GEOTHERMAL ENERGY AND STORAGE

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Executive Summary

This report summarises the main issues related to potential conflicts and possible synergies between geothermal activities and CO_2 geological storage, for the purpose of finding what further research into this area will be necessary and what further steps could be taken by IEAGHG. The majority of the information in the report is largely based on a conference held by the GFZ in Potsdam on Geothermal Energy and CO_2 Storage: Synergy or Competition, which was largely focussed on European issues and did not cover an overall global perspective.

There are two principal types of geothermal energy, the traditional hydrothermal, which mines heat using the in-situ geothermal waters and Enhanced Geothermal Systems (EGS), where alternate methods are used to mine the heat. This can involve the fracturing of a low permeability rock to increase fluid flow, as in a Hot Dry Rock System.

For geothermal activities to take place, a temperature of at least 150°C is necessary, which will usually relate to a depth of 4000m, but can be much shallower depending on the geothermal gradient.

The majority of prospective areas for CO_2 storage in Europe do not overlap areas of hydrothermal resources. The most significant areas of potential geographic overlap are Poland and the Paris basin. In these areas any potential storage projects would need to take potential conflicts into account.

There are many similarities between CO_2 storage and geothermal energy, especially in the way that exploration of the area takes place and the design process of the project. Both technologies require detailed information of the subsurface and site exploration would be a similar process and so there are many opportunities for sharing of information.

Geothermal and storage activities will usually take place at different depths, but there will be the occasional conflict of pore space, which will need to be considered during site selection and characterisation.

The only current or proposed projects combining geothermal and CO_2 storage are on a small scale and in only a few areas where it is possible for the technologies to work in conjunction with each other. Projects could exist using the same formation or using different formations in the same area. However, there has yet to be any large scale combined projects and so there is likely to be only a relatively small amount of real-life data regarding any possible synergies, therefore any IEAGHG study would likely mostly focus on modelling.

More research is needed on the possible synergies and conflicts of geothermal activities and CO_2 storage, especially in regards to using formations at different depths for different activities. If the European experience of limited overlap is repeated elsewhere in the world there will only be niche opportunities for synergy, but this is not known nor is it known or if it can be used more widely and be possible on a larger scale.

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GEOTHERMAL ENERGY AND CO_2 STORAGE

1. Introduction

This report is largely based on a conference held by the GFZ in Potsdam on Geothermal Energy and CO_2 Storage: Synergy or Competition, which was attended by Millie Basava-Reddi, IEAGHG. The aim of the report is to establish what the possible conflicts and synergies are between the geological storage of carbon dioxide and geothermal energy, and what further steps could be taken by IEAGHG. It should be noted that the conference was largely focussed on European issues and did not cover an overall global perspective. The major focus was also mostly on geothermal use for power generation, though some low enthalpy (heat generation) activities were also considered.

2. Technical Background

Geothermal energy is the harnessing of heat from below the Earth's surface for the purposes of heating or power generation. It can be used for electricity production, direct heating purposes, such as through hot springs and for efficient home heating and cooling through geothermal heat pumps.

There are two principal types of geothermal energy, the traditional hydrothermal, which mines heat using the in-situ geothermal waters and Enhanced Geothermal Systems (EGS), where alternate methods are used to mine the heat.

2.1 Hydrothermal Systems

To develop electricity from hydrothermal resources, wells are drilled into a geothermal reservoir, which can be defined as any underground aquifer (water bearing strata), which can be used for the purpose of heat production. The wells bring the geothermal water to the surface, where its heat energy is converted into electricity at a geothermal power plant. There are four commercial types of geothermal power plants, flash power plants, dry steam power plants, binary power plants and flash/binary combined power plants. Commercial plants are used worldwide, though the largest energy producer is the United States which produces 17,840 GWh/yr.

In a flash power plant, geothermally heated water under pressure is separated in a steam separator into steam and brine. The steam is delivered to the turbine, which in turn powers a generator and the cooled liquid is then injected back into the reservoir. Dry steam power plants, are run from steam produced directly from the geothermal reservoir. Binary power plants are able to produce electricity from geothermal resources lower than 150°C, by the use of a secondary liquid with a lower boiling point than water, such as isobutene. The geothermal water heats the secondary liquid through a heat exchanger, and the resulting gas turns the turbines. Flash/binary combined cycle plants use a combination of flash and binary technology. The portion of geothermal water which “flashes” to steam under reduced pressure is first converted to electricity with a backpressure steam turbine and the low-pressure steam exiting the backpressure turbine is condensed in a binary system.

