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Geothermal Conference Publications: what are we talking about?

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ABSTRACT

This paper is an investigation into trends in publication topics contained in the IGA Geothermal Conference Paper Database, and the IEA Technology Roadmap Geothermal Heat and Power Technology Development Actions. The IEA Actions are a set of recommendations to encourage the use of geothermal energy. Of interest is the correspondence between recommended action, and what has actually happened. Because the IGA database contains papers since 1977, it is possible to see trends in publication on these topics since then, to comment on the correlation with recommended Technology Development actions, and comment on near-future trends

The broad conclusion is that the geothermal industry and research efforts correspond with the recommendations of the IEA on the importance of developing EGS and types of geothermal resource other than 'conventional high and medium temperature hydrothermal'. There is less correspondence between recommendations for field studies, drilling and well logging; in other words, actual development work on real sites.

INTRODUCTION AND BACKGROUND

The International Geothermal Association maintains a free database of Geothermal Conference papers, from 1977 to the present. The content of papers in this database is the best indication of trends in the geothermal industry, not only in terms of research, but also of industry development, as many geothermal companies report on their projects at such conferences, but do not write articles for scientific or engineering journals.

In 2011 the International Energy Agency (IEA) published a Technology Roadmap Geothermal Heat and Power, which recommended the Technology Development Actions for enabling increased use of the geothermal energy resource (IEA, 2011).

The above paragraphs describe two perspectives on the geothermal industry. From the IEA, there are recommended actions; and from the IGA, reports of work carried out or planned. For this study I used the structure of the Technology Roadmap to effect a set of searches of the IGA Conference Paper Database.

The IEA recommendations were only published in 2011, a matter of several years ago, and a direct response in technical conference presentations may not be so immediate. So the focus of this paper is to look at longer term trends, and determine if these recommendations are in broad agreement with industry (and by definition, existing policy and funding) priorities.

International Energy Agency

The International Energy Agency is an autonomous agency, established in 1974. A mandate of the IEA is to "provide authoritative research and analysis on ways to ensure reliable, affordable and clean energy for its 28 member countries" (IEA Technology Roadmap Geothermal Heat and Power, 2011). The IEA Technology Roadmap is intended to define a growth path for the use of geothermal energy, and is designed to "… enable governments, industry, and financial partners to identify the practical steps they can take to participate fully in the collective effort required". Specifically, this document contains the Technology Development Roadmap needed to fulfill the full potential of geothermal as a renewable energy resource.

Figure 1 (below) shows the outline of the Technology Development plan for geothermal energy as presented by the IEA. The plan is divided into 'Disciplines', each with Actions or topics that involve specific technologies where development would encourage increased geothermal energy use. The suggested timeline (milestones) is also shown. The majority of the recommended actions are immediate, that is, should be completed in the years between 2011 and 2020, or 2025. For actions which have no particular end date, such as Modular development of EGS plants, the timeline is shown as fading out.

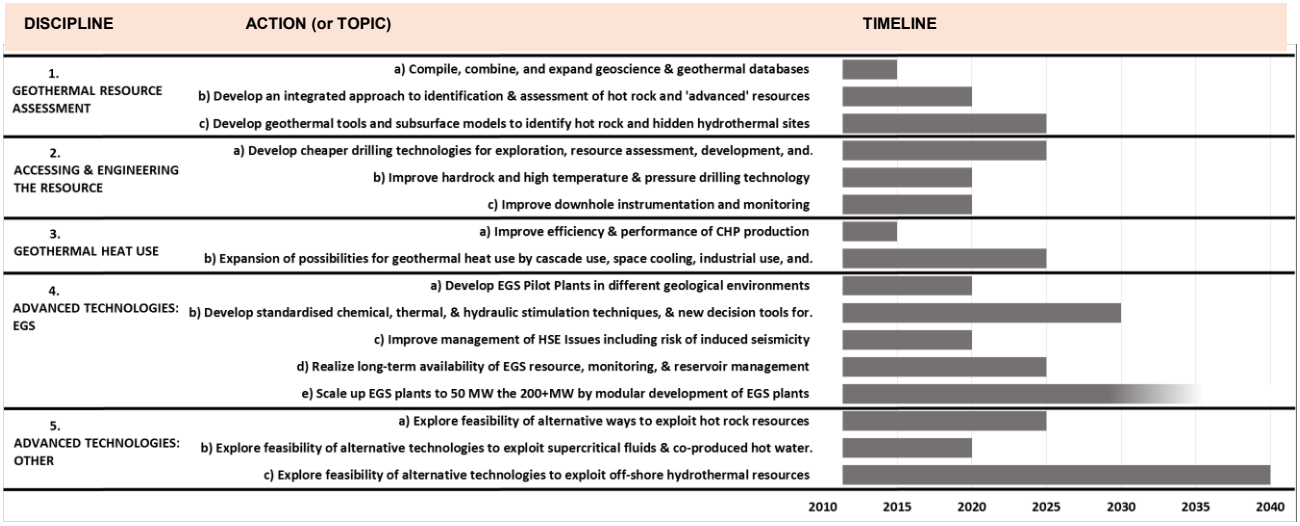

Figure 1: Technology Development: actions and milestones. From IEA Technology Roadmap, Geothermal Heat and Power (2011).

IGA Conference Paper Database

The International Geothermal Association maintains a database of papers presented at geothermal conferences since 1977. The database was pioneered by Professor Roland Horne, of Stanford University, California, and was hosted on the Stanford University servers for many years before being handed to the IGA in 2013. Although most papers appear on the database within months (or weeks) of the conference, the Geothermal Resources Council papers are only released for public access after two years, hence there is a two-year delay for GRC papers to appear on the IGA Geothermal Conference Paper Database. At the end of 2014 the database had 14,112 papers, mostly in English, but with some in other languages (Bahasa, Spanish, Japanese, and Chinese). The number of papers each year is shown in Figure 2; the relatively large number of papers in 1995, 2000, 2005, and 2010 is due to the five-yearly World Geothermal Congress, organized by the IGA, which attracts a large number of papers (more than 1000 papers in 2010).

The global coverage of the database is skewed towards English language papers, although these are not only from English-speaking countries. However, this is still the largest collation of geothermal knowledge in the world, and I believe the distribution and occurrence of topics covered is a reasonable representation of geothermal industry and research interests.

