GEORG

GEOTHERMAL RESEARCH GROUP

ANNEX I

Project Plan

RENEWABILITY OF GEOTHERMAL RESOURCES

Project ID: **09-01-012**

Coordinator: **Guðni Axelsson, ÍSOR**

Start date: **01.10.09**

Duration: **3 years**

Partners: **IES-UI, HS Orka, GNS – New Zealand**

1 Project description

Geothermal energy resources are generally classified as renewable. Their renewability has not been systematically addressed, however, and the issue is not yet fully understood. Renewability is highly dependent on the boundary conditions of geothermal systems, and in particular on their inflow, or recharge, in both the natural state and during production. The inflow is believed to be a combination of shallow inflow, which is colder than the average reservoir fluid, and deep hot recharge. The recharge is reflected in the mass balance of geothermal reservoirs during long-term utilization, which in turn is reflected in the surface deformation of the fields. Another side of the mass balance is the development, or growth, of steam-zones in high-temperature geothermal systems during utilization. The purpose of the project proposed here is to develop methods to study the recharge and mass balance and apply them to the Reykjanes-Svartsengi geothermal region in Iceland.

The proposed project aims to join together the results of several different scientific methods or disciplines to address the issue in question, in particular:

(a) High-resolution 3-D surface deformation monitoring (InSAR and GPS monitoring),
(b) micro-gravity monitoring,
(c) repeated TEM resistivity surveying,
(d) reservoir pressure- and temperature monitoring,
(e) chemical content monitoring and
(f) dynamic geothermal reservoir modelling.

Combining surface elevation and gravity data has been used to estimate the mass balance of geothermal systems during production, resistivity surveying has been used for exploration and chemical data has been used to study processes in geothermal systems and their recharge. Detailed numerical modelling of geothermal systems has also been used extensively to simulate the response of geothermal reservoirs to production. The innovative aspect of this proposal involves joining together the results of the different methods through unified modelling of aspects (a) through (e).

Extensive repeated geodetic measurements have been collected in the study areas for decades. These include conventional optical levelling, precise GPS geodetic measurements, satellite radar interferometric observations utilizing InSAR satellite data, and electronic distance measurements prior to advent of GPS. All available data will be combined to infer 3D-deformation fields. This includes geodetic data that ÍSOR has collected in the geothermal region as well as data on deformation over broader area collected by IES-UI and collaborators. Derivation of a precise 3D-deformation field will be based on joint interpretation of InSAR images together with GPS derived 3D displacement vectors at the surveyed sites. Innovative new InSAR analysis techniques will be utilized.

High resolution micro-gravity surveying has been conducted in the region by ÍSOR and its predecessors at regular intervals during the last three decades. These data will be interpreted jointly with the surface deformation data. The proposed project also intends to apply repeated TEM resistivity surveying at a few selected locations in Reykjanes in particular, surveyed before large-scale production started, to monitor the growth of a steam zone in the region.

The proposed work involves the following:

(1) Literature review of methods involved.

(2) Analysis of available data; including geodetic data and micro-gravity data.
(3) Collection of further data; including acquisition of further InSAR data, a complete GPS- and gravity survey during the 1st year of the project as well as TEM surveying above the proposed steam-zone in Reykjanes repeated 3 times during the project.
(4) Revisions of modelling software (see below), or development of associated software, to incorporate simulation of surface deformation and gravity changes. The modelling software is already being revised to incorporate resistivity data.
(5) Development of a numerical model of the geothermal region and joint data simulation.
(6) Publications of results in interim reports and research articles as well as presentation at relevant conferences.

The Reykjanes region is affected by plate movements and is volcanically and tectonically active. Therefore the data analysis will include the separation of deformation due to these causes from the deformation caused by geothermal energy production.