2.2 Enhanced Geothermal Systems

There are also emerging enhanced geothermal systems (EGS), such as the hot dry rock system (HDR), where the potential reservoir is of low permeability with only a small amount of in-situ fluid. The reservoir is enhanced by fracturing, pumping water into and out of the hot rock, and directing the hot water to a geothermal power plant. This is in the development and demonstration phases, with the largest project, a 25 megawatt demonstration plant being developed in the Cooper Basin, Australia

A supercritical fluid such as carbon dioxide can be pumped into an underground formation to fracture the rock, thus creating a reservoir for geothermal energy production and heat transport. The supercritical fluid used to form the reservoir can heat up and expand, and is then pumped out of the reservoir to transfer the heat to a surface power plant or other application. This is still in the testing stage and there are not yet any large scale projects.

3. Conditions for Geothermal Activities

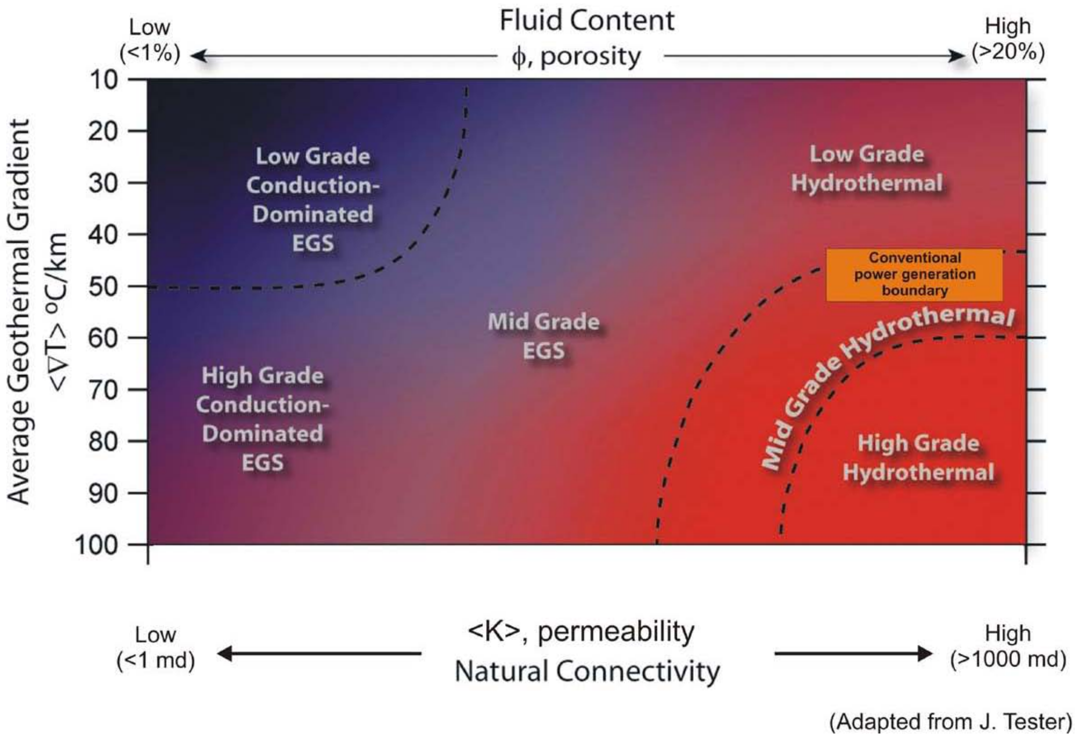
For a geothermal project to produce electricity, it is necessary to select a site where there will be sustainable production from the reservoir, with the usual lifetime of a project being around 30 years, and up to 70. Re-injection with no significant pressure change in the aquifer must be possible, so therefore a porous or fractured rock, which allows a flow rate of at least $100m^3/h$, needs to be present. It must have a sufficient temperature (usually at least 150°C), which is generally consistent with a depth of around 4000m, though can be much shallower depending on the geothermal gradient. There are also often technical requirements of the geothermal fluids, in regards to corrosion, scaling and Injectivity.

