successful communication relies on how well the public understand the information. May be disagreement between public and experts about the severity of the risk.
All we have to do is explain what we mean by the numbers	Information is explained to the public. Often communicated with little focus on what matters. Public is often unprepared to receive information. Confusion can develop if different explanations are available.
All we have to do is show them that	Explaining that the risk is acceptable because similar

they've accepted similar risks in the past	risks have been accepted in the past is disingenuous and evidence suggests it does not work.
All we have to do is show them that it's a good deal for them	Risk decisions are not made in isolation. Benefits need to be included in the decision making process. There is less research about communicating benefits to the public. Framing the benefits may be important.
All we have to do is treat them nice	Public may see disrespect as a sign they are not being listened to and have no say.
All we have to do is make them partners	The public can play a constructive role. Public can master technical material if motivated to do so. But motivation often comes from being angered which can lead to each side of the argument focusing only on data which supports their view.
All of the above	Combining all of the above creates a communication strategy that can be likened to an insurance policy. This may cost time and money but can avoid larger losses if the public does not accept the risk.

Source: (Fischhoff, 1995)

In Fischhoff (1995) and Leiss (1996) we can see the evolution away from the deficit model. Pidgeon et al. (2005) sums up that the message from social science research into risk is that risk communication needs to move beyond the deficit model, as simply proving information from experts is unlikely to address public concerns.

Klinke and Renn (2002) suggests that risk evaluation and management is not a simple process that can be standardised. Instead these risk processes are conceived of as complex issues that should involve different approaches from different disciplines. Bell, Gray, and Haggett (2005) argues that the only credible way to provide information to the public is to build trust through a two-way communication in a participatory process that involves the public.

Rayner and Cantor (1987) argues that the traditional definition of risk may be suitable for assessment and management of risk at an engineering level it but not at the larger societal level. The study suggests that policy debates should assess technology options on the basis of social conflicts over trust and equity, rather than on estimates based on the classical risk assessment approach that is a function of the probability and magnitude of events. This brings together three areas the study found were issues for the public: that consent is gained in a way that was acceptable to those that will be affected; that those affected accept the apportion of liability; and that those making decision about, or regulating, technologies are trustworthy.

Bier (2001) offers a review the state of the art on risk communication to the public and offers some suggestions on how best to communicate risk to the public. The study identifies several challenges to the understanding of the audience: small probabilities can be misinterpreted as being more likely than they are; unfamiliar terms and complex issues can create confusion; and the audience may have incorrect intuitions about risk that need to be addressed.

Wüstenhagen, Wolsink, and Bürer (2007) argues that many barriers to the implementation of renewable energy projects can be traced back to a lack of public acceptance of new technologies.

Experts in risk assessment calculate risk as a function of the probability of a hazard occurring and the magnitude of the effect if it does occur. According to (Renn, Klinke, and Asselt, 2011) this is not appropriate for risks that require societal choices and decisions that are complex, uncertain and/or ambiguous. (Sandman, 2012) includes what he terms “outrage” into risk assessment . The outrage concept seeks to capture strong, justified emotional reactions in the assessment of risk. Therefore, risk becomes a function of hazard (including both magnitude and probability) and outrage.

The risk that are most damaging to the environment are different from those that the public consider to be the most damaging (Sandman, 2012).

Experts give equal weight to the probably and consequences of a given risk, while public is more concerned with the consequences of the risk than the likelihood of it occurring (Sjöberg, 1999 and Renn and Levine, 1991). The expert approach relies on risk assessment methodologies that draw on evidence to evaluate hazards. The public generally relies on intuitive judgements, often informed by the news media, to make assessments (Slovic, 1987).

Sandman (2012) also argues that the experts tend to ignore the extent of the public concern (what he calls “outrage”) and the public misperceives the real nature of the hazard.

Renn (2003) suggested an integration of perceived and real risk. It is not suggested that the perceived risk replace a technical assessment of the nature and probability of a hazard from industrial activity. Rather that looking at the how risks are perceived should be looked at as it can assist risk experts by uncovering legitimate concerns the public may have. It can also find potential trade-offs that can be made to make the risk more acceptable.

Renn (1998) defines two risk management approaches and attempts to integrate them. According to Renn, risk has been seen as either a representation of real hazards or as a social construction. Proponents of the latter argue that there should be more public input into deciding what are tolerable risk levels. Conversely, the former argue that optimal outcomes for risk management are not achieved if the assessment is based on what happens to be drawn to the public 's attention regardless of the objective risk presented. Renn (1998) notes that many surveys and psychological experiments have shown that the perception of a risk does not match the risk calculated by experts. The author concludes that the differing views can be reconciled in well-structured and open dialogue.

Wachinger and Renn (2010) reviewed risk perception literature over the last 30 years and concluded that there is still a lack of a coherent and consistent model of how individuals perceive and evaluate risks. In the 1980s the idea emerged that values, attitudes, social influences, and cultural identity were a key part of the social experience of risk. The public's experience of risk was not just the technical definition of risk (a function of probability and magnitude).

A study in 1991 found that results from psychological or sociological studies on the effectiveness of communication and on the role of trust and credibility have not been incorporated into risk communication (Renn and Levine, 1991). Some of the lessons have been incorporated into the concept of risk. The concept of risk as feeling is discussed in Loewenstein et al. (2001), Slovic et al. (2004) and Slovic and Peters, (2006). Slovic et al. (2004) notes that modern theories in cognitive psychology and neuroscience suggest that people understand risk in two ways: the first is an analytical process that is slow and requires effort; the second is intuitive and based on experience. According to Slovic et al. (2004) the latter remains today the most natural and most common way to respond to risk. These two fundamental approaches to comprehending risk suggested here mirror the real risk and perceived risk processes introduced earlier. (Loewenstein et al., 2001) suggests that people react to risk cognitively and emotionally. The emotional response to risk therefore forms part of a person's assessment of risk.

The findings of (UK House of Commons, 2012) recommend that risk perceptions need to be understood and should inform decision-making processes but they should not be relied on when the perception differs from the evidence for the real risk. The report concludes that polices should be developed on evidence from impartial scientific sources and public confidence can be established by engaging in a risk dialogue with the public.

Nisbet and Scheufele (2009) conclude that in informing the wider public about science only a small audience of already informed people tend to be reached. This challenges the idea that simply informing or educating the public will actually be effective.

Gross (2007) research on community perceptions consultation for a wind farm pilot study in Australia found that out that a perceived lack of fairness plays an important role in public acceptance.

A study of wind energy as an option for the UK looked at factors that contribute to the public acceptance of wind projects (Halliday, 1993). Halliday concluded that the way in which a project is developed is important and the classic 'decide-announce-defend' mode is much less successful than a 'consult-consider-modify-proceed' approach when planning wind energy projects.

Kasperson et al. (1988) has a conceptual model for social amplification of risk. As many risks are not experienced directly individuals often learn about risk from other people and the media. A consequence is the event can be applied and extended to further geographical areas or to future generations.

Uncertainty is key to science and is accepted as a fundamental part of it by scientists. Some within the scientific community believe that the general public is unable to conceptualize uncertainties associated with scientific process. A study by (Frewer et al., 2003) looked at the attitudes of the scientific community in the United Kingdom. The findings support the idea that scientists are concerned that in communicating uncertainties to the public it will undermine the public confidence in them, as the public do not understand the scientific concept of uncertainty. As it is generally experts that design the risk communication framework this attitude is reflected in how risks are communicated. This has ramifications on the risk communication framework that is adopted for a project and may help explain why the inclusion of uncertainty has been avoided in the past and why the deficit model is often ascribed to (Frewer et al., 2002 and Frewer et al., 2003).

Frewer et al. (2002) looked at public reactions to scientific uncertainty in food safety in the UK and found that people were more tolerant of uncertainty if it was seen as part of the research process rather than inaction by the government. The study found that people are more familiar with the concept of uncertainty and its place in risk assessment that was thought. If the public can understand the concept of uncertainty in risk, as is suggested by this study, then a key message in risk communication should be that this uncertainty exists and what is being done to reduce it. The findings suggest that the public want the ability to make informed choices about risk assessment and management.

The Committee on Decision Making Under Uncertainty of the US National Academy of Sciences looked at uncertainty in environmental decisions and recommended that uncertainty should be explicitly communicated when informing public and decision makers (IOM, 2013). The report also found that the uncertainty of the costs and benefits in such decisions is not well understood, nor is the ability of environmental control technologies to work.