The numerical modelling software TOUGH2, developed at Lawrence Berkeley Laboratory in California, will be revised and used to set up relatively simple models of the geothermal systems involved with the focus on boundary conditions, recharge, pressure changes and mass balance rather than details of the production sections of the geothermal systems and individual wells. This software has been successfully used to simulate geothermal resources worldwide and is universally regarded as the most versatile geothermal simulation software openly available today. The project proposed involves, in particular, co-operation with GNS Science in New Zealand, which has long experience in such modelling issues through its collaboration with the University of Auckland. GNS Science has also been heavily involved in crustal deformation and gravity surveying as well as associated modelling studies.

The division of tasks and responsibilities between the different parties to be involved in the project is described further below, but the general organization will be as follows:

(A) ÍSOR will provide expertise and lead work on GPS and micro-gravity surveying and dynamic reservoir model development.
(B) IES-UI will provide expertise and lead work on the geodetic component of the project as well as provide gravity surveying expertise.
(C) GNS Science in NZ will share their experience in using the methods proposed and take part in comparing data from Reykjanes-Svartsengi and geothermal fields in New Zealand.
(D) HS Orka will provide access to relevant data collected at its expense as well as relevant production data.

Several other issues, relevant to the proposal subject, will be addressed briefly in preparation for further studies. These may include pressure interference between separate geothermal areas and the effect of steam-zone development on seismic velocity structures, to name a few.

The work proposed aims at adding significantly to the understanding of the nature of geothermal resources, in particular the recharge and mass balance of geothermal systems under production, including the localized development of steam-zones. Thus the hope is to improve the understanding of the renewability of geothermal resources. The main emphasis is on unifying analysis and modelling of data from different sources to improve this understanding. This will be founded on the extensive geothermal research experience of ÍSOR and GNS Science as well as the experience of IES-UI in volcanological monitoring.

This project aims to address specifically, and add to the understanding of, boundary conditions and their role in the long-term production response of geothermal systems. Up to now more emphasis has generally been put on detailed information on the production parts of the systems, which has been made available through the drilling and testing of numerous wells. The project also aims at adding to the understanding of steam-zone development in high-temperature geothermal systems during utilization. An important part of the project focuses on applying methods developed for geothermal fields in New Zealand to the Reykjanes-Svartsengi fields and comparing the results with results obtained in New Zealand.

A further scientific merit includes adding to the continuous development dynamic geothermal system modelling methods, including methods to simulate surface deformation, gravity changes and resistivity changes. This will help to add significantly to the understanding of geothermal systems, aid in improving the management of the resources as well as help further develop these as resource monitoring tools.

All this combined will, consequently, add to the understanding of the sustainable utilization of geothermal resources and help in the sustainable management of the Reykjanes-Svartsengi geothermal region, and geothermal resources in general.

A large part of the project work will be conducted by a PhD-student. This constitutes the most direct educational benefit of the project. The project may also include the possible participation of one or more MSc-students, even though no support is requested for that. In addition the project will contribute the general development of the scientific staff of the participant, through project involvement.

The proposed project will strengthen geothermal research co-operation in Iceland considerably through the cooperation of ÍSOR, IES-UI and HS Orka. It should also promote more interdisciplinary research in the geothermal sector in general, both within institutes and companies as well as amongst them.

The project will, furthermore strengthen ties between the Icelandic geothermal research community and the international community through the participation of GNS Science of New Zealand. GNS Science's contribution will include sharing their knowledge and experience on the research issues at hand. The project plan includes visits from GNS Science to Iceland as well as a work trip on behalf of the Icelandic participants to New Zealand.

An added educational quality arises from dissemination planned through reports and research articles and active participation at international conferences, yet to be selected.

The project aims at improving and advancing the quality of the scientific methods used, including the following. This includes making their application more cost-effective and, therefore, making them more readily applicable as geothermal reservoir monitoring tools:

i) The geophysical- and geodetic methods applied, i.e. resistivity methods (TEM), micro- gravity monitoring methods, GPS surveying methods and InSAR methods.
ii) The data processing and interpretation methods used.
iii) The dynamic numerical modelling methods used.