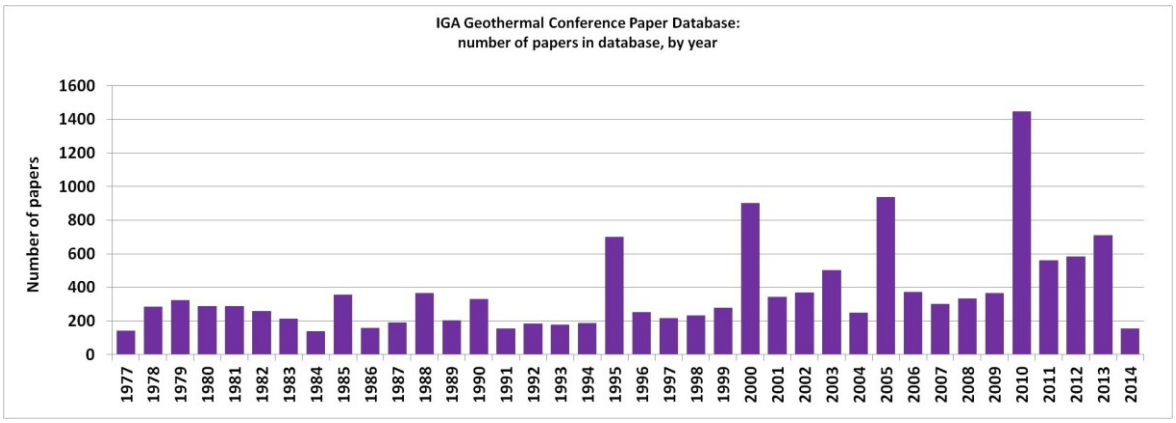

Figure 2. The number of papers in the IGA Geothermal Conference Paper Database, by year. The peaks in 1995, 2000, 2005 and 2010 are World Geothermal Congress years. There are a total of 14,112 papers.

The aim of this work

This paper uses the structure and subject matter of the IEA Technology Roadmap Geothermal Heat and Power Technology Development Actions, to effect a search of the IGA Geothermal Conference Paper Database. It looks at the annual number of papers that relate to each Action (or topic), thus identifying publication trends in the geothermal energy topics. These trends are indicated by the frequency and annual number of publications at geothermal conferences. The reason for using this database is that it captures the majority of non-commercial geothermal conferences, and is an indication of the research and or practical field work and development occurring in these topics.

Methodology

The methodology is to look at each separate Action item, and search the IGA Conference Paper Database using keywords which will capture the majority of papers on that topic. In order to select search terms, the wording of IEA Actions had to be evaluated, and in some cases, interpretations of the intent were necessary in order to produce a meaningful search result. These instances are clearly documented. Some of the Actions are overlapping, and sometimes one has to adjust the search; for instance, the 'geopressured' resource returned very few recent papers, but from a geological standpoint, sedimentary basins are a related resource and should be discussed with respect to this topic.

I need to point out that this is an investigation of geothermal conference publication content, not the operational characteristics of the IGA Conference paper database. In order to be independent of an internet connection while working on this paper, I copied the entire database tables into Microsoft Excel and performed all the searches using this software.

The paper keywords and title were searched. It is especially necessary to also use the title because many papers (3243 in all) in the database do not have keywords. There are papers in Bahasa Indonesia, Chinese, English (the majority), and Spanish. All other non-English papers have English titles and/or keywords so presented no difficulty for searches. Titles and keywords for all Spanish and Bahasa papers were translated into English, and the translations were used in the searches. For transparency the search parameters are itemized, as it is acknowledged that the process and conclusions depend on this choice; others are encouraged to choose different searches if they disagree with those presented. Unless otherwise stated, the search parameters are linked by 'OR'. I should also note that wild-cards were used, allowing for a character strings, that are plurals and derivatives of words. Where I have to describe a wild-card I have used the asterisk '*' symbol.

There are several large subsets of data relating to types of geothermal resource. These subsets were identified and used as the basis for searches on those resources. An 'allEGS' subset consists of a search for 'EGS' 'HDR', Engineered Geothermal System*', 'Enhanced Geothermal System*', and 'hot dry rock'. An 'allAdvancedTechnologies' subset which includes 'offshore', off-shore', 'submarine', 'geopressured', 'geo-pressured', 'supercritical', and 'super-critical'.

There is no specific mention of the sedimentary basin geothermal resource in the IEA report, and it is the opinion of the author that papers on sedimentary basins are a significant geothermal resource. Hence I also created a 'Sedimentary Basin' subset which includes 'sedimentary basin*', and 'sedimentary aquifer*'.

Once the papers on the requested topic have been located, they are sorted by year. The annual number of papers is then converted to a percentage of the annual total number of papers in the database. A five year moving average is also computed in order to highlight trends. The location of the median (the year by which there are 50% of the publications) is noted, as an indicator of recent interest.

TECHNOLOGY DEVELOPMENT: ENABLING PROCESSES FOR GEOTHERMAL ENERGY

1. Geothermal Resource Assessment

Overview

One of the aims of the IEA Technology Roadmap is to "develop publically available database, protocols, and tools for resource assessment and on-going reservoir management to help spread expertise and accelerate development" (IEA, 2011). This has identified as three sub-categories: Action 1a (involving databases); Action 1b (methods of exploration and resource assessment); and Action 1c (tools for early assessment, i.e. remote sensing and modeling tools which can be used before or after drilling). Actions 1a and 1c are based on desktop, theoretical, model, and surface-based work, whereas I have assumed that Action 1b may involve more practical field work and possibly subsurface exploration.

Actions

Action 1a: Compile and combine existing geological databases, and expand geological datasets to develop a publically accessible data base of geothermal resources.

'Database' was the search term for this first action. In fact, the majority of papers identified did not just involve geological databases, but discussed geothermal-specific databases, with the very earliest paper describing institutional and legal information data (Hussey, 1979) to national data such as heat flow (Blackwell et al, 1992) or geothermal fluids and temperature (Bonte et al, 2000); geothermal field and steamfield data (Arellano et al, 1995 and Anderson et al, 2013); land use and GIS based data (Austin, 2014); to the more recent US Department of Energy lead National Geothermal Data System (NGDS) (Anderson et al, 2013b), which aims to supply 'cutting-edge geoinformatics' to all geothermal stakeholders. Figure 3 shows the percentage of papers for each year. 80% of these papers were written after 2000 (2.6 papers/year), showing that there has been a more recent interest in this topic, and that access to geothermal data was identified by the industry as an important means of enabling geothermal development. 20% (2 papers/year) of the papers were written after 2011, suggesting that output hasn't changed greatly since 2000.

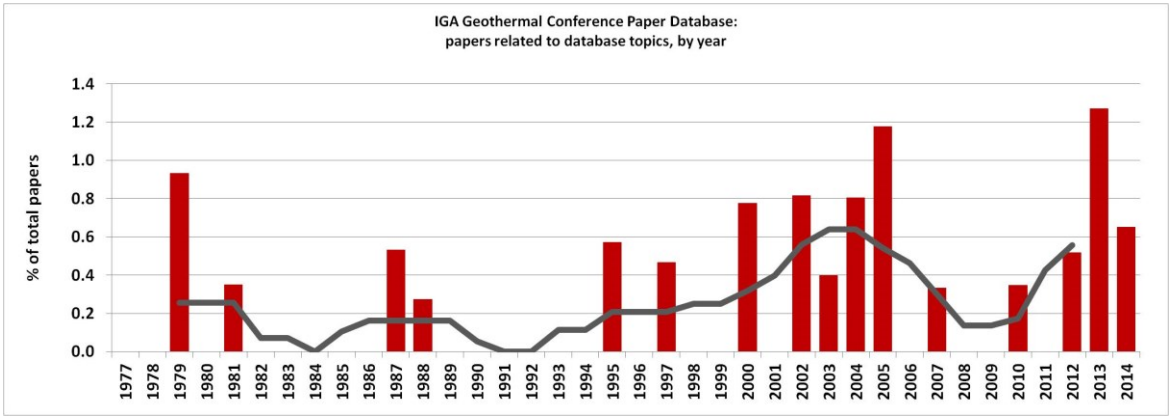

Figure 3. Records returned from the IGA Database on topics related to Action 1a.