The type of reservoir can be of a sedimentary type, either a porous or fractured sandstone or limestone, or in the case of an enhanced geothermal system (EGS), a crystalline rock, which can be consequently fractured.

Traditional geothermal systems are only available in certain areas, which is not necessarily where power generation is needed. Hot dry rock systems do not require an already highly porous and permeable formation. The permeability can be enhanced by pumping high pressure cold water down an injection well into the rock. The injection increases the fluid pressure which causes the rock to fracture, by mobilising shear events. The injected water travels through fractures in the rock, capturing the heat of the rock until it is forced out of a second production well as very hot water, which is subsequently converted into electricity using either a steam turbine or a binary power plant system. The cooled water is injected back into the ground to heat up again in a closed loop. The major advantage of this technology is that it can potentially be used in most places, though it may not always be economically feasible.

As can be seen in the below diagram, the use of EGS can make use of areas, where power production from conventional geothermal energy would not be possible.

Figure 1 (Antics and Ungemach)



4. Concerns of using geothermal energy

The lifetime of each project is expected to be between 30 and 70 years as by this point outflow temperature will have dropped by 10˚C, though over time, the temperature will recover. This means that even though geothermal energy can be considered a renewable resource, as the temperature will recover due to heat flow, it can also be considered exhaustible, as it can be exploited over the conductive heat supply.

To achieve the longest possible lifetime for each project, reservoir engineering and management become very important.

Reservoir engineering addresses, heat in place, reservoir performance, well deliverables, heat recovery and reservoir life.

First a conceptual model is built using data from surface and subsurface exploration and well data. From this reservoir simulations can be carried out, which can help predict the likely outcome/ evolution of the reservoir. A production management scheme can be developed from this and heat extraction can begin. The system should be continually monitored for any changes. An issue that can arise is premature cooling, caused by thermal breakthrough to the production well, thus reducing the life of the project.

To prolong the life of the project, alternate production and injection wells can be drilled.

A major issue of using EGS is the possibility of induced seismicity. It is often thought that major seismicity only occurs at depths of greater than 5km caused by major changes to the state of stress, but it should be noted that there have been many cases of shallow seismic events, including rain induced seismicity in Germany and Switzerland, where the small pressure changes associated with precipitation is enough to cause earthquakes within the shallow subsurface. In an enhanced geothermal system, fluid is injected into the formation. The injected fluids rarely exceed the level of the least compressive stress in the crust and it is not the amount or pressure of an injected fluid that supplies the energy to generate an earthquake. The fluids merely decrease the resistance to failure, and it is the ambient tectonic stress that drives the seismic activity (Deichman, 2010).

There are not that many current examples of EGS for comparison studies, and so, while it is possible to understand the causes of induced seismicity, it is difficult to predict which geothermal projects will experience it.

5. Competition for the Underground

Several activities make use of the underground including mining, hydrocarbon exploration and production, natural gas storage and waste disposal, as well as geological storage of CO_2 and geothermal energy production. There is not necessarily overlap in each case, but when there is, it is necessary for either one to take priority over the other, or for the two activities to work together, which may not always be possible. The below table shows the main requirements of CO_2 storage and geothermal projects.

Table 1: Comparison of Geothermal and CO_2 Storage Requirements

	Geothermal	**Storage**
Minimum Depth	2000m	800m
Preferred Depth	3000-6000m	1000-2500m
Temperature	≥150˚C	Low/intermediate ≈ 30-50˚C
Porosity/ permeability	High	High
Rock Type	sandstone/ limestone/ crystalline rock that can be fractured	Sedimentary
Internal Structure	Fracture zones with dense	No fault systems (that could be