Wardekker et al. (2008) explored how uncertainty and uncertainty communication is viewed by scientists and policy makers in the Netherlands. The study found there is sometimes a difference between the levels of certainty science can actually deliver and what it is expected to deliver. It is reasonable to extent the view of policy makers that science can expected to produce levels of certainty that are not reasonable to the public as a whole. The study also found that there is particular interest from policy makers in uncertainty around environment impacts. Similarly, this might reasonably be extended to the wider non-scientific public.

Reid (1999) suggests that risk analysts need to address the issue of trust for risk communication. In looking at the role of social trust and knowledge in the perception of hazards (Siegrist and Cvetkovich, 2000) concludes that experts and authorities are relied on when people lack the necessary knowledge to make conclusions about risks and benefits. This fits in with the deficit model. The assumption this model leads experts to is that the public's perception of risk can be reduced by experts explaining or emphasising the benefits.

The causal link between trust in experts and authorities and social acceptance of energy sources may not be straight-forward. A study by Bronfman et al. (2012) study of Chilean attitudes to different energy sources sought test a model that establishes social acceptance of an energy source is directly caused by perceived risk and benefit and also by social trust in regulatory agencies. The study found that for conventional energy sources there was a causal link but not for non-conventional renewable sources. Public acceptance of non-conventional renewable energy sources (including geothermal) and the public perception of risks and benefits from their use are not correlated with public trust in experts. The authors suggest that this may be rooted in the public's uncertainty about the current risks and benefits of using each technology. This suggests that the link between looking to experts to help assess the risks and benefits of unfamiliar energy technology may not be as simple as building trust in the authorities, but may also require a general familiarity with the new technology among the public.

Renn and Levine (1991) distinguishes between and defines "trust", "confidence" and "credibility". Trust has five components: perceived competence of the source; lack of perceived bias; an adequate representation of all relevant points of view; consistency of message and actions; and perception of good will. Confidence is then the perception of this idea of trust over time. Credibility is then the extent of which this perception of confidence is shared in a population. All three terms are based on the idea that it is the perception that is key not what the message is objectively.

The perception of trust in expert sources varies by location. A survey of EU public opinion found that nearly half of Europeans believe that scientist cannot see the wider issue as they are narrowly focussed on specific scientific and technical issues (European Commission, 2010). Furthermore, this survey found that close to three in five surveyed agreed that scientists can no longer be trusted to tell the truth about controversial issues as they depend too much on industry funding. The results for the survey varied across the 27 members states of the European Union. In the US public opinion seems to be more positive towards the scientific community. In a survey in the US, less than one in ten expressed no confidence in the scientific community (National Science Board, 2012).

Knowledge and support of geothermal is often below that of other renewable technologies (Howell, Shackley, and Mabon, 2012).

A workshop held in Scotland in 2011 investigated the public's perspectives of low carbon technologies (Howell et al., 2012) At the beginning of the one-day workshop there was a lot of uncertainty about geothermal but support had significantly increased by the end. Support for geothermal increased from 34 per cent to 65 per cent, while the proportion that was uncertain decreased from 62 per cent to 28 per cent. Similarly, in Australia support for geothermal increased after a workshop (Dowd et al., 2011). Both countries do not have large amounts of installed geothermal so the initial uncertainly may be expected, what is interesting is the increase in support after some information was given. These findings suggest that information about the benefits of geothermal (and EGS) may increase its profile among renewable energy options.

An Australian large group study found that funding for geothermal was typically a high priority, but behind solar, wind and wave/tidal (Dowd et al., 2011). These responses indicate the public is supportive of geothermal as an energy technology compared to traditional energy technologies, but the support is not as strong as that reported for energy technologies like solar and wind. However support was stronger for geothermal in Adelaide and authors infer this may be in part due to the well-known EGS demonstration project in South Australia (Cooper Basin).

2.4. Industry Response to Induced Seismicity

The IEA (Majer, Baria, and Stark, 2008) and DOE (Majer et al., 2012) protocols suggest several steps to mitigate the risk of damaging seismic events and to help ensure public acceptance or support for EGS projects. Most countries do not have regulations that specifically address EGS yet there may still be local regulations regarding maximum vibrations and ground shaking. These protocols suggest dialogue with the public and local authorities at various stages of the project. It also recommends that a mitigation plan is developed based on a seismic assessment of the area and the development of a seismic monitoring network in the area (not just the operations site). It also recommends a process for evaluating damage in the event a seismic event occurs.

Quantitative thinking about risk management is typically explained as: risk = hazard / safeguards (Kaplan and Garrick, 1981). Therefore, by increasing the safeguards the risk can be decreased. Bommer et al. (2006) established a traffic light system for the project in El Salvador. The system is summarised in Table 3 below.

Table 3. Traffic Light System for Induced Seismicity

Traffic Light Colour	Threshold	Result
Red	Ground shaking is expected to damage to buildings in the area.	Injection is suspended immediately.
Amber	People feel ground motion but damage is unlikely.	Injection continues with caution and, if necessary, at reduced flow rates. Monitoring is intensified.
Green	Ground motion is below thresholds or occurs less frequently than background seismicity in the area.	Injection continues as planned.

Source: (Bommer et al., 2006)

This system was adapted for the Basel project's action plan during injection and stimulation of the reservoir. The action plan worked and when seismic events occurred that were unacceptable the operator suspended drilling and stimulation pending an independent risk analysis (Häring et al., 2007). The subsequent analysis found that it was not possible to continue the project (Baisch et al., 2009).[1]

Protocols point out that the major shortcoming of the traffic light system is that it does not address the issue of seismicity that occurs after the end of the injection period (Majer et al., 2007; Majer, Baria, and Stark, 2008; and Majer et al., 2012) By design, the traffic light system is applicable only after a seismic event has occurred.

Four research areas were identified by ENGINE. It was suggested that developing technologies to image fluid pathways would improve the mitigation of hazards from seismicity (ENGINE, 2008b). The best practice recommendations developed by

[1] More information about the risk analysis of the project can be found at http://www.wsu.bs.ch/geothermie (some reports are only available in German).

ENGINE recommend that in densely populated areas EGS projects are prone to increased public awareness and concerns, which requires more public communication and the potential that injection activity may need to be reduced to maintain long-term acceptance of the project (ENGINE, 2008a).

2.5. Lessons from Other Industries

The acceptance of other energy technologies is discussed in a range of other literature. Lessons from the acceptance of other wind energy in Australia is discussed in Gross (2007); solar energy in Spain in Heras-Saizarbitoria, Cilleruelo, and Zamanillo (2011) and hydrogen (Flynn, Bellaby, and Ricci, 2006; Wolsink, 2012). Hansen et al. (2003) discusses risk and public perception of food risks. Cypser and Davis (1998) and Savadori et al., (2004) discuss similar issues related to biotechnology. Public trust in energy technology in general is discussed by (Ashworth et al., 2011). These studies from other industries show that the public concern with new technology is not just related to objective risk but what they perceived to be the risk and what they perceive the benefit to be. The studies also highlight the issue of where befits accrue and where risk is borne.

3. Methods

Broadly this study seeks to bring the lessons from the field of risk communication and assessment to inform an assessment of the induced seismicity issue's impact on the viability of EGS to be deployed widely to help meet future energy demand. An initial step was a comprehensive analysis of the literature on the current state of EGS was done. Primarily this drew on published articles, project reports and outcome of workshops and conferences. The analysis of this literature showed that induced seismicity was an issue and that the industry and experts had been reporting about the issue and undertaking research about it.

This research was conducted in order to determine whether the issue of induced seismicity presents a risk to the viability of EGS. The literature revealed that EGS faces substantial economic hurdles the technology that need to be overcome before EGS can become viable for commercial use of a large scale. This study looks at the induced seismicity issue and draws on research and knowledge from the EGS technical field, that of seismicity and that the field of risk communication and management.

The original hypothesis that induced seismicity was an issue was adjusted in light of the technical material available that suggested EGS operations will not lead to a large damaging seismic event. The focus of the research then centred on the perception of risk. For this study this meant the public acceptance of risks of EGS operations inducing seismicity.

The literature study revealed cases of induced seismicity linked to EGS projects. The Basel case of induced seismicity causing minor damage and leading to the halting and subsequent closure of operations was used to inform the understanding of the seriousness of reaction to induced seismic events. This is a well-documented case, other cases are less well covered and required more use of looking to local media sources for information of what happened and how the local population perceived it.