Action 1b: Develop an integrated approach for identification of hot rock and advanced hydrothermal resources, and assessment of their geothermal potential.
Initially all the papers were from the subsets 'allEGS' and 'allAdvancedTechnologies' (described in the Methodology Section). The Sedimentary Basin subset was searched with the same parameters, and (after removing duplicates) and resulted in another 7 records, which are shown as an addition to the dataset (blue bars, Figure 4). The search terms were for 'resource assessment' and 'exploration'. This yielded predominantly reports of field investigations and tests, describing what is actually being done on the ground. The results show that there is has been three periods of increased interest in assessing EGS resources: in the early 1980s, the early 1990s and around 2009. There is a total of 111 papers, of which 50% have been written since 1999. The papers referring to sedimentary basins are all relatively recent, with the first in 2004.

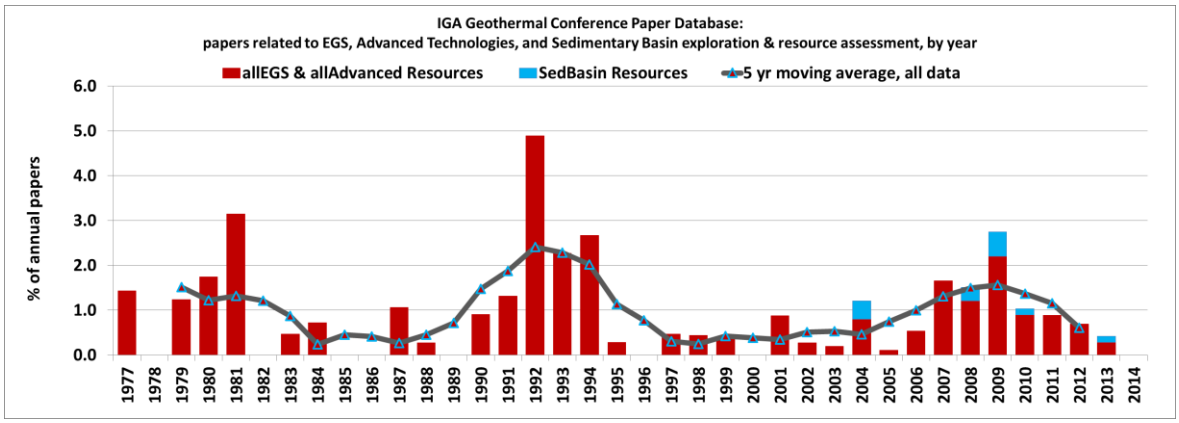

Figure 4. Records returned from the IGA Database on topics related to Action 1b. The red bars are results for the 'allEGS' and 'allAdvancedTechnologies' records only; the blue bars represent the extra records from the Sedimentary Basin subset.

Action 1c: Develop geothermal tools and sub-surface models for identifying suitable hot rock and hidden hydrothermal sites (Figure 5).
This is interpreted to mean tools that can be used without directly accessing the subsurface. This is commonly geophysical investigations, GIS techniques, and modelling, including modelling subsurface temperature and/or flow conditions. Selected search terms were 'geophysic*', 'GIS', 'geographic*', and 'model*'; the initial search was only from the subset 'allEGS' (the red bars, Figure 5). An alternative approach is that because there is a lot of crossover in tools for investigation and modelling of the subsurface, this search should be from the entire database (blue bars).

The "allEGS" database only search resulted in 228 records; there is a peak of papers in the early 90's, and a low in 1997 with an increasing number of papers since then. In 2014 these papers were over 6% of total annual papers, and 50% have been written since 2009. However, searching for these topics with respect to geothermal in general returned 2376 records, which shows that since 1977 around 15 % of all papers are related to these topics, increasing to 46% in 2014.

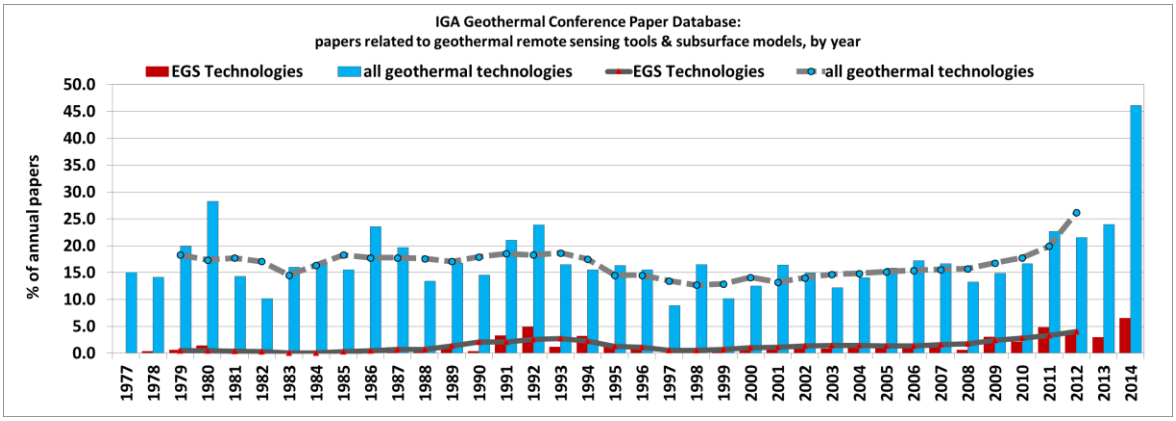

Figure 5. Records returned from the IGA Database on topics related to Action 1c. The red bars are results for the EGS records only; the blue bars represent the records for the same search of the entire IGA Conference paper database records. The grey lines are the five year moving average.

Summary and Discussion
It appears that the use of knowledge-based tools, computer techniques (modeling), and remote sensing techniques (geophysics and GIS) is increasing. Papers reporting exploration of specific areas or exploration techniques tend to make up a smaller component of the total fraction of papers, and have a more variable distribution over time, with localized peaks but currently a downward trend.

The IEA actions specifically mention geothermal resources other than the high and medium temperature resources which have been the mainstay of geothermal electricity generation for the last 50 years. The desire to encourage use of other geothermal resources is

important, however, there is a lot of crossover in the techniques used for subsurface investigations, and the results of searching the entire database for Action 1c is a better reflection of activity in this area which will benefit all types of geothermal development.

2. Accessing and Engineering the Resource

Overview

The first two Actions in this Section are about developing drilling technology, so one search for drilling technology encompasses both these Actions. The last Action 2c is concerned with measuring and monitoring the resource.

Actions

Action 2a: Develop cheaper drilling technologies for exploration, resource assessment, and development and exploitation of reservoirs and explore advanced drilling approaches.

