Measuring the Success of EGS Projects: An Historical to Present Day Perspective

Catherine E. Stafford*
Granite Power Ltd, Level 6, 9 Barrack Street, Sydney, NSW 2000.
*Corresponding author: cstafford@granitepwr.com

World wide, Enhanced Geothermal System (EGS) projects have been around for over 35 years, commencing with the Fenton Hill research and development project in New Mexico back in 1972. Many years of knowledge have been accumulated through various research and commercial projects.

As to be expected with an evolving industry, some significant development issues are still to be fully or properly overcome, such as appropriate down-well technologies and management of induced seismicity. However, several factors indicate that this 'new' type of geothermal technology and its associated industry has moved beyond being just a research and development concept. Such factors include: the growth in the number of commercial projects, with some of these now in production; cementing of the industry through associations and government incentives; the development of geothermal reporting codes for commercial credibility (i.e. Australian and Canadian); and considerable progress in the resolution of ongoing development issues.

This paper provides a perspective on the success of EGS projects to date. This is very much a first-pass assessment as the technical and commercial data publicly available is currently too sparse and project specific to enable a rigorous quantitative study at this stage. However, it is intended to offer a snapshot take on the success and evolution to date of the EGS sector of the geothermal industry. It reveals that many projects have been successful at what they set out to achieve. It is also apparent that EGS development in Australia is likely to be more 'successful' than elsewhere because the continent's stress regime allows favourable sub-horizontal fracture development.

Keywords: Enhanced geothermal system, EGS, hot dry rock, HDR, success, industry, Hot Rock

Definition of EGS

Geothermal power has been generated from hydrothermal geothermal resources for many decades. However, such resources are limited to areas where accessible hydrothermal systems are found, such as the world's volcanic regions e.g. the Pacific Rim countries.

Geothermal exploration in all areas requires a balance of accessible temperature, water supply and an adequate flow rate in order to produce electricity economically. Water may have to be introduced to the system or may be present. In geothermal plays away from conventional geothermal terranes, required temperatures will likely be found at greater depth where permeability is often decreased (tight rocks), so reservoir enhancement by physical or chemical means is required to obtain flow rates that are considered economic.

Over the years the concept of enhanced geothermal reservoirs has been described with several acronyms e.g. Hot Dry Rocks (HDR), Hot Wet Rocks (HWR), Hot Fractured Rocks (HFR) and HR (Hot Rocks). Such projects have comprised the artificial creation of an underground heat exchanger by the drilling of a well into e.g. granite, the stimulation of that well to create a reservoir (usually by hydraulic stimulation and/or chemical stimulation), and the drilling of a producer well into the margin of the created reservoir.

In the last few years EGS has become the most accepted descriptor in the northern hemisphere. Recent definitions include:-

- *"EGS are a new type of geothermal power technologies that do not require natural convective hydrothermal resources."(*en.wikipedia.org/wiki/Enhanced_Geothermal_Systems)
- *"EGS are engineered reservoirs created to produce energy from geothermal resources that are otherwise not economical due to lack of water and/or permeability."* Department Of Energy, USA: http://www1.eere.energy.gov/geothermal/enhanced_geothermal_systems.html)
- "*An Enhanced Geothermal System is an underground reservoir that has been created or improved artificially*." TP GEOELEC: the newly formed GEOELEC-Platform, was launched on 2nd of December 2009, and comprises more than 130 geothermal experts from the industry and the research sector who voted on the definition of EGS in March 2010. The secretariat of the panel is managed by the European Geothermal Energy Council. (http://www.egec.org/ETP%20Geoelec/Conclusion%20EGS%20definition.pdf)

This latest definition, would include all conventional geothermal wells that have been stimulated to improve reservoir performance.

During the development of the Geothermal Industry Technology Roadmap (DRET, 2008) the Australian community recognised that terms such as HFR, HDR and HWR were rather specific, and that EGS could be applied to geothermal resources with significant existing permeability. Therefore the term Hot Rock was adopted to encompass that end of the spectrum of geothermal resources that required significant permeability enhancement. The term Hot Sedimentary Aquifers is applied to that end of the spectrum where significant permeability exists naturally.

Here we consider the success of enhanced geothermal systems, with focus on the unconventional (non-volcanic related) systems.