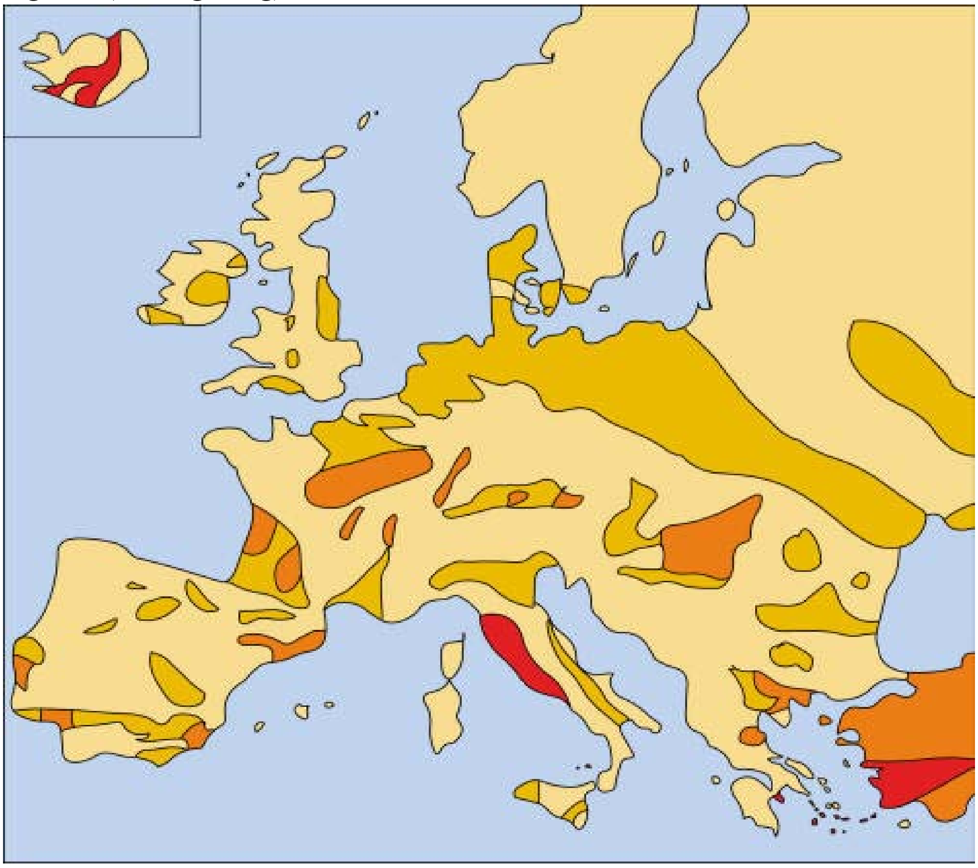
	fracture network	leakage pathways)
External Structure	n/a	Structural trap
Caprock	n/a	Excellent quality

6. Possibilities of Overlap between Geothermal Activities and CO_2 Geological Storage

The possibility of overlap in Europe is looked at as an example, but it can be assumed that there will be similar situations worldwide. This is looked at in simple terms of geographical overlap and not in 3D, which is looked at in later sections of this report.