Action 2b: Improve hard rock and high-temperature, high pressure drilling technology.

Action 2a and Action 2b both focus on drilling technology, so in the interests of simplicity, the selected keyword for both these items was initially 'drilling'. Some care and consideration was required, however, as many papers reporting the results of drilling also include this as a keyword. Hence the search for related papers was 'drilling NOT exploration'. The results (Figure 6) show a fairly consistent reporting of drilling technology since 1995 retaining around 5% annual share of papers.

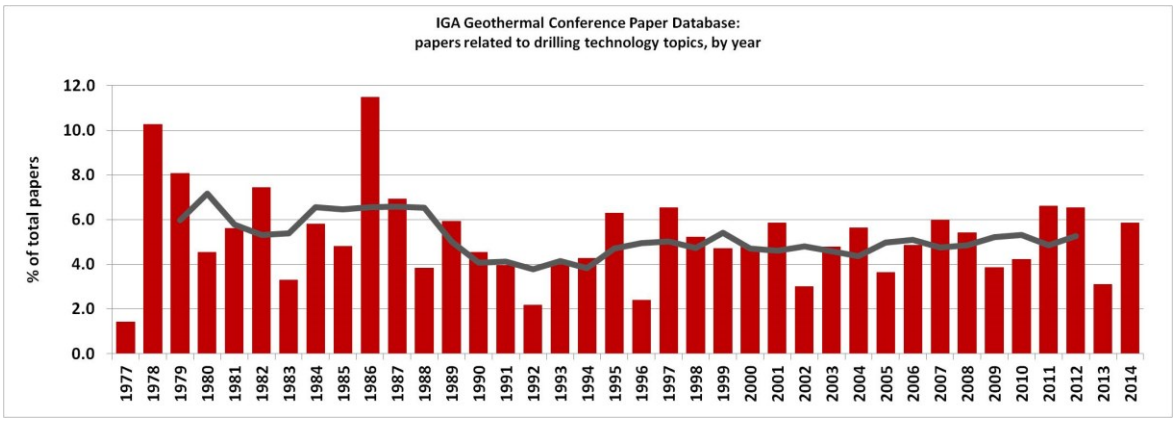

Figure 6. Records returned from the IGA Database on topics related to Actions 2a and 2b; drilling technology topics. The grey line is the five year moving average.

Action 2c: Improve downhole instrumentation and well monitoring.

High temperature, corrosive fluids, boiling, and scaling are among the processes that make geothermal wells a testing environment for measurement and monitoring tools. Yet well data is absolutely necessary for engineers and scientists to understand the reservoir. In order to identify all the work on this topic, five search parameters were used: 'well logging', 'instrumentation', 'high temperature electronics', 'well monitoring', and 'logging tool'.

According to the papers presented at geothermal conferences, papers on these topics peaked in the late 1970's, and the early 1990s, by which time 50% of the 99 papers were written. The number of papers (as a percentage of the annual total papers) has been declining since then (Figure 7). Of all the papers identified, only one paper was published in each of 2012 and 2013, and none in 2014.

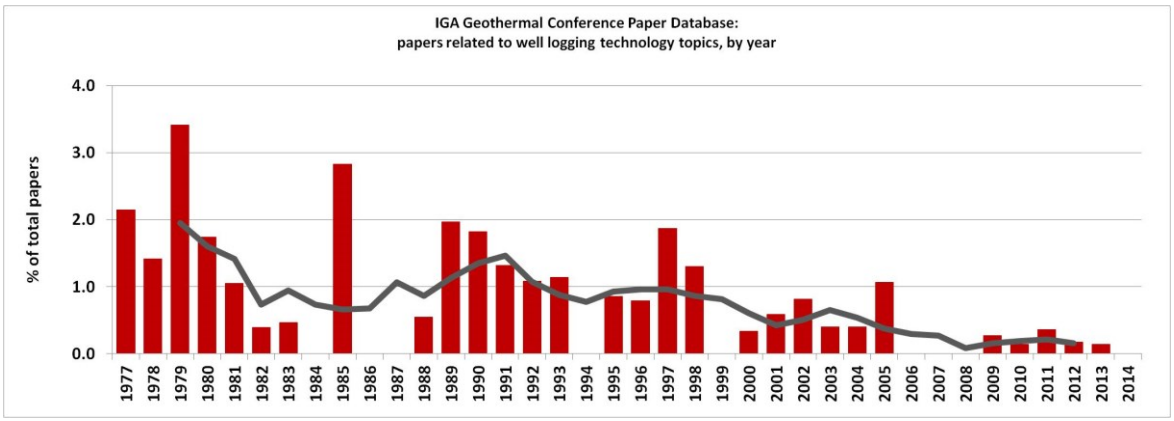

Figure 7. Records returned from the IGA Database on topics related to Action 2c; well logging technology topics. The grey line is the five year moving average.

Discussion

The interest in drilling technology has been extremely consistent over time, according to Figure 6.

Given that it is difficult to make sound decisions on resource matters without good data, Figure 7, showing the declining proportion of publications related to well technology topics, is somewhat surprising. Reasons for this may be that the technology is often commercially sensitive, and/or that new technology may be found in the Exhibition at geothermal conferences rather than being reported in the technical sessions.

3. Geothermal Heat Use

Overview

The direct use of geothermal heat has a long history (Lund et al, 2010). The IEA Technology Roadmap does not focus on the general 'direct use' of geothermal heat, possibly because much direct use is considered a 'mature' technology; however, it does attempt to identify under-utilized or potentially new applications for geothermal heat (space cooling, and 'new' industrial applications).

However, the context of this section is 'direct use' of geothermal heat. Before the trends relating to IEA Actions are discussed, Figure 8 is presented, showing all the records for 'direct use' in the entire IGA Conference Paper Database. The proportion of papers was highest in 1980, and had declined to around 4% from the late 1980s to 2006, when it declined again to 2% of the total records. 50% of all papers identified were written by 1995.

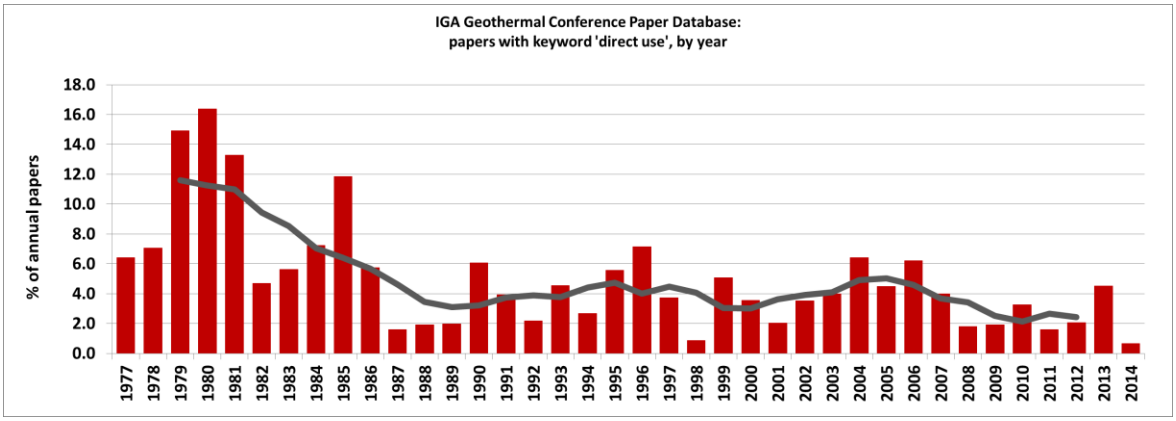

Figure 8. Records returned from the IGA Database for a 'direct use' search. The grey line is the five year moving average.