The protocols and guidelines developed to address the risk and concern around seismicity induced by EGS operations were critically assessed with respect to what has been learned in the field of risk communication and management. This was used to assess how concerns and risk had been addressed. This involved assessing what the state of the art is in risk communications and using that knowledge to assess how the issue of seismicity is dealt with.

The published literature on EGS is overwhelming positive and supportive of the technology. The literature study found nothing the outright opposed the continued investment in the technology or was firm that the economics issue are unlikely to be resolved in the future (with appropriate funding). Many acknowledge the economic hurdles that need to be overcome. It is not clear if the positivity in the literature is due to a common opinion that EGS is viable with the right investment and development of technologies or if because it is a niche technology in an already niche field (geothermal power) that it has not received much attention in the wider scientific and technical community. This made ideas and literature from other fields important to help inform the understanding of whether the risk of seismic events from EGS is important. Important because while the EGS field of study focuses on the objective and technical risk EGS present sit does not address how the new technology is perceived.

The idea of the need for a narrative is adopted from the literature on innovation and applied to the development of EGS. As there are few EGS projects most of the ideas from projects that have occurred and had seismic difficulties needed to be extrapolated. Research from other fields enable and guide the teasing out of lessons from cases where seismicity has been an issue.

Another assessment was undertaken of the risk assessment and communication literature with a focus on drawing out what would help inform the study into how the issue of induced seismicity could have and effect on the overall viability of EGS. The development of risk communication and assessment over the last few decades demonstrated that the risk assessment for EGS did not take into account new ideas about the best way to address public assessments of risk. This could be that the response to induced seismicity are new and are yet to be fully developed. But the lesson from another field showed that the issue could be larger than may be expected if only the objective risk assessment tools and ideas are referred to.

4. Results And Analysis

This section considers the technical and economic feasibility of EGS in light of the current literature. The paper recognises that EGS is not yet commercially viable on a wide scale due to a range of economic challenges. In addition to the economic challenges facing EGS this paper considers the EGS industry's management of risk and public perception of risk. The section on risk explains that in order for EGS to become commercially viable it will need to avoid early setbacks such as those potentially caused by public concern or rejection of operations.

4.1. The Economics of EGS

The aim of the US GTO EGS programme is to create a 5MW reservoir by 2020 and achieve a LCOE of US6 ¢/kWh by 2030 (Ziagos et al., 2013). EGS has been described as having classic, small, niche technology attributes (Stephens and Jiusto, 2010) EGS has received limited political or public attention outside of a few areas. Three of the most active EGS companies in the US are Ormat Technologies, GeoThermex, and AltaRock Energy, each much smaller than the largest coal-affiliated companies (Stephens and Jiusto, 2010).

The commercial viability of EGS depends upon the successful demonstration that EGS reservoirs can be developed, sustained, and replicated under varying geological conditions (MIT, 2006 and DOE, 2008); these areas of R&D priority are reflected in the most recent DOE's EGS grants.

A workshop in 2001 identified the following areas for improvement before EGS becomes commercially viable in USA: a 20 per cent reduction in drilling costs, a production flow rate of 80 kilograms per second, and a 20 per cent improvement in conversion efficiency (Gurgenci, 2011). With the exception of the Landau project in Germany, past projects have not successfully sustained commercial production rates (50-100 kilograms per second) (Ziagos et al., 2013). Landau project is a partial EGS project as only one well required stimulation by injecting fluids (the other was naturally permeable).

For geothermal projects the cost are paid up front for the project. With fossil fuels fuel costs over the life of the project make up a substantial part of the cost. This cost is paid over time. Costs are reduced if fuel consumption is reduced. For geothermal reduced power output has no effect on costs as the majority of the costs have already been paid. This is the same case for EGS. The majority of the costs of an EGS project are invested up front.

The cost and capital characteristics of an EGS project make EGS projects sensitive to the consequences of inducing felt seismic events. Having a project closed, or provoking more restrictive operating parameters, introduces a potentially serious risk to EGS operations. Because so much of the project must already be invested before stimulation even begins causing a felt event means risking that investment.

There is a high financial risk for EGS projects without the risk of project shutdown or changes to injection/circulation parameters to avoid seismicity issues. The commercial success of EGS depends mainly on flow rate. Successful commercialisation equates to reaching a defined temperature combined with a defined flow rate. Having to reduce the flow rate because of the risk of inducing seismic events will affect the viability of the project. This is regardless of whether the parameters for flow are limited because of a "real" risk or if they are unnecessarily low to deal with a perceived risk.

Capital costs for geothermal power plants (including those using EGS technology) can be divided between surface costs (plant equipment and construction) and subsurface costs (reservoir exploration and drilling). The subsurface costs can be further divided between exploration and drilling cost and stimulation cost (including costs of design, execution, monitoring and assessment of results). There is less certainly around the subsurface costs of a geothermal plant. For conventional geothermal plants the surface costs can be better estimated than subsurface costs when the characteristics of the reservoir are not well known (Chamorro et al., 2012). As the reservoir needs to be engineered for an EGS plant this makes the subsurface costs even less certain than a conventional geothermal power plant. The majority of the cost in developing an EGS project is invested in the subsurface.

(Tester et al., 2006) undertook a survey that estimated the costs of 5,000 and 10,000 metre deep wells at 7 and 20 million USD respectively. These figures are for 2004, since then costs for drilling have escalated as crude oil prices have risen and the demand for land rigs has increased. (Ungemach and Antics, 2010) updated the figures and gives well drilling costs for 5,000 or 10,000 metre wells at around 15 and 40 million USD respectively (10.7 and 28.6 million Euros). Costs for geothermal are to some degree linked to costs in the oil and gas industry as they share the same drilling rigs (GTO, 2008b).

While the system for a convectional geothermal project makes up 25 to 50 per cent of the project cost, for EGS it is 60 to 80 per cent (Petty et al., 2013 and Gurgenci, 2011).

Most of the examples of induced seismic events from EGS that have been a concern have occurred at the stimulation phases. This makes the drilling costs for an EGS project relevant as they are already invested when stimulation begins. That these costs are a relatively large proportion of the overall budget is important as they may be at risk if induced seismicity is deemed unacceptable by a local population. Furthermore, if the costs are difficult to assess for the subsurface part of construction, assessing the impact of changed flow rates is more difficult.

EGS is not economically viable and still has to address some fundamental economic issues before it becomes commercially viable. This makes other issues with the technology (such as the seismicity issue) important as it does not have an established market nor doe sit have a solid argument that it is economically viable.

Whether or not EGS is commercially feasible is directly asked in Sanyal et al. (2007). Among the findings is that the capital requirements of EGS projects are too expensive. They are isolated projects. If EGS projects were developed in larger numbers the cost could get closer to conventional geothermal projects ($4,000 per kW for EGS compares to $3,000 to 3,500 per kW for conventional projects).

If drilling costs increase due to the demand for rigs that can drill to the depth needed for EGS, it will be essential to the emergence of EGS as commercially viable that there are further technological advancements.

To be viable EGS must lower its costs. Electricity prices need to be substantially higher than they are today for EGS to be viable. As prices are unlikely to increase sufficiently to make EGS viable, it will need to lower its costs (Sanyal et al., 2007).

Economic modelling of EGS by (Kitsou, Herzog, and Tester, 2000) concludes that R&D should focus on the development of techniques for the definition, formation and stimulation of reservoirs and that pilot projects should work towards attaining productivity levels needed for commercial operations. The (Tester et al., 2006) report indicates that for EGS to be economic existing projects will need to be three or four times more productive.

Bloomflied and Laney (2005) estimated the drilling cost for EGS and concluded that there is insufficient information available about the costs of drilling below three kilometres for geothermal and data from the oil and gas industry should be used.

Gowda, Hogue, and Moore (2011) used the Geothermal Economics Calculator (GEC) to calculate the construction costs of a 17.5MW EGS project. The total cost calculated was 114 million US dollars (excluding indirect and contingent costs). Exploration, confirmation, and main well costs amounted to about 55 per cent of capital of this. In a scenario by Glacier Partners (2009), exploration and drilling amount to 55 per cent of the total project cost. If the project is cancelled, this capital is lost. It amounts to a significant part of the overall construction budget.