The Rapid Growth of the EGS Sector

This preliminary (and non-exhaustive) review has found that to date there are in existence, or now terminated, some forty-seven EGS projects (to mid June 2010). These projects are listed in Table 1.

The data presented in this compilation is somewhat incomplete, has been variably sourced and as a result accuracy cannot be guaranteed. In the time-frame available for this preliminary study, project data was often difficult to acquire or was not acquired. It is recognised that such omissions impact on the results and hence, any interpretation of those results. For example, it may be more likely that there is non-publicity for unsuccessful projects or unsuccessful parts of projects. A more rigorous study is certainly needed but at this stage of the industry's development may not be possible due to the limited and site specific nature of the data.

The data show that over the last four decades, over 50% (27) of the EGS projects commenced in the last 5 years (Figure 1 and Table 1). Over the whole of the last decade 78% (37) of the total projects were commenced (Figure 1) with over half of these projects being commercially funded as opposed to demonstration or R&D projects (Table 1).

Conversely, during the 1970's, 80's and 90's projects were predominantly research-driven (Table 1).

The huge growth in the number of projects seen over the last five years indicates that confidence in this sector has grown rapidly. This can be attributed to the knowledge and acquired skills gained from the early projects, technology development e.g. drilling deeper being more easily attained and with less risk, government policy and to the perceived success of previous projects.

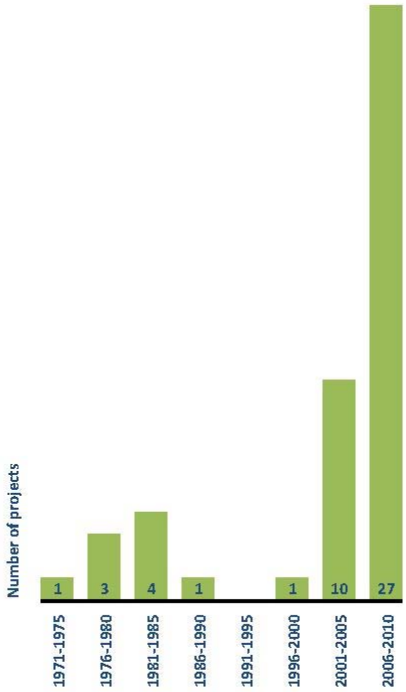

Figure 1: Bar chart showing the number of EGS projects commenced from 1970 to 2010.

Indicators of Success

In a mature EGS industry, success would likely be measured by the amount of power produced i.e. in megawatts. However, relatively little data is yet available with only a modest number of projects well developed. Thus, measuring success is difficult at this stage. However, it is suggested that even a preliminary evaluation is useful as a tool for all concerned.

A broad-brush assessment is presented here looking at technical success and commercial success of projects, with these being defined below.

In terms of the development of the industry, there are many other factors, which are not discussed here, that can be indicative of the growth of the geothermal industry as a whole, as well as for the EGS sector. These include: acceptance of risk and risk management; wide application of the technology; government support via grants; geothermal studies; legislation; service industry support via dedicated groups and research and development; number of R&D/demonstration projects; number of commercial projects.