Renewability and the long-term response of geothermal systems to production is an issue of great social value. This applies in particular to the possible contribution of geothermal resources to sustainable development. The proposed project will also add to the entrepreneurial quality of HS Orka, and other geothermal power companies in Iceland, by adding to the understanding of geothermal resources and their sustainable utilization.

2 Objectives and GEORG WP relevance

The main objective of the project is to add significantly to the understanding of the nature of geothermal resources, in particular the recharge and mass balance of geothermal systems under production, including the localized development of steam-zones. Thus the hope is to improve the understanding of the renewability of geothermal resources. The main emphasis is on unifying analysis and modelling of data from different sources to improve this understanding. This objective is highly relevant for Work Package (WP) 4, which deals with improving the understanding of the nature of geothermal systems, the methodology for their exploration and assessment as well as utilisation, and Task 1 of WP 6, which aims to improve understanding of the renewability of geothermal resources to help ensure a long term economically optimal geothermal energy utilization. This is in addition to the objective being relevant for WP's 2 (Education and Training) and 8 (Dissemination and Outreach).

Meeting this objective should aid in achieving GEORG's main goals of increasing geothermal utilization and making Iceland an energy independent case study and carbon neutral society because of the increased understanding of geothermal systems the project should enable. The project should also aid in the development of a more creative research and education environment in Iceland, strengthen the ties between industry and research organizations as well as increasing beneficial international co-operation.

3 Work plan and time schedule:

The main phases of the proposed work are the following (see project description below):

(1) Literature review of methods involved.
(2) Analysis of available data.
(3) Collection of further data as needed.
(4) Revisions of modelling software to incorporate simulation of surface subsidence and gravity changes.
(5) Development of numerical models of the geothermal region.
(6) Two project meetings in Iceland and a project workshop in New Zealand.

The results of these phases will be published in interim reports and research articles. It is assumed that the thesis of the PhD student involved in the project will be composed of three research articles.

Time schedule:

Subtask	Start	Finish	Deliverable/Milestone
(1) Literature review	01.10.2009	01.10.2010	Research article
(2) Data analysis	01.01.2010	01.04.2012	Interim report(s) / Research article
(3) Data collection	01.03.2010	01.10.2011	Interim report(s) / Research article
(4) Software revision	01.10.2010	01.10.2011	Interim report(s)
(5) Model development	01.09.2011	01.10.2012	Interim report(s) / Research article
(6) Project meeting 1 (Icel.)	Oct. 2009		
(7) Project meeting 2 (NZ)	Jan. 2011		
(8) Project meeting 3 (Icel.)	May 2012		

4 Project Management

The proposed project will be managed by the following team of experts having long-standing and comprehensive experience in geothermal- and volcanological research:

Dr. Guðni Axelsson, ÍSOR and UI
Dr. Freysteinn Sigmundsson, IES-UI
Dr. Chris Bromley, GNS Science

ÍSOR is the main geothermal research institute in Iceland with about 90 staff members. The institute and its predecessors have been involved in geothermal research for more than half a century. In this project ÍSOR provides expertise on geophysical methods, geothermal reservoir physics and reservoir modelling. Several other ÍSOR experts will be involved in the project including K. Árnason, H. Eysteinsson, I. Þ. Magnússon, S. Halldórsdóttir and H. Björnsson. ÍSOR is also in cooperation with the developers of the TOUGH2 modelling software at LBL in California through other projects, an association that will be used as needed in this project.

The University of Iceland has long-standing experience in application of geophysical and geodetical methods, in particular for volcanological research. Other IES-UI staff members to be involved in the project include M. T. Guðmundsson, Þ. Árnadóttir and R. Petersen. The PhD-student of the project is yet to be selected.