Map of locations of potential areas for geothermal projects

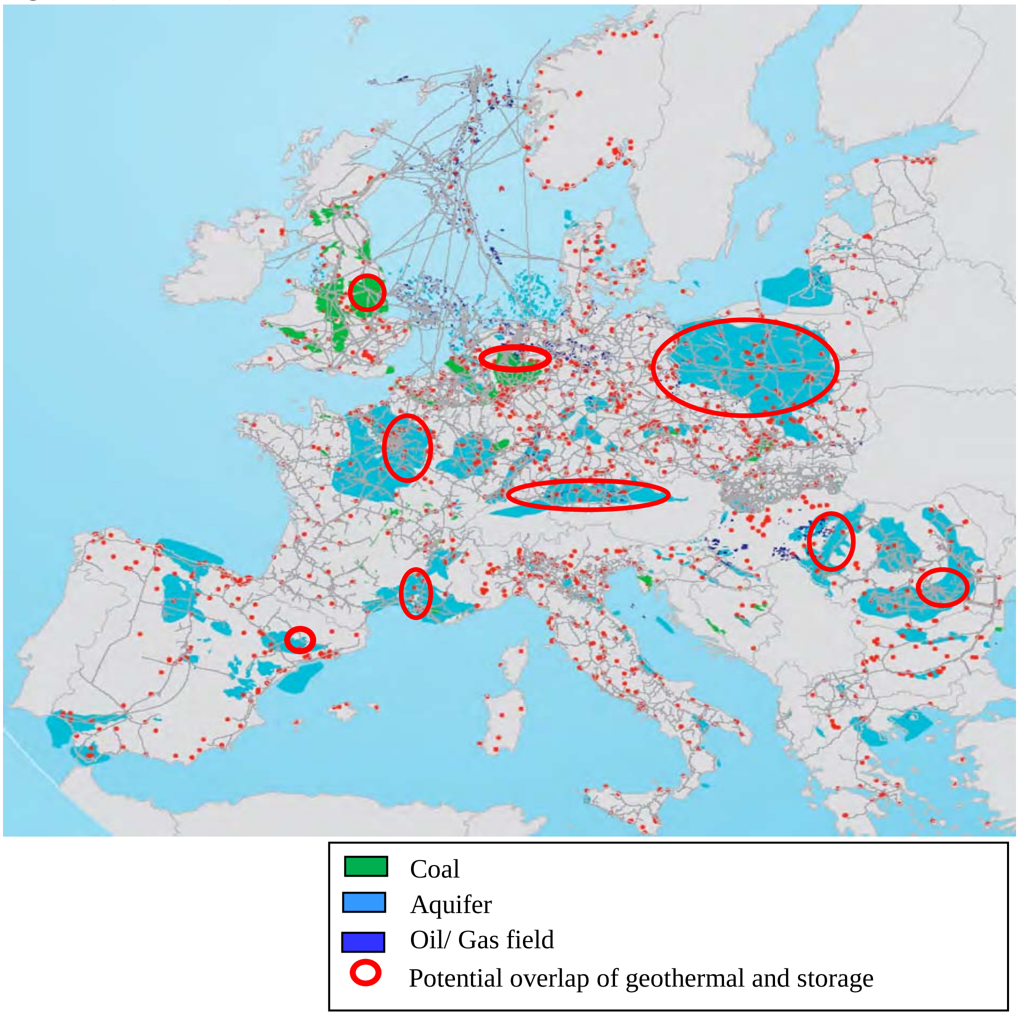
Figure 2 (www.egec.org)



High enthalpy (electrical power)
High temperature basins (el. power, district heating)
Medium temperature basins (district heating)
Everywhere (EGS)

Map of potential areas for geological storage of CO_2

Figure 3 (Hazeldine)



If you take the possibility of EGS being feasible anywhere then there will be overlap at all onshore locations. However as this is still an emerging technology, it would make more sense to look at the locations of conventional hydrothermal reservoirs.

Figure 3 shows where the most overlap occurs (in red circles). The majority of prospective areas for CO_2 storage do not overlap areas of hydrothermal resources. The most significant areas of potential geographic overlap are Poland and the Paris basin. In these areas any potential storage projects would need to take potential conflicts into account.

7. Possibilities of Synergy

Both geothermal and geological storage activities are still in the development stages and can have a common baseline in research. They will use similar instruments and approaches to reservoir modelling and understanding of underground processes, to enable site development. Storage sites have more interest in the monitoring of the site and they have different site selection criteria, but the research process and development phase, especially concerning EGS, are similar.

7.1 Information Sharing

Geothermal activities and geological storage of CO_2, both require detailed information of the subsurface. This information may have already been gathered by the oil and gas industry; otherwise new surveys may need to be carried out for site selection purposes. It may be possible for there to be more information sharing between the two industries, especially if a site is deemed unsuitable for one activity.

For storage sites, the aim is to have leakage rates of zero, and it has therefore been necessary to conduct much research in the area of wellbore integrity in order to avoid leaky wells. This is an example of information gained from geological storage that can be used for geothermal activities.