Table 1: EGS Projects Identified, as of Mid-June 2010

	Start	Where	Region	Project	Who	Purpose	Status	Success: Technical	Success: Commercial	Reservoir rock	Depth	Temperature	Production temperature	Power output	Main source	Comment
											km	°C	°C	MW		
1	1972	USA	NM	Fenton Hill		R	TE	Y	Y	Granite	3.5	195	158	3	1, 7	Producing power for >20 years. Ended 1996
2	1976	Germany	Bavaria	Falkenberg		R	TE	Y	N	Granite	0.3	85			1, 10	Successful fraccing, & short circ tests. Project finished 1985
3	1976	UK	Cornwall	Rosemanowes	Camborne School of Mines	R	TE	Y	N	Granite	2.7	79			1	Successful drill, frac & circulation for four yrs. Ended 1991
4	1977	France		Le Mayet de Montagne		R	TE	Y	N	Granite	0.8	33			1, 10	Granite from surface. Successful frac & circ tests.Project ended 1994
5	1982	Japan		Ogachi				Y	N		1.3	240			1	Volcanic. Poor connectivity (~90% water loss)
6	1983	Japan		Higashi-Hachimantai		R	TE	Y	N	Granite	0.4	60			10	
7	1985	Sweden		Fjallbacka		R	TE	Y	N	Granite	0.5	15			1	Successful 40 day circulation test. Ended 1989
8	1985	France		Soultz-en-Foret	ENGINE	R	OP	Y	Y	Granite	4.2	200	155	1.5	1, 7, 8, 9	Prod. power for >15 years.
9	1988	Japan		Hijiori			TE	Y	N	Granodiorite	2.7	270	163		1, 4	A lot of short tests, with varied results; & water loss ~50%
10	1999	Australia	NSW	Hunter Valley	Pacific Power	D	TE			Granite					1	Elcom. Discontinued due to funding issue. Site later acquire by Geodynamics
11	2001	Australia	NSW	Jerry's Plain	Geodynamics	C				Granite						Inferred resource
12	2001	Switzerland		Basel		D	TE	Y		Granite	5	200			2	Fraccing caused 3.4R earthquake). Proj suspended.
13	2002	Germany		Bad Urach				Y		Mica-syenite	3.3	170			2	Series of successful short frac & circ tests
14	2002	Australia	SA	Cooper Basin	Geodynamics	C	DR	Y	Y	Granite	4.3	250	200		1, website	Proof of concept achieved 2009 (flow btw 2 wells)
15	2002	USA		Coso		R		y							1	Stimulated same fracture via 2 wells. Second stimulation caused swarm of EQs
16	2002	USA	NV	Desert Peak	Ormat	C									1	Adjacent to conventional geothermal area.
17	2003	El Salvador		Berlin		C	OP	Y	Y		2					Stimulation of tight injection well for existing geothermal field
18	2003	Germany	Hanover	Horstberg (GeneSys)	GEOZENTRUM	R	TE	Y	N	Sandstone	3.8				2	Single well. Frac & circ was achieved, and inadequate circulation was proved.
19	2004	Australia	SA	Paralana	Petratherm	C	DR			Metasediments	4.1				1	Have drilled injector well Paralana-2
20	2005	Australia	TAS	Charlton-Lemont	KUTh	C	FU			Granite					website	Inferred resource
21	2006	Australia	SA	Olympic Dam	Green Rock Energy Ltd	C	FU			Granite					website	Inferred resource
22	2006	Australia	SA	Parachilna	Torrens Energy	C	FU			Cryst Base/Sandst	<5				website	Inferred resource
23	2006	Australia	SA	Crower	Geothermal Resources	C	FU			Granite						Inferred resource
24	2006	USA	CA	Glass Mountain			TE									Cancelled due to political and environmental permitting issues.
25	2007	Germany		Landau		C	OP	Y	Y		3.4		150	2.5-2.9	2, 6	Commercial. Commissioned in Nov 2007. Expansion is reported planned.
26	2008	Germany		Bruchsal		C	OP	Y	Y		2.5		128		2	Operating. Commercial. Commissioned 2009
27	2008	Germany		Groß Schönebeck		R	DE	Y	Y	Sandstone	4.4				2	Following several stimulations, a well doublet is ready for planned power production.
28	2008	Australia	QLD	Nagoorin	Granite Power	C	FU			Meta-sediments	5				website	Inferred resource
29	2008	Australia	VIC	North Narracan	Granite Power	C	FU			Metasediments	5				website	Inferred resource
30	2008	USA	NV	Brady EGS	Ormat	C	DR			Meta-tuff					3	
31	2008	USA	NV	NW Geysers EGS	Geysers Power	D									3	Ptr: Lawrence Berkely Nat Lab
32	2008	USA	ID	Raft River Expansion	Uni Utah	D					1.8	149			3	
33	2008	USA	CA	Geysers	Altarock	D	SU	N								Suspended due to difficult drilling conditions (serpentinite)
34	2008	Germany		Insheim	HotRock Verwaltungs	C	DE	Y	Y		3.6	?	>155		website	Power plant planned operational 2011
35	2009	Australia	SA	Roxby	Southern Gold	C	FU			Granite					website	Inferred resource
36	2009	Australia	WA	Jurien-Woodada	New World Energy	C	FU								website	Inferred resource
37	2009	Germany		Unterhaching		C	OP	Y	Y		3.4		122	3.4	2, 5	Commercial. Operating. Commissioned 2009
38	2009	Switzerland		St Gallen	Geowatt	C					4.1	150		(3-5)	8	
39	2009	UK	Cornwall	Eden Project	EGS Energy	C	FU			Granite	4			(3)	website	
40	2009	UK	Cornwall	United Downs	Geothermal Engineering Ltd	C	FU			Granite	4.5			(10)	website	
41	2009	USA	AK	Naknek Geo Project	Naknek electric	D					4.2				3	
42	2009	USA	NV	New York Canyon	TGP Development	D									3	
43	2009	USA	OR	Newberry Volcanic Bend	Altarock/Davenport	D	PE			Volcanics				(15)	3	
44	2009	Germany		Hannover (Genesys)	GEOZENTRUM	R	DR			Sandstone	3.9					
45	2010	Latvia		Riga EGS										(3-4)	8	
46	2010	Norway		Oslo EGS											8	
47	2010	Germany		Rulzheim	HotRock Verwaltungs	C					3				website	