R&D is not all the assistance a new technology may need in order to be brought to market. New technologies face a number of barriers even when the technical feasibility has been demonstrated (Sagar and van der Zwaan, 2006). The total cost of bringing EGS to commercial viability has been estimated at between $300 and $400 million (MIT, 2006) and $800 million–$1 billion (DOE, 2008) spread over 15 years.

Sagar and van der Zwaan (2006) look at technological innovation in the energy sector and argue that R&D efforts have been the basis for changes in energy production in the past and this will remain the case.

Stephens and Jiusto (2010) notes that some EGS actors have seen a decreasing overall investment trend in EGS. Some entrepreneurs in the US, Canada and Australia have backed away from or pulled out of EGS projects in favour of developing conventional geothermal projects which have fewer uncertainties associated with them. This suggests that government funding and support will remain essential for EGS.

The levelised cost of electricity for EGS is most sensitive to operations and maintenance (O&M) costs according to Sanyal et al. (2007). For the cost optimisation Sanyal (2009) takes the operations and maintenance cost from the U.S. geothermal industry. The study also concludes that reduction of operating and maintenance costs is the most important step in optimising economics of EGS for electricity. However, operational costs may be higher for EGS if seismic monitoring is going be required. Protocols by Majer et al. (2012) recommends monitoring over the life of the project and possibly longer. However, Sanyal et al. (2007) believe that unit O&M cost of an EGS project should be less than that of a conventional geothermal project and mitigate (though it is not stated as to what extent) the higher capital cost of an EGS project.

The issue of liability can make the costs of precautions worthwhile as they become inexpensive when considering the potential cost of compensation, defending lawsuits and possibly having to cancel the project altogether (Cypser and Davis, 1998). The last point is particularly relevant for EGS as a lot of the capital cost will already be invested in the project when injection occurs.

If it becomes necessary to isolate EGS projects from population centres there are additional costs, not to mention the lost opportunity to co-generate heat for district heating. It is not just the risk of an individual project being suspended or closed that could affect the viability of EGS. If the perception is that there is an extreme risk from EGS the public may call for constraints that restrict where EGS projects can operate. This could require EGS projects to be restricted to isolated areas away from populations. The cost of isolating EGS projects from population centres is discussed by (Wolfowitz and Ames, 2010). The analysis involved developing scenarios based on a variety of different restrictions on the proximity of EGS projects to fault zones and population centres in California and Nevada. Many of the scenarios show less than a 5% increase in capital cost due to constraints. However, while restrictions on EGS siting are unlikely to change the economics of individual EGS projects directly it may limit the overall installed capacity of EGS and the ability to exploit high-grade resources. This could have an indirect affect as limiting the construction of EGS projects will limit the economy of scale benefits that would contribute to lowering EGS costs. The growth of installed EGS projects has been pointed to as a key part of lowering the cost of EGS projects through an economy of scale (Sanyal et al., 2007). The Wolfowitz and Ames (2010) study also concluded that if constraints are far in advance of what is reasonable based on current seismological research there is a significant increase in the capital cost for EGS.

Cataldi (1999) provides an actual cost estimate for gaining social acceptance for geothermal projects. These sorts of costs are not included in the current EGS economic models. The suggested amount may be up to around two to four per cent of the total construction cost for the project and constitute the largest external cost (if total costs = cost of technical activities + external costs). These are for conventional geothermal projects and not EGS and do not explicitly address the issue of induced seismicity. Costs may escalate if we included the induced seismicity issue as assessment and monitoring for seismicity is included. Conversely, EGS projects at this stage in their development have higher capital costs than conventional projects, so the proportion for an EGS project may be lower. Nonetheless it gives an idea of what effect social acceptance may have on the economics of EGS.

The narrative, or “story”, of a new innovation is important to its success. According to Bronfman et al. (2012) the public acceptance of electricity generation technology is the determining factor in whether it will be successful. Wüstenhagen et al. (2007) suggests three dimensions of acceptance of renewable energy sources: socio-political acceptance, community acceptance and market acceptance. While the economic modelling establishes targets for EGS to reach in order for commercialisation this builds towards the market’s acceptance of the EGS technology but not the socio-political or community acceptance. Economic viability is no doubt part of achieving acceptance in these areas but it is not the sole determinant.

Lounsbury and Glynn (2001) proposes a framework that focuses on how entrepreneurial stories facilitate access to new capital and market opportunities. The framework suggests that to be successful entrepreneurs need to develop stories about who they are and how their idea will bring benefits for society. Sagar and van der Zwaan (2006) describes three phases for the innovation of technology: basic R&D, demonstration, and commercial roll-out. EGS is still in the R&D and piloting phase. There are commercial EGS operations but they are at very early stages and have relied on substantial government funding. Large-scale commercial roll-out of EGS technology is still a long way away. EGS technology is a still at the early stage of mostly R&D with a few pilot programmes, while some operations are described as commercial because they are partially funded by private money they still rely significantly on government funding or assistance. In order to advance and fulfil its promise EGS needs to continue to attract funding from government and other investors. The implication of Lounsbury and Glynn's (2001) framework for entrepreneurs is perhaps applicable because EGS technology is still largely at an early stage in its progression to large-scale commercial viability. Stephens and Jiusto (2010) applied Lounsbury and Glynn's (2001) framework to EGS and argued that the technology needs early success stories that the industry can use to explain the value of the technology and justify the costs to develop it in to a commercially viable technology.

An implication of this is that early difficulties will also form part of EGS's innovative narrative. Events at this early stage are likely to have an impact of how EGS is viewed as it is developed.

According to Webler and Tuler (2010) new energy technologies need to be accepted and adopted to reach their potential. It is not just a question of solving the technical questions for new energy technologies to succeed. R&D for new technologies focuses on overcoming the technical barriers and this has been the experience for EGS. The focus is on solutions to technical problems or getting the technology efficient enough to be economical. The potential social barriers are similarly dealt with in a technical manner by explaining and educating the public of the objective reality of the new technology. EGS is described by Stephens and Jiusto (2010) as a new and niche technology without extensive connections to the existing electricity generating infrastructure. This has made it more difficult for the sector to secure investment in new projects.

In the development of renewable energy sources the renewable camp are often compared as a group. However, EGS complements other renewables and can be seen as really competing with conventional base-load providers (coal, gas, nuclear for example). Different scenario projections made by Purkus and Barth (2011) about the role of geothermal in the provision of electricity were less optimistic if base-load electricity continues to be provided by conventional sources. In these scenarios geothermal (including EGS) is just an additional source of electricity that must compete with conventional base-load electricity producers while having higher associated investment costs.

Chatzimouratidis and Pilavachi (2008) studied the overall impact on the living standard of local communities of ten types of power plants (coal/lignite, oil, natural gas turbine, natural gas combined cycle, nuclear, geothermal, biomass, photovoltaic, wind, and hydro). Both positive and negative impacts of power plant operation were considered using multiple criteria and using different weighting scenarios. Regardless of the weighting scenarios studied, geothermal was ranked as the most favourable of the power plants.

Seismic events linked to EGS projects in Switzerland, France and Germany has raised public and governmental concerns about the risk of induced seismicity from EGS operations. With projects being put on hold or being cancelled has made the issue of induced seismicity an economic issue for EGS developers.

When the stimulation activities at Basel were halted in 2006 the stimulation of the reservoir had not been completed. In order for the project to be economic further stimulation was needed. However the analysis of the project after it was halted concluded that further development would accompanied by further seismic activity (Baisch et al., 2009). When operations stopped, 56 million CHF of the 80 million CHF originally budgeted had already been invested into developing the project.

The EGS plant in Landau, Germany has operated since 2007. In 2009 two earthquakes of magnitudes of 2.4 and 2.7 were felt by the population of Landau (Baisch et al., 2010 and Groos et al., 2013). There were reports of minor damage to buildings. The maximum injection pressure has been lowered as a result of these events (Evans et al., 2012). Two felt seismic events with magnitudes of 2.2 and 2.4 occurred during the stimulation of the reservoir near Insheim (about 4 kilometres from Landau) in April 2010 (Groos et al., 2013). At Soultz the injection programme had to be changed due to complaints by locals due to events up to magnitude 2.9 being induced and felt (ENGINE, 2008a).

Baisch et al. (2010) asserts that the public perception of geothermal projects is becoming increasingly negative in Germany.