GNS Science also has extensive and long-standing (50 years) experience in volcanological, geothermal and environment research. The institute has about 250 employees, mostly scientists. Other GNS scientists that will be involved in the project include T. Hunt and S. Samsonov. GNS Science also collaborates directly with the University of Auckland, which has comprehensive experience in geothermal reservoir modelling under the guidance of M. O. Sullivan.

HS Orka is the fourth participant in the proposed project. The company has been utilizing the Svartsengi field for three decades for energy production and the Reykjanes field since 2006. HS Orka has extensive experience in geothermal exploration and geothermal resource management. In addition to Guðmundur Ó. Friðleifsson listed above Mr. Ómar Sigurðsson of HS Orka has extensive and long-standing experience in geothermal reservoir engineering and modelling.

5 Budget overview

Consortium: **ÍSOR / UofI / GNS Science**

Name of Project: **Renewability of geothermal resources**

ISK '000	Year	Unit cost	Year 1 2009/2010 Man-months	Year 1 Total	Year 2 2010/2011 Man-months	Year 2 Total	Year 3 2011/2012 Man-months	Year 3 Total	**Grand Total**	
Salaries including overhead		**Unit cost**	Man-months	Total	Man-months	Total	Man-months	Total		
ÍOSR	Expert	1.200	3	3.600	5	6.000	3	3.600	13.200	
IES-UI	Expert	1.200	3	3.600	3	3.600	3	3.600	10.800	
GNS Science	Expert	1.600	1	1.600	1	1.600	1	1.600	4.800	
PhD student	NN	600	6	3.600	12	7.200	12	7.200	18.000	
Total			13	12.400	21	18.400	19	16.000	46.800	
Operational exp.										
Gravity/GPS monitoring - instrument fees				0		3.500		0	3.500	
InSAR data				200		200		0	400	
TEM surveying - instrument fees				400		800		400	1.600	
Total				600		4.500		400	5.500	
Travel expenses										
Travel New Zealand-Iceland				400		0		400	800	
Travel Iceland-New Zealand				0		1.000		0	1.000	
Conference participation				0		0		300	300	
Total				400		1.000		700	2.100	
Total cost				13.400		23.900		17.100	54.400	
Financing										
ÍSOR				2.300		4.600		5.200	12.100	
IES-UI				3.000		3.000		3.000	9.000	
GNS Science - work in NZ				1.600		1.600		1.600	4.800	
HS Orka - gravity monitoring, GPS + TEM surveying				0		5.200		1.500	6.700	
Total other financing				6.900	51%	14.400	60%	11.300	32.600	60%
Requested funding from GEORG				6.500	49%	9.500	40%	5.800	21.800	40%
Total financing				13.400		23.900		17.100	54.400	100%

Note: in the Year 3 column the printed percentages for Total other financing (66%) and Requested funding from GEORG (34%) appear to the right of the Year 3 totals.

Explanation of cost:

The following aspects of the project budget should be considered:

(a) The budget has been revised such that the funding requested from GEORG has been reduced by 3.9 MISK. This corresponds to about 50% of the support originally requested for the third year of the project. This is partly met by a 50% reduction of the work-load of the project's PhD-student during the first year. In addition other financing has been increased (ÍSOR and HS Orka) during the third year.

(b) ÍSOR's matching contribution covers overhead associated with the work of the PhD-student, who will be located at ÍSOR. Thus GEORG's contribution towards the student's salary will not exceed the 9.5 MISK limit. It also covers about half of the instrument- and salary cost associated with repeated TEM resistivity surveying. It also covers a part of the salaries and overhead for ÍSOR scientists involved in the project.

(c) The University of Iceland's matching contribution covers most of the salaries and overhead for permanent staff involved in the project.

(d) GNS Science's matching contribution covers salaries and overhead of GNS scientific staff involved in the project.

(e) HS Orka's matching contribution covers instrument cost associated with gravity- and GPS field measurements in the Svartsengi and Reykjanes fields as well as half of the instrument cost associated with repeated TEM-surveying. It also covers about half of the salaries of staff involved in the field work