KEY:-

Purpose
C Commercial
D Demonstration
R Research and development

Status
DR Drilling
OP Operational
TE Terminated
PE Permitting
FU Fundraising
DE Development

Technical success
Y indicates project was successful in stimulation and flow testing (if undertaken)

Commercial success
Y Indicates project achieved flow rates and temperatures sufficient to enable a project to be commercially developed

References (see main text for full references)
1 MIT Report 2006
2 M Back (re current Germany, pers con, 27/4/09) or M Haring (re Basel, pers con, June 09)
3 Jennejohn 2010
4 Tezuka 2007
5 Reif 2009
6 Baumgartner et al 2007
7 Brown 2009
8 Holm et al 2010
9 Cornet 2009
10 Evans and Valley 2005

Note:
Blank cells indicate data not yet collected or available
Parentheses indicate expected power output
Projects in blue indicate assessment for technical success

Technical Success

At this stage of the industry's development, and in terms of 'technical success', a project could be deemed successful if circulation, or another specific technical goal was achieved e.g. creating a reservoir. This is particularly important when considering the early R&D projects. For example the Rosemanowes project, which did not set out to commercially produce power but to prove rock mechanics concepts behind EGS and achieve circulation. In that context, the project was a success, and as such has been valuable in driving the industry forward.

There are several environmental factors that can be said to affect the technical success of a project. Of these arguably the most important are water losses and induced seismicity. These risks have impacted on the identified projects to varying degrees, ranging from little to no impact to the suspension/cancellation of the project e.g. Basel.

These constitute risks to the project which need careful management and mitigation. Such management and mitigation strategies have been developed over the last few years (e.g. Majer *et al*. 2008, Morelli and Malavazos 2008) and continue to develop, with this having a huge impact on the public perception of the industry. However, for the purposes of this assessment they will not be considered to affect the technical success of a project.

Commercial Success

The 'commercial success' of a project can be measured with regard to the economics of that project at that particular site. It is dependent on drilling costs, temperatures, location relative to power infrastructure, markets, and feed-in tariffs as well as other factors. Several of these 'modifying' factors can change with time, as a result of a changing or uncertain regulatory environment e.g. emission trading schemes and power prices. This means that the economics of a project can change with time, all other factors being constant.

Several of the EGS projects to date did not set out to commercially produce power, but to explore the development of EGS. Hence, these projects cannot be assessed in terms of being a commercial success.

As a first-pass and broad-brush approach to assess commercial success, it is defined here as either production of power, or the project being advanced enough to have proven its potential to produce power via long-term circulation tests.

Environmental factors such as induced seismicity or unsustainable flow rates can be deemed to affect the commercial success of a project, as they can lead to the closure of the project. Hence, they are considered here.

Preliminary Assessment of the Success of EGS Projects

Twenty projects allowed a first-pass assessment of technical success, as defined above. Of these projects one was deemed not successful due to drilling difficulties (serpentinite) leading to a suspension of the project (Geysers). This represents a 95% technical success rate for EGS projects.

Stimulations were noted to be successful within a range of lithologies (Table 1).

With regard to the commercial success of these projects: many of the earlier (1970-2000) projects did not set out to be commercial, and of these nine projects (see Table 1, Rows 1 - 9) only two can be considered as commercially successful and produced/is producing power (Fenton Hill and Soultz, Table 1, Rows 1 and 8).