Following the induced event at Soultz on 16 July 2002 that was felt and heard by the public, a committee of experts was established to review the incident. Recommendations by the group were incorporated into the plan to mitigate similar events. The new restrictions to activities (of ensuring there were not sharp pressure changes) became part of the stimulation plan for Soultz and led to the subsequent stimulations to take longer and use considerably more fluid (Majer et al., 2007). This study notes that the committee did not provide any evidence for their findings. This raises the issue of operation may face tighter operating restrictions than the evidence suggests in order to avoid felt seismic events in populated areas.

The cost of inducing seismicity does not just concern the cancelation or alteration of the project, and the subsequent lost investment, but also the potential compensation needed if an event is induced that causes damage. Following the seismic events in Basel, over 2,000 claims were filed for minor damage to buildings costing the operator 7 million CHP (Häring et al., 2007; Howell et al., 2012) and (Baisch et al., 2009; Wood, 2012). A risk analysis of the project was conducted following these events. The analysis concluded there was a high probability of stronger events if development and operation continued (Baisch et al., 2009; Tester et al., 2006). The largest expected event was M_L 4.5 and 14 to 170 felt events were expected during the 30-year operating period. The damage was expected to total 40 million CHF but there was a 15 per cent chance it would exceed 600 million CHF in case of an extreme event. According to the analysis report the expected property damage was considered unacceptable in Switzerland in terms of both the frequency of the occurrences and the value of damage.

To put these seismic events into context, Basel has had a large earthquake in its history that seriously damaged the city. Magnitude estimates for the 1356 Basel Earthquake range from Mw 6.0 to Mw 6.9 (Majer et al., 2007; RMS, 2006). That is about three magnitudes larger than the events caused by the EGS project.

Furthermore, Cypser & Davis (1998) and Ungemach and Antics (2010) looks at the issue of induced seismicity and legal liability. It raises the possibility of induced seismicity to be considered an issue even if it does not cause damage or injury. The (Cypser and Davis, 1998 and Hunt and Morelli, 2006) study of legal issues related to induced seismicity concluded that induced seismicity can become a legal issue even if no damage is caused (the seismicity may be a nuisance or a trespass issue). This means that while the magnitude of an induced seismic event may have been too small to cause damage if it was just felt it might expose an EGS operation to legal issues. The focus or the industry response to the risk of seismic events being caused by EGS operations have focussed on the probability of operations causing damage or injury to property or people, focussing on the probability of a maximum magnitude event. However, the frequency of all felt events should be addressed as it is smaller but more frequent events that will cause nuisance or trespass issues. The nuisance factor may be important if frequent felt seismic event upset people's lives, particularly if the events are felt at night and people's sleep is disrupted. The concern for the public will also be how long it will occur, particularly if it occurs after injection and during operation, indicating an on going nuisance.

In Switzerland the operator stood trial for the seismic event that occurred at Basel. He was acquitted but it shows the potential for the issue of induced seismicity to be an issue of public concern and moving beyond just a financial issue for a project.

The recommendation of the establishment of a process to deal with damage claims prior to any event occurring is important and recommended in the protocols that have been developed (Majer et al., 2008 and Majer et al., 2012). This is important to maintain public acceptance but to also establish what damage can be linked to an induced event and the extent the operators are liable for damages.

Knowledge that certain actions have caused harm in the past will make harm in the future foreseeable and therefore creates a duty to investigate the potential for harm from induced seismicity (Cypser and Davis, 1998 and Stephens and Jiusto, 2010).

The case of a natural earthquake occurring during or after an injection operation could lead to a situation where the public link the natural earthquake to the EGS operations. The public may not accept an industry explanation that the EGS operation did not cause the earthquake and perceive the EGS operation a fault and too risky to continue. The US GTO has recognised this risk and has concluded that any seismic event that halts a project is a catastrophe and a focus of their work should be on limiting seismicity (GTO, 2008c).

A further problem would be establishing to what extent damage caused by the natural earthquake was exacerbated by previous ground shaking caused during the injection process (Majer et al., 2007).

4.2. Risk Communication and Assessment

As discussed above, substantial cost reductions and improved flow at certain temperatures are needed to make EGS commercially viable. However, EGS must also provide evidence that it can be operated safely and reliably. This evidence of success is needed in part to build EGS's innovation "story", that is of a reliable, safe and economically viable way to produce electricity and/or heat. It will take clear demonstrations that EGS projects are able to operate within acceptable risks. This will not only avoid public concern but may go further and gain support for this technology.

To address uncertainty in risk assessment management requires a mix of statistical analyses and expert judgment. Statistical modelling requires a solid body of information. There have been few EGS projects so this body of information is not yet large enough. The classical definition of risk defines it as a function of the magnitude and probability of an event occurring. The public perception of the risk also includes (Sandman, 2012)'s idea of "outrage" in the assessment of risk.

The public focuses on the magnitude of what will happen if the hazard does occur rather than seeing risk as a function of probability and magnitude, each equally weighted, as experts do. Therefore, the public has a higher concern for risks that have high consequences and low probability than low consequence with high probability of occurring. For the public it is often the perceived risk that concerns them, and the perception of risk by the public give added weight to what the potential consequences are in a risk assessment. The risk communication for AltaRock's Newberry project emphasises that while the probable maximum magnitude seismic event is M=3.5-4.0 it is very unlikely to occur (less than one per cent probability of occurring) (AltaRock, 2011). For the expert described above the consequence is a 4.0 seismic event but as it is so unlikely to occur the risk can be assessed as low. However, for the member of the public described above the risk may be calculated as much higher as they give more weight to the possible consequences and under value the probability of it occurring. The two groups could reach different assessments of what the risk is.

The public perception of the risk from EGS operations has had an effect on EGS projects in the past. These examples establish that the seismic risk can affect a project and that it is not just the expert definition of risk (i.e. "real") that matters, the public's idea of risk (i.e. the "perceived" risk) is also key. It is how the public perceives the risk that determines their concern or "outrage" (concern defined by (Sandman, 2012)).

In the past experts have approached risk communication in terms of persuading the public and addressing a knowledge gap in their understanding. This deficit model of risk communication contrasts perceived risk with real risk. In this model the perceived risk represents a misunderstanding or lack of awareness about the real risk, which objectively represents the reality of the situation (Leiss, 1996). From such a belief it is easy to see why communicating the reality of the situation to the public is the how to overcome their mistaken perception of the risk involved. Communicating risk situations to the public is regarded as an act of persuasive communication (Leiss, 1996).

The risk of seismicity comes both from the real risk, a calculated risk based on the scientific understanding and evidence gathered about induced seismic events from EGS operations, and the perceived risk, based on how that risk is viewed and assessed by the public.

The classical approach to the issue of perceived risk from induced seismicity is to educate the public and untangle their misunderstanding of what the real risk is. Ideally this education will change the perceived risk to resemble the real risk. The effectiveness of this approach has been questioned. The understanding of the best way to approach risk communication has changed over time and simply providing information to the public may not be sufficient to address people's concerns. The move towards a two-way communication where the information used to assess risk is shared between all sides is suggested to bring better risk assessment outcomes. Not only in having all stakeholders accept the risk but that the risk represents all the information, scientific and public concerns. Most recent strategies for addressing risk include both the two-way communication and the stakeholder engagement (IOM, 2013).

Another importance with the perception of risk is also the perception of the hazard. While the magnitude 3.4 event in Basel in 2006 did little physical damage to buildings it did concern the public. The short period of shaking was accompanied by a loud noise similar to an explosion that contributed significantly to the frightening effect of the event (Deichmann, 2012).

In the process of assessing and managing risk there is often a mismatch between the level of certainty the public expect from experts and the level of certainty they can realistically deliver. Experts within an industry become used to working with the uncertainties and limitations in their industry (Fischhoff, 1995). However, these experts need to avoid assuming responsibility for risk management that they cannot deliver on because their understanding of the technology and/or of the risk is not complete or has an inherent level of uncertainties.

None of the responses to the issue of seismicity address the how to, or even whether or not to, communicate the idea of uncertainty in communicating risk information. By not communicating these ideas the industry runs the risk of public rejection resulting in shut down or restriction of operations and therefore considerable financial loss. EGS should work to communicate these ideas to the public as current risk literature suggests.

To address uncertainty risk assessment management requires a mix of statistical analyses and expert judgment.