Figure 9. An example of the cascade use: the Prawn Park, Wairakei, New Zealand. This successful aquaculture venture uses heat from Wairakei separated geothermal water to farm prawns for the restaurant trade. The steam pipes to the Wairakei Power Station can be seen in the far left of the photo.

Action 3a: Increase efficiency and performance of combined heat and power (CHP) production by improving components such as pumps, heat exchangers, re-injection technology, scaling prevention, peaking/back up unit and storage tank. Optimize balance between heat and power load in geothermal CHP.

The key phrase from Action 7 is 'combined heat and power'. There are 27 papers related to this topic. These papers are still a very small fraction of total, but the frequency of papers has increased since 2003, with papers in eight of the last twelve years (Figure 10). 50% of the papers have been written since 2005.

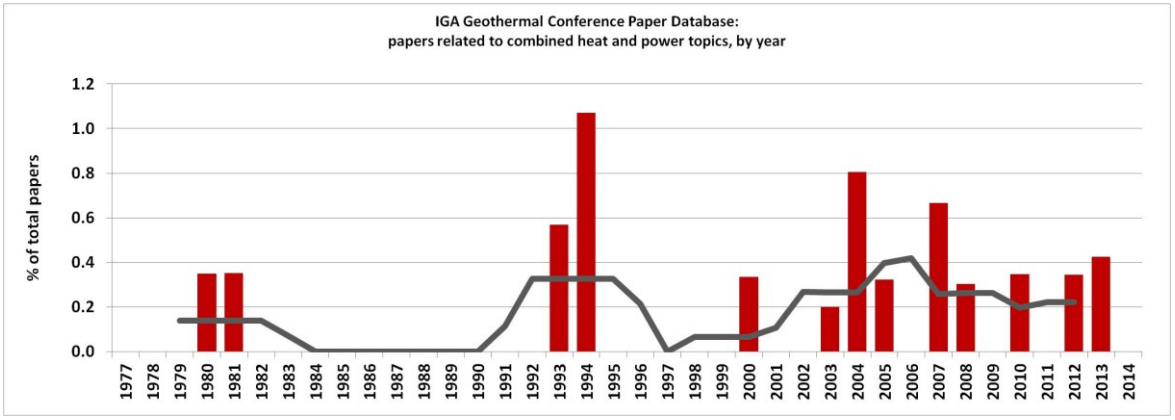

Figure 10. Records returned from the IGA Database on topics related to Action 3a; combined heat and power topics. The grey line is the five year moving average.

Action 3b: Explore expansion of possibilities for geothermal heat use by means of cascade use, use in space cooling, in new (industrial) applications and hot rock CHP.
Action 8 uses 'geothermal heat', 'cascade', 'industrial', 'space heating, and 'shallow geothermal'. Some care has to be taken with 'cascade' in order to exclude papers relating to the Cascade Range. While it is difficult to disentangle the two topics, specifying NOT 'range' and NOT' Oregon' appeared to work reasonably well. Note that papers on geothermal heat pumps were not excluded. The search listed 566 records in the database. After a high in the late 1970's, interest in this topic has increasing since 1987 (Figure 11), and it comprises around 4% to 5% of total papers since 2001. 50% of the papers have been written since 2003.

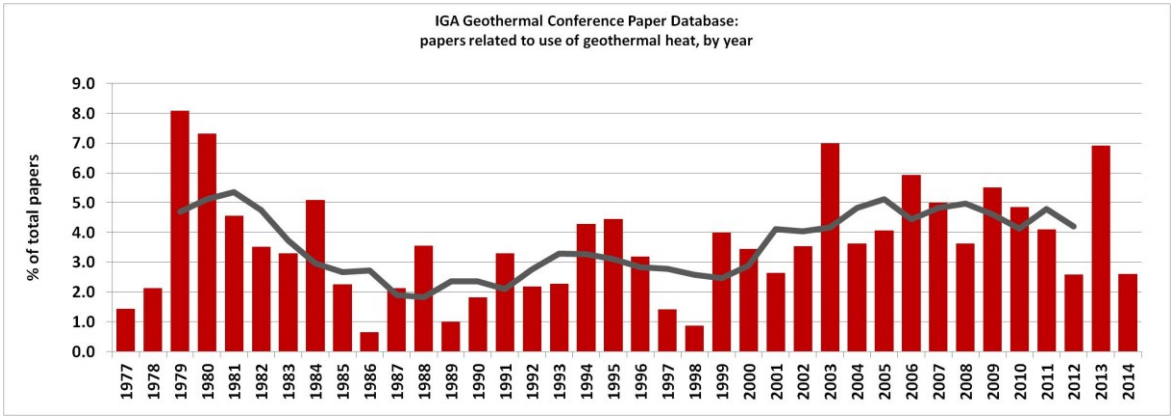

Figure 11. Records returned from the IGA Database on topics related to Action 3b; geothermal heat use topics. The grey line is the five year moving average.

Discussion
While records for 'direct use' have declined, the searches related to IEA topics show different trends. 'Geothermal heat' which actually includes searches for five sub-topics of direct use, shows an increasing proportion of papers, and CHP papers are becoming more frequent on an annual basis. Thus the difference in results could possibly be due to keywords and titles becoming more specific over time. It appears that despite the results shown in Figure 8, it is likely that interest in direct use applications is increasing.

4. Advanced geothermal technologies: EGS

Overview
This section uses the 'allEGS' subset of papers. There are 1046 papers in total on this topic, distributed over time as shown in Figure 12. There was a peak in publishing in the early 1990's; followed by a low in 1998, but since then the proportion of papers has been increasing (based on the 5 year rolling average) to just below 15% of total papers annually. However, searches of the 'EGS' subset most likely under-represents the number of papers (and hence the amount of research) on any of these EGS related topics, because of the possibility of cross-fertilization of ideas and techniques. Figure 13 shows the Soultz-Sous-Forets EGS project in France.