7.2 Different Formations in the Same Area

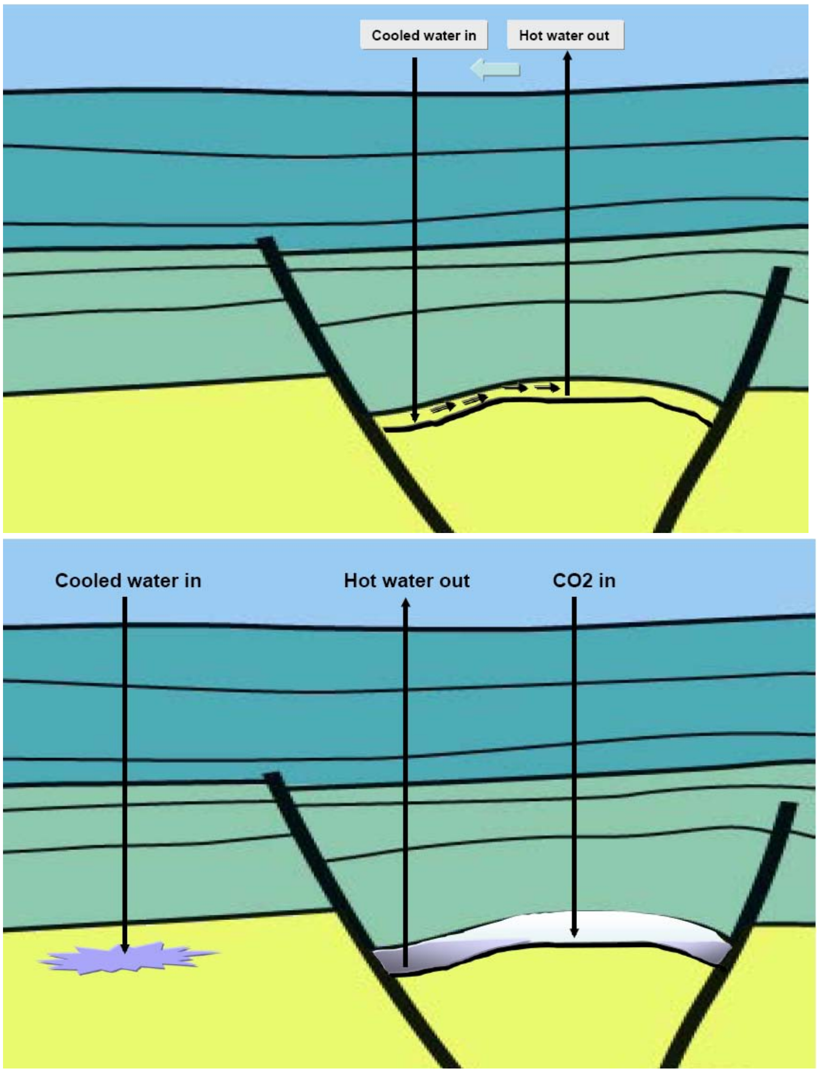
It has been proposed, due to the different requirements of storage and geothermal projects and the different likely depths of each project, that it may be possible to have both activities taking place in the same area, but using different formations at different depths. This proposition would depend upon the particular circumstances of the site in question and may not always be possible. The effects of one activity on the other would need to be assessed as well as the likely order of activities. For example, the geothermal project would be taking place at a deeper location and may involve drilling through the storage formation. It would also need to be decided who was responsible for what.

Advantages gained could be the reduction of pressure in the storage formation, by having a production well, which would extract brine, which could be injected into the geothermal system along with the ‘cold’ produced geothermal water. This would all be very site specific and dependent on what other pressure fields would arise.

7.3 Using the Same Formation

Another suggestion, from a proposed project in northern Denmark by Vattenfall, which is currently in a very early stage, was the possibility of using the same formation for both geothermal and storage activities (diagram below). The proposed formation is Triassic sandstone at approximately 2km depth. There have been delays in the storage project and it has become likely that the geothermal project will happen first.

Figures 4 and 5 (Adapted from Christensen, 2010)



Two wells, one injection and one production, could be placed in the formation for the geothermal project. After some time one of the wells could be converted to a CO_2 injection well and the produced geothermal water would then be injected into another part of the formation, separated from the storage area by a fault. This would have the added advantage of reducing the effects of pressure in the storage formation. There are also other possibilities of disposal of the produced geothermal water into the sea, but this would depend on the quality of the water. The estimated project lifetime is between 30 and 40 years.

It was emphasised that a great deal of forward planning would be necessary for this project to take place.