What was not predicted by the operators was that the events after the magnitude 3.4 event were of a similar strength (Häring, 2007). Some of these felt events occurred months later. There has been criticism that the Basel project operators did not keep the local population well informed (AltaRock, 2010). However, even if they were well informed the population would have had to also be aware of the limitations and uncertainties of predicting the seismic activity from the operations. They would have also needed to inform the public that events may occur after stimulation activates have ended. Giving the public the stimulation schedule, as suggested as best practice, is not enough if the public do not understand that the felt event may not just occur during the stimulation activity. Here the communication of uncertainty is important to give the public a clear understanding of what may happen. Failure to provide this understanding in this case led to a backlash.

Risk needs to be considered alongside the costs and benefits that are connected to that risk. Assessing risk in isolation is meaningless, as without considering the benefits of a risk there would be no incentive to accept any risk if there is no associated benefit. This is where energy projects, including EGS, need to demonstrate not just what the risk is but what benefit the community that will have to live with the risk will receive from the project. The problem renewable projects have is one of the key benefits occurs at a global level and the individual project contributes only a tiny amount to the benefit. Renewable energy technologies have less effect on climate change, which is a global benefit of opting for a renewable plan over a non-renewable plant. On an individual level, however, opting to establish an EGS plant instead of a non-renewable plant will have almost no effect on global climate change. The benefit to the local population for the particular EGS plant may be low and accrue to those that do not have to accept the risk.

What the public thinks about an issue is important because it is a major force in the politics of democratic countries. This means that public acceptance of an industry can have a considerable impact on its viability.

There are several attributes of a risk that can cause it to be perceived as less acceptable. The attributes in the table below are from risk management of public health but offer several attributes that allow us to analyse the acceptance of risks. It is applied to the risk of induced seismicity to demonstrate that the perception of a risk can vary from its objective assessment of severity if the nature of the risk has certain characteristics.

Geothermal energy has not been widely exploited and the development that has occurred has largely been limited to particular geographic locations. As a consequence public experience with projects has been limited.

Table 4. Attributes of less acceptable risks applied to EGS induced seismicity.

Risks are generally more concerning and less acceptable if perceived:	Explanation	Applied to EGS and the induced seismicity issue
to be involuntary rather than voluntary	Voluntary risks are more acceptable than imposed risks.	Risk exposure is not necessarily voluntary. Public may have some say in citing and operations but individual consent is not needed.
to be of questionable benefit	Risks with clear benefits and understood risks are more acceptable.	EGS is not a well-understood technology so the benefits may not be understood without explanation or education. Some of the benefits from EGS are global (e.g. lower greenhouse gas

		emissions) where as the seismic risk is local.
as inequitably distributed (some benefit while others suffer the consequences)	Risks that do not target particular parts of the population are more acceptable.	Arguably the risk does not distinguish between locals. However some may see themselves as more vulnerable if they live in buildings that may be more affected by seismic activity. Also, locals may think they accept all the risk while the benefit is shared by all.
as inescapable by taking personal precautions	The ability for the individual or community to control risk makes the risk more tolerable.	The risk cannot be avoided by taking individual precautions. The public may therefore push for more community control over EGS operations. This could lead to restrictive parameters if the perception of the operation is high risk, regardless of the objective risk.
to arise from an unfamiliar source	The more familiar and understood the risk the more acceptable it is.	EGS is unfamiliar. The seismic risk it presents is still being studied and understanding of it and how to control it is not yet well understood. In areas without much natural seismicity the public may be unfamiliar with ground shaking.
to come from human activity	Risks from nature are more acceptable than those coming from human activity. Having someone to blame increases pressure for a response.	Seismicity caused by EGS is man-made. The operator can therefore be "blamed" for any felt seismicity.
to cause hidden and irreversible damage	Irreversible risks are less tolerable.	Induced seismic events can occur even after operations have been suspended. There may be public concern that felt events, regardless of causing little or no damage, may have a cumulative affect on structures.
to pose some particular danger to small children or pregnant women or more generally to future generations	Risks affecting vulnerable parts of the population are less tolerable.	The risk is faced by the whole community but nothing targets any individuals.
to threaten a form of death or injury arousing particular dread	A sense of dread decreases risk acceptance.	Experts say EGS will not cause a large event. However there is a perception that this is possible and may invoke a sense of dread in some.
to damage identifiable victims	Injury and damage grouped by time and location are less	The fear that EGS causes a large earthquake is

	acceptable than those spread out.	associated with a particular group of individuals i.e. those living close to the operation.
to be poorly understood by science or subject to contradictory statements	Risks are better tolerated if seen to be managed by trusted institutions.	EGS is still a niche within geothermal energy, which itself plays a small part in energy generation. EGS is still developing and experts are still investigating the link between EGS operations and induced seismic events. EGS is still developing its track record with the public.

Source: Attributes drawn from UK Department of Health, 1997; Reynolds, 2011 and Renn, 1998)

EGS operations demonstrate some of these attributes that could see the perceived risk being less acceptable than the real risk. The hazard of damage or worry from felt seismicity is involuntary for the community.

The emergence of the issue of induced seismicity in energy industries in the United States led to the (Committee on Induced Seismicity, 2012) report. The report looked at a number of energy technologies and found that induced seismicity may be associated with the development of different energy technologies involving fluid injection (including EGS) and sometimes fluid withdrawal. The report concluded that a large event or one that results in significant damage was unlikely. Nevertheless, the report also concluded that the issue required attention and management as any felt event was likely to be of concern to the local communities affected. The report provides a ten-point checklist that evaluates the risk of injection inducing seismicity and a seven-point checklist to help determine if seismicity is naturally occurring or induced.

The report's recommendations for best practice for the EGS industry provide for public concerns to be identified and addressed. This is only at the initial stage, after this the addressing of public concerns relies mainly on keeping the public informed about the project and when injection operations will occur.

A problem with informing the public of the planned injection schedule does not take into account the fact that at several sites seismic events have occurred after the shut in period. Informing the public when the injection operation takes place does not prepare them for an event weeks or months later. Some of the post shut-in events at Basel occurred months after operations were halted. The US report on induced seismicity and energy technologies recommended that the geothermal industry in the US adopt the traffic light system and fully explain to locals to ensure as a safeguards measure it is understood (Committee on Induced Seismicity, 2012). Operators would still need to communicate the limitations of the system and the uncertainties this creates for monitoring induced seismicity.

EGS uses hydraulic stimulation which is widely used by the oil and gas industry petroleum, shale gas and coal seam gas industries to enhance reservoir permeability. Hydraulic stimulation rarely constitutes a physical hazard as the forces involved are too small (Bendall et al., 2012). Although large events are unlikely small events can present a risk of causing some damage, albeit often minimal. The potential for damage from an EGS operation depends on where it is sited: it depends on geology of the area, the quality of buildings and infrastructure nearby, and the number of people in the neighbouring area (Bommer et al., 2006; Majer et al., 2012; 2007; Morelli, 2009).

Although the problem of induced seismicity is encountered in a number of industrial activities there is little published regarding acceptable thresholds of motion and guidelines on how the hazard can be quantified, monitored and controlled (Bommer et al., 2006 and Committee on Induced Seismicity, 2012). This has improved with Bommer et al.'s (2006) traffic light system and guidelines developed for El Salvador and the adaption of this system to Basel. Protocols have been adopted by the GEA (Majer et al., 2008) and the US (Majer et al., 2012) but these still lack details on appropriate thresholds. Participants at the EGS evaluation workshop in 2007 considered that the risk from induced seismicity is a public relations issue rather than a major problem (GTO, 2007).

The EGS industry and international and government agencies appear to appreciate that the risk of seismicity is an issue that needs to be addressed. The protocols developed and adopted by the IEA-GIA Executive Committee focuses on educating the public and putting the issue of induced seismicity in context (Majer et al., 2008). Public involvement is elaborated on in the protocols adopted by the US and suggest public involvement and a two-way dialogue (Majer et al., 2012).

Baisch, Schrage, and Kreuter (2010) states that the development and operation of geothermal systems can be numerically modelled. However, a limitation to modelling is the information regarding geological and hydrological parameters prior to drilling. Simulations cannot usually be calibrated during the planning phase of a geothermal project. In Germany regulators require a seismic risk assessment to be completed at an early stage of the project. Because of the uncertainty in simulations a worst-case scenarios is considered that tends to overestimate the risk (Baisch et al., 2010).