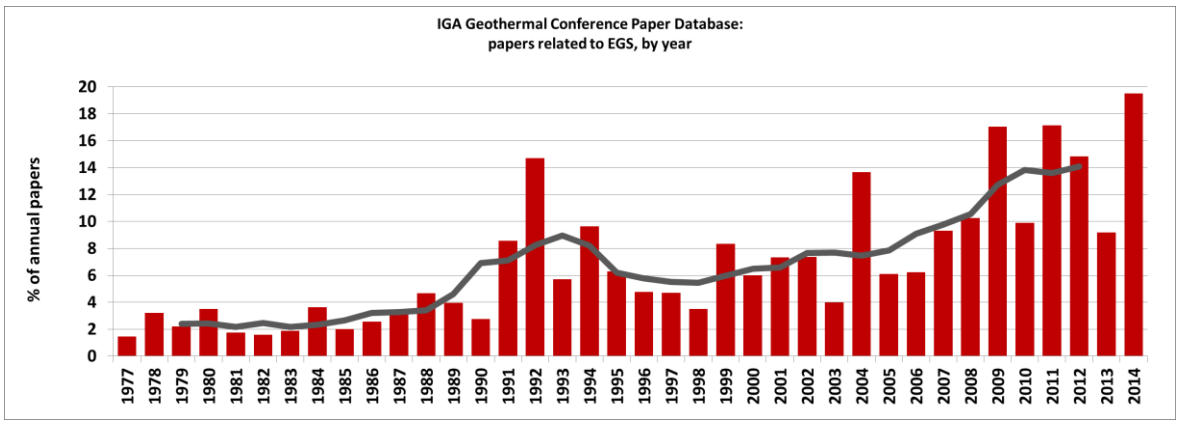

Figure 12. All publications related to EGS, with the five-year moving average shown as a grey line.

Figure 13. Soultz-Sous-Forets, currently a research facility for engineered geothermal systems.

Actions

Action 4a Develop EGS pilot plants in different geological environments including by cross-fertilization with hydrothermal development.
This Action is considered in conjunction with Action 4d and 4e.

Action 4b: Develop standardized chemical, thermal and hydraulic stimulation techniques, and new decision tools for optimal reservoir modelling and to enhance EGS production (Figure 14).
The four search terms 'stimulation', 'modeling', 'modelling', and 'simulation' were used here. Creating permeability is a major challenge for EGS development, and the search identified 316 papers on the topic. Overall the pattern of annual percentages is a subdued version of the EGS pattern. The number of papers has been increasing since 1998, and reached the highest level in 2014, at over 11% of total annual papers. 50% of all papers on this topic have been written since 2008. Figure 15 is a photo of the Newberry, Oregon EGS site during a recent stimulation project.

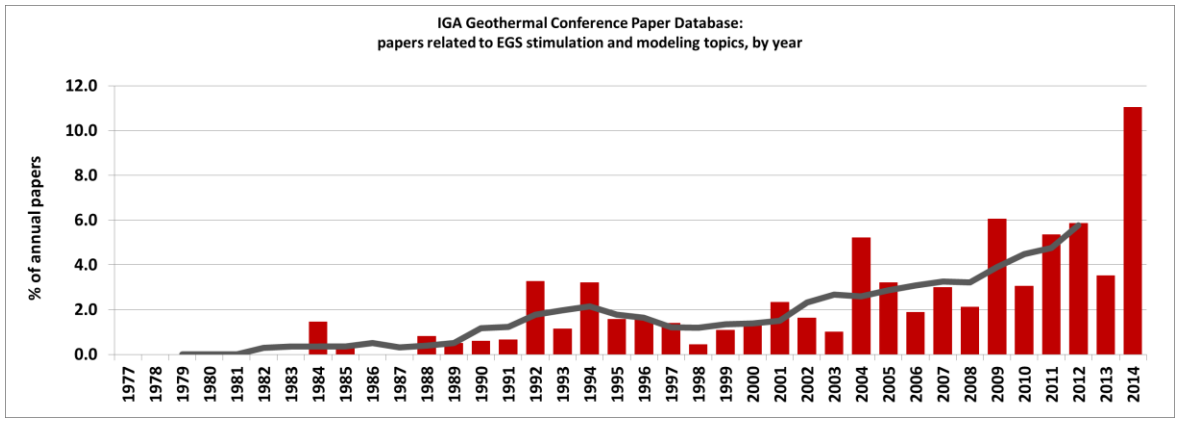

Figure 14. Records returned from the IGA Database on topics related to Action 4b; EGS well stimulation and reservoir modelling. The grey line is the five year moving average.

Figure 15. The Newberry EGS site, Oregon, USA.

Action 4c: Improve management of health, safety and environmental (HSE) issues, including risk associated with induced seismicity.

Induced seismicity is generally considered by communities near a proposed development as a major environmental risk factor for EGS developments (Karvounis et al, 2014). This action was interpreted to address this perceived environmental risk, and not the financial risk of drilling unsuccessful wells. In this instance, the search terms within the EGS subgroup specified 'induced seismicity' and all permutations of 'micro seismic*', to capture all possible spellings. In Figure 16 the five year moving average shows the same pattern as for all EGS papers, however, publication of papers on this topic is quite variable over time; although the 5 year trend has shown an increasing percentage of papers since 1998, the short term variations are quite extreme, with 0.25% (one paper) in 2003 to 3.6% (13 papers) in 2004.

A search using the term 'risk' in the EGS subset resulted in not just environmental risk, but financial risk (for instance Cooper et al, 2010). While this is an interesting subject, in this case it appeared to be getting away from the point of the topic, and those search results are not presented here.

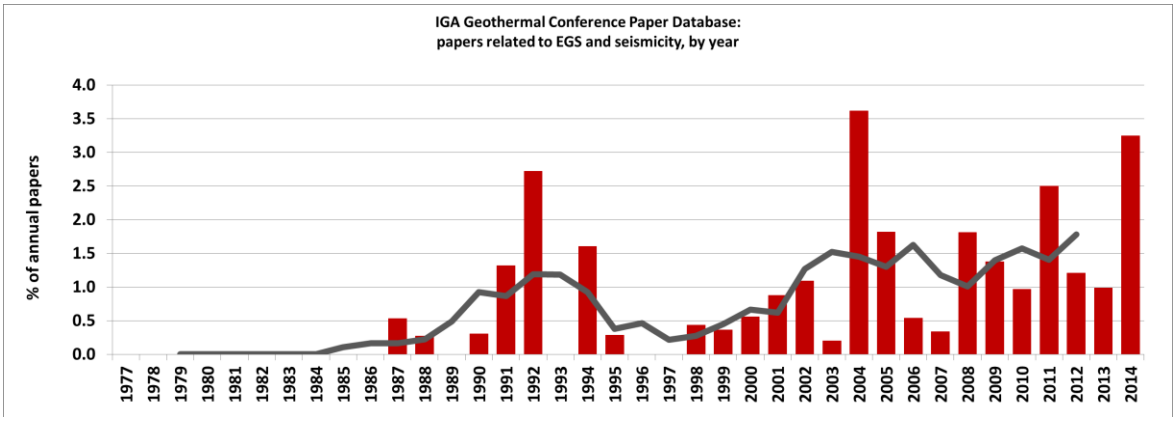

Figure 16. Records returned from the IGA Database on topics related to Action 4c; EGS and induced seismicity. The grey line is the five year moving average.

Action 4a Develop EGS pilot plants in different geological environments including by cross-fertilization with hydrothermal development.

Action 4d: Realize long-term availability of the resource, monitoring and reservoir management in EGS.