However, the seven technically successful projects commenced in this last decade, for which commercial success could be assessed (Cooper Basin, Berlin, Landau, Bruchsal, Gross Schonebeck, Insheim and Unterhaching), all are producing power or have been proven capable of producing power and are planning development for power production.

Reservoir development in Australia has been shown (e.g. Geodynamics, Cooper Basin) to be aided by the prevailing continental compressive stress regime (Hillis and Reynolds 2000), Under these conditions, hydraulic reservoir stimulations likely result in sub-horizontal fracturing leading to enhanced well connectivity. Hence, in Australia, a greater level of success may be anticipated.

Conclusions

It is appropriate to be cautious about the concept of success here, which has necessarily been kept relatively simple. In the future, the geothermal industry could arguably better define success as achieving a typical cost of production for power delivered into the retail market that is less than or equal to coal (on a pre-carbon tax basis) and then prioritise its R&D objectives according to the prospective contributions of various potential technical advances to achieving that benchmark of success.

At this moment in time, the early indicators generated from this industry worldwide show:-

- An exponential growth in the number of EGS projects over the last 5 years
- A commercially dominated industry in 2010 as opposed to R&D dominated activity 10 years ago.
- Early indications that technical success is consistently being achieved with this

translating into commercial success (where this is an aim)

The next decade will likely be a period of consolidation and further growth for this part of the geothermal sector, with several more projects likely to be producing power at the end of this period. As part of that evolution, projects are likely to increase in size.

Regulatory frameworks and government policies are needed which encourage this momentum and help consolidate the industry over this period with government support continuing to be made available at appropriate levels to further growth and encourage investor interest.

References

Baumgärtner, J., Menzel, H., and Hauffe, P.,2007, “The Geox GmbH Project in Landau - The first geothermal power project in Palatinate / Upper Rhine Valley”, in Proceedings *First European Geothermal Review, Geothermal Energy for Electric Power Production*, p. 33, Mainz, Rhineland Palatinate, Germany.

Brown, D.W., 2009, Hot dry rock geothermal energy: Important lessons from Fenton Hill. Proc. Thirty-Fourth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 9–11.

Cornet, F.H., 2009, From hot dry rock to enhanced geothermal systems: the Soultz-sous-Forets project, AAPG European Region Annual Conference, Paris-Malmaison, France, 23-24 November 2009

DRET (Department of Resources, Energy and Tourism) 2008, Canberra, 64pp.

Evans, K.F. and Valley, B., 2005, An overview of enhanced geothermal systems, www.geothermal.ethz.ch/.../Geothermal%20publications/EvansEtAl_2005_EGS-Overview.pdf

Hillis, R.R. and Reynolds, S.D., 2000. The Australian Stress Map. *Journal of the Geological Society, London*, 157, 915-921.

Holm, A., Blodgett, L., Jennejohn, D. And Gawall, K., 2010, Geothermal Energy: International Market Update, Geothermal Energy Association Report, May 2010.

Jennejohn, D., 2010, US Geothermal Power Production and Development Update, Geothermal Energy Association Report, April 2010

Majer, E., Baria, R. and Stark, M., 2008, Protocol for Induced Seismicity Associated with Enhanced Geothermal Systems. Report produced in Task D Annex I (9 April 2008), International Energy Agency-Geothermal Implementing Agreement (incorporating comments by: C. Bromley, W. Cumming, A. Jelacic and L. Rybach).

Morelli, C., and Malavazos, M. (2008), Analysis and Management of Seismic Risks Associated With Engineered Geothermal System Operations in South Australia, in Gurgenci, H. and Budd, A. R. (editors), Proceedings of the Sir Mark Oliphant International Frontiers of Science and Technology Australian Geothermal Energy Conference, Geoscience Australia, Record

Reif, T., 2009, Economic aspects of geothermal district heating and power generation, Presentation, Tallinn Uni of Technology, 17 April 2009/GeotIS, Geothermische Vereinigung

Tezuka, K., 2007, Japanese EGS Experience and modelling efforts - a Review of the Hijiori HDR project. ENGINE Workshop 2, Volterra, 1-4 April 2007.