While analysis and experience indicates that EGS stimulation will not cause major earthquakes there are still uncertainties around exactly what information is needed (GTO, 2008c). It is also not yet clear how long monitoring should go on for. This creates an uncertainty in the operating expenses for a project if long-term monitoring is required even after a project reached the end of its life. A further complication is that to create a reliable monitoring network instruments may need to be installed in boreholes. However, the heat where they are installed decreases instrument life (GTO, 2008a). This means the monitoring network will need not just on-going monitoring but on-going maintenance costs will need to be considered for the economics of the project.

Majer et al. (2007) suggests that the occurrence of felt seismic events may be a characteristic of EGS operations.

As EGS projects have been R&D pilot programmes there is no experience to date of a long-term, continuously operated EGS plant. There is therefore nothing to draw lessons from on the behaviour of engineered geothermal reservoirs and seismicity beyond the stimulation phase. It is therefore not clear how these engineered systems will behave when operating over the 20-30 year life time of the wells/reservoir (Majer et al., 2007). The examples of induced seismic events that have been felt have [mostly] occurred at the stimulation phase of the EGS projects. What occurs during the operating phase of an EGS plant remains an uncertain part of the EGS future. Developing this knowledge is dependant on EGS projects going into long-term operation to develop a base of knowledge, which can be analysed.

Bommer et al. (2006) notes that published guidance on human induced vibrations suggests that if it is temporary is more likely to be acceptable than those that are on-going. It is also noted that short-term projects where there is low awareness among the nearby population may also give rise to more adverse comments.

The issue of induced seismicity is seen as a public relations issue as the risk of a damaging seismic event is low. Low both in the maximum event that will occur and low in the likelihood of it occurring. The quantitative approach to risk therefore sees this as a low risk. The potential damage is low and the likelihood is low, therefore the risk assessment is that it is a low risk. The issue here is that the public does not necessarily calculate risk in such a way.

The current standards for EGS developers to address seismic risk are incomplete. The IEA has adopted a protocol for developers to deal with the issue (Majer et al. 2008). This protocol was subsequently drawn on to develop more substantial protocols for the DOE in the US (Majer et al., 2012). The IEA and DOE protocols do not provide specific methodology to establish risk tolerances. The DOE protocols are considered to be a living document so should hopefully adopt any subsequent lessons from EGS research or experience.

In Basel, on 8 December 2006, a magnitude 2.6 event occurred that exceeded the predefined safety regulations. Stimulation started in 2 December and was planned to run for 21 days but after this event the action plan for the operation called for the suspension of stimulation activities and a shut-in of the well. Five hours after the shut-in the magnitude 3.4 event occurred. This was felt by the public in Basel and caused minor damage to some buildings in the city. In early 2007 four more seismic events with magnitudes between 2.8 and 3.2 were felt by the population (Baisch et al., 2009 and Deichmann, 2012).

Part of the Basel project's mitigation plan for induced seismicity was to adapt the traffic light system that was established for and used in El Salvador. The thresholds were tightened for the Basel project.

The planning for the Basel project had not ruled out the probability of an event like the magnitude 3.4 event that occurred. A seismic monitoring network was established in response to stimulation operations. The plan of action the operators had in place worked as it was designed to and stimulation was halted when the strong event occurred. The operators themselves ended the stimulation operations not the authorities. Though it worked as designed it did not avoid the strong event or the following aftershocks. This fact highlights the limitation of the traffic light system, not only in relying on the initial event to occur but also that it is not a tool that can address the issue of seismicity post-injection.

In 2011 an ombudsmen was appointed by the local government in Landau to act as a point of contact for all citizens who have recorded damage allegedly caused by seismic activity.

Experts sometimes assume that the public understands that what they can do to mitigate lowers the risk but does not remove it and what they should communicate is that there is uncertainty in risk management.

A report in 2009 of the Landau seismic events suggested that the felt events there in 2009 were caused by the geothermal operations at Landau (Keilen et al., 2010). Another report in 2012 reiterated this and similarly suggested that the felt seismic events in Insheim were probably the result of the geothermal operations at Insheim (Althaus and Fristschen, 2012).

After the July 2006 event at Soultz changes were made to the stimulation operations. However, these changes did not avoid further seismicity. There were 30 events above 2.0, with the largest being a 2.9 event on 10 June 2003. The recommended changes were made after the initial incident in order to avoid similar events, the fact they did subsequently occur in spite of the changes left the project with a credibility problem (Majer et al., 2007). This has created difficulties for the project. This highlights the problem of communicating uncertainty to the public. The experts may have been aware that the changes made to the operation would have avoided further events based on their understanding of how the induced seismicity was caused. That they could not guarantee to avoid further events should be communicated to the public. To the experts this may seem obvious, that is they were not certain about the connection, but the public an often assume that science can provide certainty where it cannot. This underlines the point that experts need to avoid assuming responsibility for risks where their understanding may be limited or uncertain.

For almost all technologies there are specialists who are in favour of the technology and there are experts who have objections against it (Siegrist et al., 2000). EGS technology has not faced significant objections from experts. Awareness of EGS among environmental organizations and scientists appears limited (Stephens and Jiusto, 2010). There may be scepticism about EGS being able to become commercially viable but not outright objection to the use of the technology. It is not clear if this is because EGS has few downsides or if it is a niche technology within a niche energy source (geothermal). Either could change, if more EGS projects gave rise to new issues or emphasise existing concerns. Furthermore, if EGS becomes a more prevalent use (as proponents suggest it could with 100GWe by 2050 in the US) then this may see experts with objection become more vocal.

Another issue that has emerged concerning renewable energies is the so-called "green on green" where environmental groups may clash over the use of renewable technology in certain areas. An example from one renewable technology illustrates the issue. In a study of public perceptions of wind power in Ireland and Scotland found that environmentalists are not necessarily a homogenous group (Warren et al., 2005). The study found that the perception of wind power ranged from support for the development of wind power as it is a clean energy technology to opposition to development because they impact the landscape. Within the spectrum of opinion there are those who support renewable energy in principle but oppose specific projects.

Ascribing resistance as simply NIMBY-ism (Not In My Back Yard) can be counter productive to gaining public acceptance as the label is seen as offensive by the community (Wolsink, 2012).

Induced seismicity is less of an issue if the EGS operation is in a remote area without a population living near by. This is not always desirable. The Basel Deep Heat Mining Project took place close to city because it cogenerated electricity and heat for district heating in Basel. The Basel project was a demonstration of the potential for the coexistence of EGS projects with other industrial activities within city limits (Tester et al., 2006). Cogeneration requires proximity to population centres. While electricity can be transported over long distances economically with the right infrastructure, the transport of heat is very limited. The heat loss and cost of underground district heating pipes makes it necessary to be close to the population centre the heat is being provided for. Avoiding populated areas would remove the ability of EGS to be used for district heating.

One of the suggested lessons from the Basel project was to avoid EGS projects near populated areas (Ungemach and Antics, 2010). In areas where there are few people and/or they are economically dependent on the EGS operation there is likely to be a higher tolerance of seismic risk. However, Majer et al. (2007) has suggested that Switzerland has a very risk adverse population.

The project at Cooper Basin, Australia is in a remote area and there is little or no concern by the community about the risk of induced seismicity (Hunt and Morelli, 2006). The relationships between hydraulic input pressure and induced seismicity studies can be tested without risking seismic events felt by a large population. In such areas the variables needed for commercial operation can be developed while minimising the risk of the projects being prematurely ended or having to limit operations to avoid seismic hazards occurring. Such projects may therefore be the most valuable to further knowledge about EGS systems.

In the US, the DOE has suggested that EGS projects should only take place in unpopulated areas until the link between EGS and seismicity is better understood (GTO, 2007).

Buildings in areas with low natural seismic activity may not be engineered to the same standards as areas with higher levels of natural seismicity (Simpson, 1986). This could create a concern about inducing a large seismic event among the population.~

4.3. Lessons from another technology

In France the oil industry has been calling for a review of the ban on hydraulic fracturing ("fracking"). The oil and gas industry has argued that there is a double standard in legislation as geothermal fracking is permitted while shale fracking has been banned (Alic, 2013 and Patel, 2013). The oil and gas industry in countries with moratoriums or bans on them fracking may question why geothermal is permitted to conduct similar operations. The geothermal industry claims the processes are different but this may not matter as this may increase public opposition to EGS projects if they are perceived to be the same processes as fracking for oil and gas. There is little opposition to EGS to date principally because it is still a niche technology. EGS operators will need to be ready to react to any criticism and be able to show that the risk from EGS operations are able to be managed or at least predicted with acceptable certainty. This makes dealing not only with the objective risk of induced seismic events important but also highlights why the issue of the public perception of the risk is dealt with by the EGS industry as it progresses. If the oil and gas industry leads a debate about fracking, the geothermal field, including EGS, will likely be dragged into it and receive more attention.