Action 4e: Scale up EGS plants to 50 MW and then to 200+ MW by stacking modules in series and/or parallel.

These Actions 4a, 4d and 4e are considered together, as all specifically refer to use of EGS systems to generate power. The 'allEGS' subset of the database was searched for the terms 'pilot plant', 'power plant', 'electricity generation', power generation', 'power', 'production AND model*', (based on the assumption that current investigations into how EGS production might work in reality, will be model-based). Records with 'exploration' or 'resource assessment' were removed. The concept of a pilot plant has been presented at geothermal conferences since 1980, with the first EGS 'pilot plant' paper in the IGA Database (Figure 17), which describes a scenario for a commercial EGS development (Foster, 1980).

The search of the 'allEGS' subset returned 94 records. The publication record is variable over time, with a peak in the early 1990s, followed by an average proportion of 0.5% of total records, increasing to 1.5% by 2007, although dipping in 2011 and 2012. 50% of papers have been written after 2007.

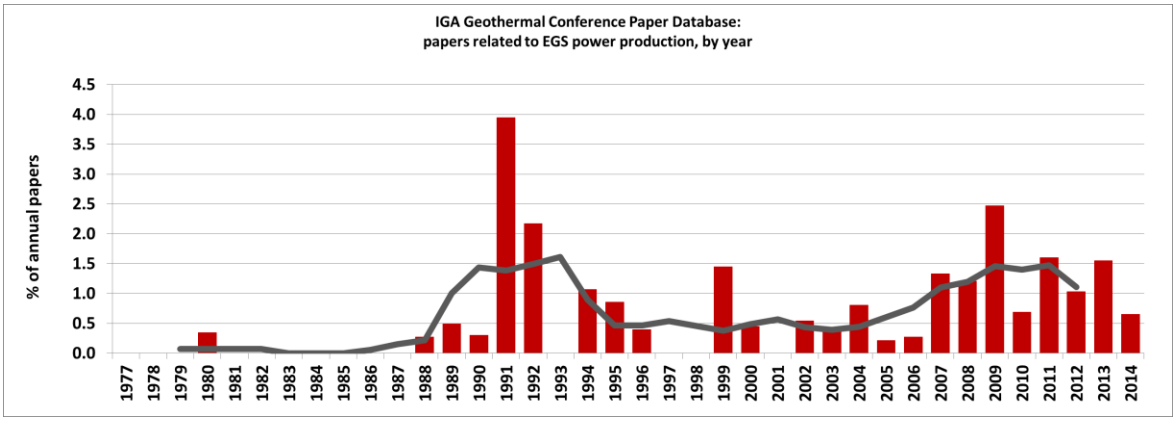

Figure 17. Records returned from the IGA Database on topics related to Action 4d and 4e; EGS power production. The grey line is the five year moving average.

Discussion

Coverage of all EGS related topics has been increasing over most the entire time period covered by the IGA Conference Paper Database, with a local high in the early 1990s. In 2012 EGS papers comprised 19.5% of the total number of papers. Within this subset, publication on pilot plants has been highly variable, and for most other years the proportion is less than 1%. However, the five year moving average now shows an overall increasing in the proportion of papers over time. The subjects of stimulation, and seismicity, show a stronger increase, and by 2014 they represent 11% and 3.3% of all annual papers, respectively.

In general, it is evident that EGS technologies are coming to the forefront of geothermal industry investigations, reflecting the importance that this resource is expected to play in future geothermal development. References to full-scale production still comprise less than 1.5% of total publications. This indicates that there is still a lot of investigation and development work with respect to engineered geothermal systems, before they will contribute a significant fraction of total geothermal energy use.

5. Advanced geothermal technologies: other

Overview

These are defined in the IEA Roadmap as offshore, geo-pressured, supercritical, and hot water from oil and gas wells (co-produced). Although sedimentary basins, as a type of geothermal resource, are omitted from the IEA Roadmap, they are included here as a separate category. This emphasizes that these are a specific resource that the industry considers is worthy of investigation and research, so its inclusion provides a better snapshot of actual effort invested in alternative geothermal technologies.

Actions

Action 5a: Explore feasibility of alternative ways to exploit hot rock resources.

Of all the 'advanced' resources, 'geopressured' is the only one not in the following Actions 5b and 5c. However, it is possible that the description given in the Roadmap does not encompass related resources that have been of recent interest to the industry – namely, sedimentary basins or hot sedimentary aquifers. In fact, I suggest that the majority of geopressured systems will also be a sedimentary basin resource. For clarity the two topics have been kept as separate searches, but both are presented on Figure 18. The results of 'geopressured' or 'geo-pressured' are the red bars in Figure 18. There are 67 papers, of which 50% were written by 1981. The number of papers declined to less than 0.5% of all papers and remained at this level until the present. In contrast, the search using 'sedimentary basin' or 'sedimentary aquifer' (blue bars) shows an increasing interest over recent time. 50% of papers have been written since 2009, and the average contribution to the entire annual output is just below 1.5% of total papers.

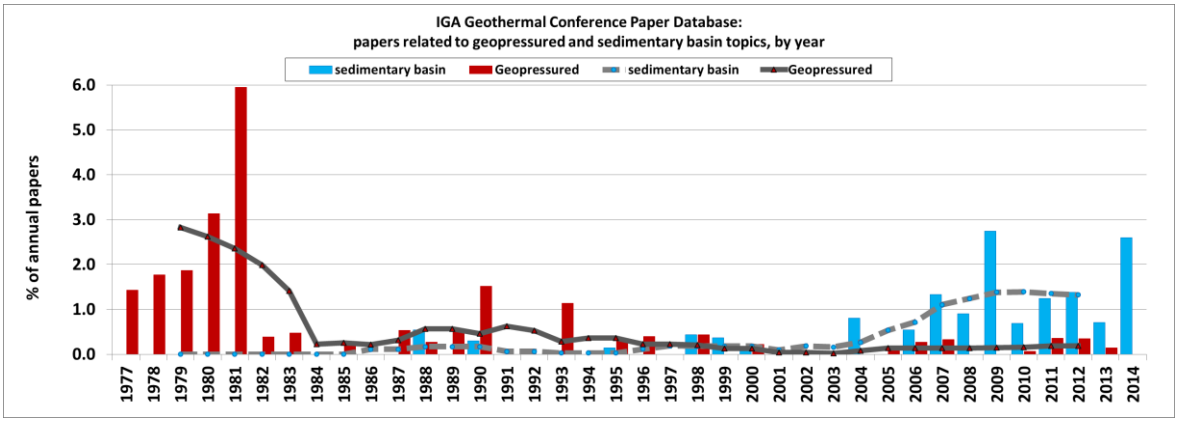

Figure 18. Records returned from the IGA Database on topics related to Action 5a; exploring the feasibility of alternative geothermal resources (in this case geo-pressured and sedimentary basin reservoirs). The grey lines are the five year moving averages.