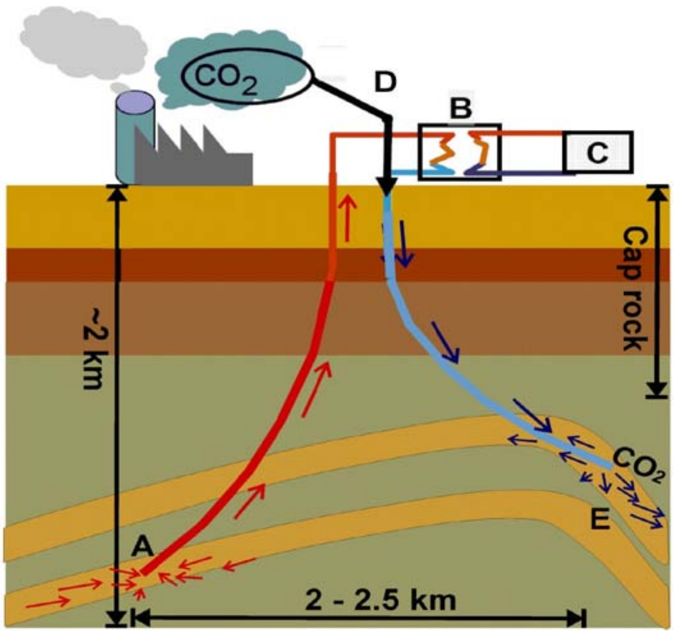
7.4 Delft Aardwarmte Project

A pilot project in Delft (figure 6) is to convert a 79MW co-generation heat power plant into a zero-emission plant by producing 5MW of sustainable geothermal energy and capturing and storing the remaining 11980 tonnes CO_2 (Karl-Heinz et al, 2009).

Preliminary modelling shows that the system could produce geothermal energy and co-inject CO_2 for a lifetime of 40 years.

By using the two technologies in conjunction in this way, it may prove to be more cost effective

Figure 6 (Van Wees, 2010)



8. Public Acceptance

CO_2 storage projects have recently had problems regarding public acceptance and it has been discovered that projects can be delayed, for example at Barendrecht in the Netherlands, or even stopped completely if the local populace object strongly enough.

Geothermal projects, on the other hand, have generally been more widely accepted by the public, with the possible exceptions of places where there has been induced seismicity, such as Basel in Switzerland.

One of the reasons suggested for this is that geothermal energy is seen as a renewable energy source, whereas CO_2 storage is seen as a waste disposal program.

9. Conclusions

There are many similarities between CO_2 storage and geothermal energy, especially in the way that exploration of the area takes place and the design process of the projects. Both technologies require detailed information of the subsurface and site exploration would be a similar process and so there are many opportunities for sharing of information.

Geothermal and storage activities will usually take place at different depths, but there will be the occasional conflict of pore space, which will need to be addressed at the time of site selection and characterisation.

For the two activities to work in synergy together appears to be possible, but has not yet taken place on a large scale and further study is required. Therefore knowledge of whether a site can be used for geothermal projects at a deeper level, especially in regards to EGS, after storage of CO_2 has taken place, becomes very important.

There is likely, only to be a relatively small amount of real-life data regarding the possible synergies of geothermal and CO_2 storage activities and any IEAGHG study would probably mostly focus on modelling. The only current projects or proposed projects are on a small scale and in only a few areas where it is possible for the technologies to work in conjunction with each other.

Induced seismicity has been experienced in some geothermal projects and the possible impact of CO_2 injection on seismicity could be an area for future research.

Regarding public perception, CO_2 storage may be seen in a more positive light if used in conjunction with geothermal energy.

10. Recommendations

More research is needed on the possible synergies and conflicts of geothermal activities and CO_2 storage, especially in regards to using formations at different depths for different activities.

It is necessary to find out if there will only be niche opportunities for synergy or if it can be used more widely and be possible on a larger scale. It may be useful to carry out an IEAGHG study at some point in the future to explore this as there is currently much uncertainty and controversy in this area, however the lack of much real-life data would make this particularly challenging. Any study should also look how any joint projects could encounter issues such as induced seismicity and the public perception towards joint projects could be considered.

Also noted is that the conference attended gave an overall European perspective and so it could be useful to carry out further research to get a more worldwide perspective into the issue.

Overall it is felt that IEAGHG should continue to monitor the results from the Delft project in the Netrherlands and any other such projects members could make IEAGHG aware of. Then the need for a study in this area could be reconsidered at an appropriate time in the future.

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References

Conference: Geothermal Energy and CO2 Storage: Synergy or Competition? GFZ Potsdam, Feb 2010;

European Geothermal Energy Council website; http://www.egec.org/

Geothermal Energy Association Website; http://www.geo-energy.org/

A Geothermal Site Combined with $C0_2$ Storage; Karl-Heinz Wolf et al, 2009; IOP Conference Series: Earth and Environmental Science. Sci. **6** 172025