Public concern about fracking has lead to bans in some parts of the US and Canada, moratoriums in Bulgaria and France, and increased regulation in Australia and The United Kingdom. Wood (2012) argues that the oil and gas industry relied on arguing that the environmental concerns were based on misunderstandings of the objective risk fracking posed. Seeking to address the deficit in public knowledge has not allayed concerns and the public concern has become the basis for moratoriums or outright bans on the practice. This shows that the perceived risk can have significant impacts on an industry.

5. Conclusion

This paper has shown that the nature of EGS means the public perception of it as a safe technology is important to its commercial success. EGS is still a relatively immature technology and is yet to prove itself economically viable for widespread development. The economics of EGS present the biggest hurdle to its widespread commercial development. EGS operations cost too much and do not yet produce sufficient electricity (or heat for those connected to district heating) to be commercially viable. Drilling the wells and developing the subsurface network of an EGS operation take the majority of investment. EGS projects therefore have the majority of the money invested when the seismicity issue may become a problem.

In light of the economic issues stopping the viable widespread commercial use of EGS the issue of induced seismicity may not appear to be a significant issue for the industry. There have been cases where individual projects have been cancelled, delayed or had limits placed on activity after inducing seismic events that were felt by the local population and caused them to question the acceptability of the risk presented by EGS operations. The issue has received the attention of the EGS industry and responses to the issue have been developed. These responses have focussed on educating the public and address misunderstanding about the technology an the nature of the risk. They also have developed ways to mitigate the issue. These methods do not address the whole problem. To experts the risk is small, the hazard is small and its likely varies, but it is very unlikely to cause a large damaging event. Experience from other industries and in the literature and case studies from risk studies have shown that the public focuses more on the consequences of an action and less on its likelihood of occurring.

The problem of projects being upset by public concern is heightened by the capital structure of an EGS project. Significant amounts of the investment for a plant are made early on. The current state of reservoir modelling means that the induced seismic issue is often only fully known after this investment is made. If the operation subsequently causes concern amongst the local population or authorities this investment may be at risk. This paper has shown that this has occurred in Basel, Switzerland. Furthermore projects in Landau, Germany and Soultz, France, have had to alter their operations because of similar concerns. These may only be a handful of cases but as there are relatively few EGS projects they represent key parts of the development story of the technology. The Landau and Soultz project may present features that suggest they are not “full” EGS projects, however, they are often included under the EGS term and their success and difficulties is contributing to the narrative of EGS technology.

This paper has argued that as a new and innovative technology EGS needs to establish a story that shows investors (private and public) that the technology is a safe and reliable method to generate electricity and/or heating that presents risks that are manageable and acceptable to local populations.

The literature on innovation suggests that new technologies need to develop a strong narrative (i.e. a “story”) that inspires confidence in the technology from the public and investors (public and private). False starts have a negative impact on this narrative. False starts such as Basel are important when the technology has few projects operating to provide electricity and/or heat. The association of EGS with seismic events that are felt and cause damage (albeit minor damage) presents a risk to the acceptance of new technology. The literature has shown that people tend to support their preconceived idea about a risk and that if it is seen as too risky it is difficult to shift that perspective. New information is more likely to be selectively used to support their already held ideas.

Support for EGS is essential to the development of EGS. Because it is a technology that has yet to surmount its economic issues it will continue to rely heavily on public funding. Ultimately, the risk is that the public rejects EGS as a niche technology that is too risky to be worthwhile spending public funds to pursue. This is heightened when EGS struggles to make a case for its economically viability. It also must compete with other technologies that can meet future energy needs. This is especially true of other renewables that have established markets (such as wind and solar power). There is nothing about EGS that guarantees its success, other options exist and the public favour may not just be about the object risk and benefit but about the public assessment of the risk and benefits of the technology.

Other technologies, such as fracking, have faced restrictions or bans on their use because they are publically perceived as presenting unacceptable risk. The objective assessment of the risk presented may make them acceptable. The potential of EGS to provide power with few environmental impacts means it may escape so of the concern associated with fracking, but the fracking case does show what can occur the public perception of risk is ignored and the focus is just on trying to bridge a public misunderstand about risk.

While EGS projects in the US and Australia may be able to continue in remote and sparsely populated areas, projects in Europe (especially those that also generate heat for district heating alongside electricity) will be near population centres. The paper has argued that people's understanding of risk is often not limited to their own experience but drawn on from others. EGS projects globally will build towards the public's understanding of this technology. This is especially the case while EGS is a new, niche technology that few are aware of.

The industry has addressed the issue of induced seismicity and has developed guidelines and protocols to manage and mitigate the risk. These reactions need to show they are capable of mitigating the risk. The protocols developed and adopted in the US for example are supposed to be living documents. This is important as they currently focus on EGS as a technical issue that is most a public relations exercise to address misconceptions among the public. They do not address the public perception of the risk present. An assessment that gives more weight to the potential consequences than the likelihood of it occurring. In communicating with the public it may be more beneficial to focus not on how likely it is for an event to be induced but what that event will be. Even the larger predicated seismic events are small compared to natural seismicity. Experts also need to be clear and communicated the uncertainty in their understanding. The worry among experts is that communicating uncertainty may undermine public confidence in their abilities. Research about communicating uncertainty to the public suggests that the public do understand scientific uncertainty and what information so as to make an informed choice.

The nature f the seismic risk also has an effect on it acceptability. There are several characteristics that make risk less acceptable to the public. The risk of EGS induced seismicity has several of these characteristics. Again underlining that the perception of risk is important when assessing risk and needs to be included in any risk assessment.

This paper has shown that risk perception is important. Even if perceived risk is rejected by experts in favour of an objective risk assessment it is still part of a democratic decision making process. Experts have traditionally sought to address perceived risk by trying to inform the public and bring it into line with the objective assessment. This paper has demonstrated that the field of risk communication and management has recognised that perception plays a role in the overall assessment of risk. Decision making about risk has moved on from the traditional deficit model to include public perception and ways to allay concern about risk. Communicating the benefit local receive from the projects is important. The benefits of EGS that are most focussed on accrue to the population as a whole, not only to those nearby. The risk however is solely borne by locals. The risk locals are being asked to accept looks different to experts and the public. The idea that risk assessment has an emotional element for the public should be included in risk management and communication. It should not only be looked at as a misconception of the public that can be cleared up by educating them and bridging what experts often see is a deficit in the public's understand of how to objectively assess a risk.

EGS is a promising technology as it provides the potential to provide large amounts of energy with limited environmental degradation. As a technology it promises to allow areas that have not traditionally had access to geothermal energy to access this renewable energy. This benefit is at the national or even global level but the risk of induced seismicity is borne by a local population. So while it is important for the industry to highlight its renewable nature they must also develop and communicate the local benefits of this technology.

EGS technology has could unlock vast amounts of energy that can be used to meet future energy demand. It can do this while limiting the production of green house gases. It is also a renewable power generating that can provide base load supply to a network. It therefore holds great promise. However, it is yet to demonstrate that it can be done economically. With a acceptable return on investment EGS will continue to rely heavily on public funds. Without a strong economic case to support it the public acceptance (or at least avoid public concern) of it becomes an important issue. The EGS industry has accepted that induced seismicity is an issue and that it is not just about damage and injury but about nuisance as well. However, responses so far (and most are relatively new and evolving) address it only as a technical and public relations issue. This paper has demonstrated that it is not just about objective risk and the perception of the risk is also important. Going beyond the deficit model to address the difference in risk assessment will be important for EGS to develop its narrative as a reliable and safe technology. This stand alongside its need to demonstrate that it can be economical to the overall viability of this technology. Demonstrating economic and technical viability are absolutely key to the development of EGS. The issue of induced seismicity may appear less important next to the economic hurdles, however the risk is that concern about it may undermine the case for a technology that has no established market and alternatives also competing for public funding and market attention.

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