Action 5b: Explore feasibility of alternative technologies to exploit hydrothermal resources such as supercritical fluids and co-produced hot water from gas and oil wells.
The only difference between this and the previous action is that they specify different types of resource. For Action 5b, the two types of resources encompassed are very different, however, they are relatively easy to describe by the search terms are 'gas well*', oil well*', oil and gas', 'supercritical', and super-critical'. Figure 19 shows that there was some interest around 1980, then no records at all until 1995. Since 1999 there have been papers every year on at least one of these topics, and 50% of papers have been produced since 2005. The five year moving average has remained between 0.5% and 1% since 2005. This is a similar pattern to geopressured and sedimentary resources (Figure 18).

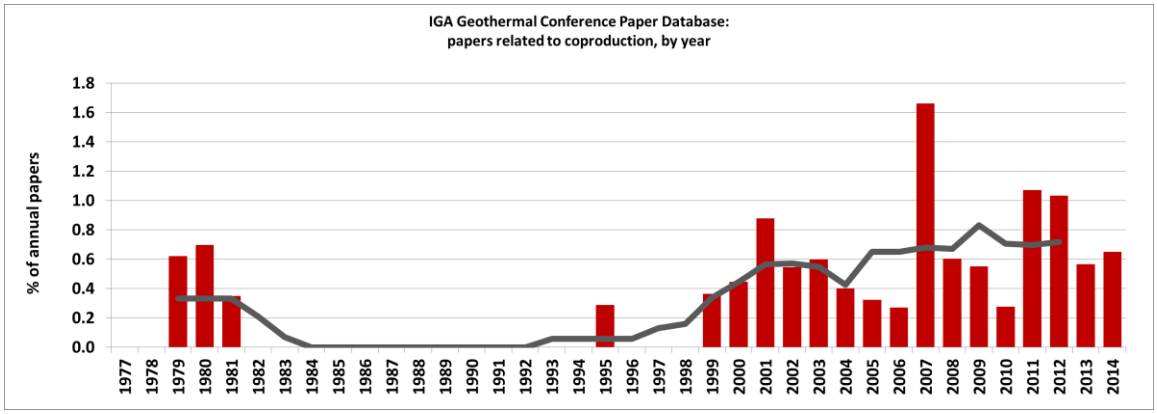

Figure 19. Records returned from the IGA Database on topics related to Action 5a; coproduction of geothermal fluids from oil and gas wells. The grey line is the five year moving average.

Action 5c: Explore feasibility of alternative technologies to exploit off-shore hydrothermal resources (Figure 20).
This search for this topic was of the entire database, as we still have a lot to discover about submarine geothermal, not only about how to exploit it, but about the nature of the systems and associated ecosystems. The search only recovered 22 records; all except one were published after 1998. They still comprise a very small fraction of total annual papers, reaching a maximum fraction of 0.6% (4 papers) in 2008. 50% of all the papers have been presented since 2008.

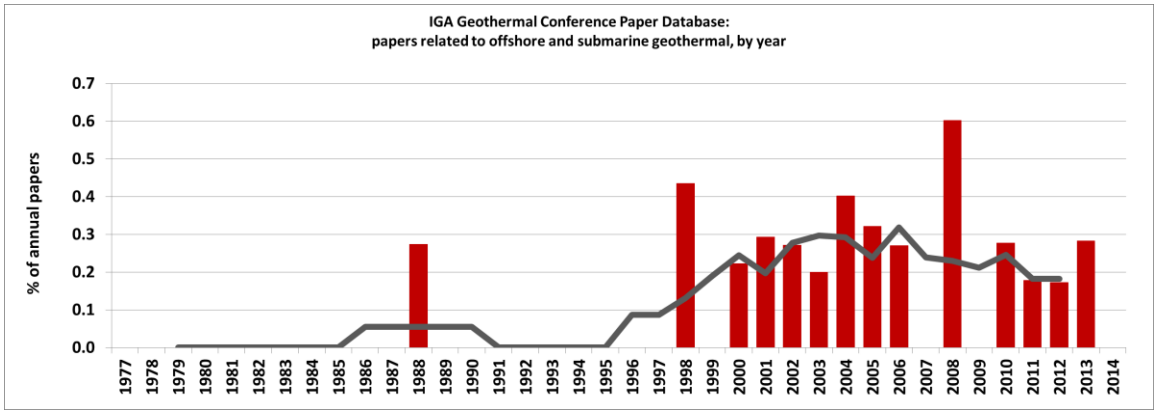

Figure 20. Records returned from the IGA Database on topics related to Action 5a; exploring the feasibility of alternative geothermal resources (submarine geothermal). The grey line is the five year moving average.

Discussion
Figures 18 to 20 above show that interest in alternative, or under-utilized geothermal resources, is generally increasing. Interestingly, after a good deal of early interest in geopressured resources, after 1984 there was very few geopressured resources reported, whereas sedimentary basin resources made a significant appearance in 2004 and had a small but constant presence since. The alternative resources from oil and gas reservoirs, and very hot wells have also made a small but constant contribution since 1999.

DISCUSSION

A major question arising from this study is: does the distribution of paper topics reflect, or relate to, the recommendations of a body that influences renewable energy policy?

In answer:

1. In the EGS field, there is a reasonable correlation between action and recommendation. Papers with respect to engineered geothermal systems have been increasing since 1998. Within the EGS dataset trends are less consistent. Developing permeability in the reservoir is a primary challenge to overcome before any development can succeed. Once this work has seen some widespread field success, the proportion of studies on induced seismicity, pilot plants, and power production will likely increase in line with the next stage of EGS development. From the above examples, it is apparent that there is significant interest in enhanced, or engineered geothermal systems, and that this will continue.

2. There is also a correspondence between recommendations for work into geothermal resources other than EGS and 'conventional' hydrothermal. It is noted that specific mention of water from sedimentary basin aquifers is absent from the IEA Roadmap; yet it appears that this is the most popular type of alternative geothermal resource since 2000.

3. Roadmap recommendations for new uses for geothermal heat also correspond with a steady increase in reported geothermal topics.

However:

4. There is evidence of a good deal of cross-over of tools and techniques. A major point of interest for all geothermal resources is modelling and remote sensing technologies which contribute to understanding subsurface conditions. The Roadmap recommends the development of tools suitable for 'hot rock' (i.e. EGS) and 'hidden' geothermal resources, however, it appears that for all types of geothermal resource, these topics are a huge, proportion of geothermal conference presentations; up to 45% by 2014. It is difficult to predict the future rate of growth in this area as if this rate of increase continues it will encompass all conference papers in the next several years!

5. The proportion of actual field studies, in EGS technologies at least, is not growing, and well logging technology papers are declining. In the case of well logging technology, the number of papers presented may not be a good indicator of progress or advances, in this field. Drilling technology is constant, but not increasing.

CONCLUSION

For the conclusion the question is: by this work, can we offer any constructive comments on the formulation of priorities for geothermal energy technology?

1. Because of the amount of crossover in tools and techniques, it is more reasonable to frame recommendations without referring to specific types of systems.

2. Care may be needed in formulating recommendations that address the ultimate need for field studies, exploration, drilling, and well testing. It appears that there is a large amount of work in modelling, and possibly remote sensing, which may not have translated into specific developments.

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