ANNEX I
Project Plan

Biological Utilization of Geothermal Gas

Project ID: 09-01-017

Coordinator: Guðmundur Óli Hreggviðsson, University of Iceland

Start date: 1. June 2009

Duration: 2 years

Partners: University of Iceland, Prokatín ehf, Mannvit Engineering

1 Project description

General description of the project, clarify what the intended work involves and specify the need or importance for this work in connection with geothermal energy.

General description

About 1% of the geothermal steam that is being used in geothermal power plants is non-condensable gas consisting mainly of CO_2, H_2 and H_2S. The current release of this poisonous and erosive gas to the atmosphere is very undesirable and finding a suitable way to reduce this emission is becoming extremely important. However, the geothermal gas contains chemical components that many microorganisms can use for growth and are the main energy sources in hot spring microbial ecosystems. The organisms use the chemical energy in H_2 and H_2S and at the same use CO_2 as a carbon source for biomass production. The geothermal gas currently released to the atmosphere can thus be treated as a natural resource and by microbial cultivations utilized for production of valuable products at the same time as H_2S and CO_2 would be reduced or removed completely from the effluent gas. With this biological utilization in mind, the GEOGAS project framework was conceived. Within this framework, substantial research and development has been carried out for the last several years in collaboration between Univ. of Iceland, Mannvit Engineering, Univ. of Akureyri, RES School of Renewable Science, Matís, Reykjavik Energy and Prokatín ehf. The present grant proposal aims to connect the GEOGAS project with the GEORG program and seek funding for certain aspects of the GOEGAS projects.

Scientific merit

The applicant and the cooperating partners have been devoting the past several years to research on the use of geothermal gas for the cultivation of microorganisms. A small-scale laboratory has been operated at the Nesjavellir geothermal power plant and we have successfully demonstrated the feasibility of growing microorganisms using the geothermal gas from the power plant. The cooperative start-up biotech company Prokatin ehf has recently made an agreement with Reykjavik Energy (OR) for the construction of a several thousand liter pilot scale fermentation facility ("*Laboratory of Geothermal Biotechnology*") at the Hellisheiði power plant. The estimated cost for constructing and running this research facility is in the order of 100 Million ISK and the facility will be an invaluable asset for the current project for large scale as well as small scale studies of microbial cultivations. This facility will be one of its kinds in the world and give opportunity for unique scientific experiments and development of applications.

Technical / Entrepreneurial / Social aspects

The aim is to develop a system for large-scale production of microbial biomass using the geothermal gas effluent from geothermal power plants. In one aspect, the system is a bioremediation system for reducing emissions of undesirable gases but on the other hand gives a potential for production of several thousand tones of microbial biomass per year. We are currently focusing on bacterial cultivation using hydrogen and hydrogen sulfide as energy sources but the research is a part of the larger GEOGAS research and development plan, with the aim of using both bacteria and, at later stages, also microalgae for complete utilization of all CO_2 originating from geothermal power plants. An overview of the GEOGAS project is provided in the following figure:

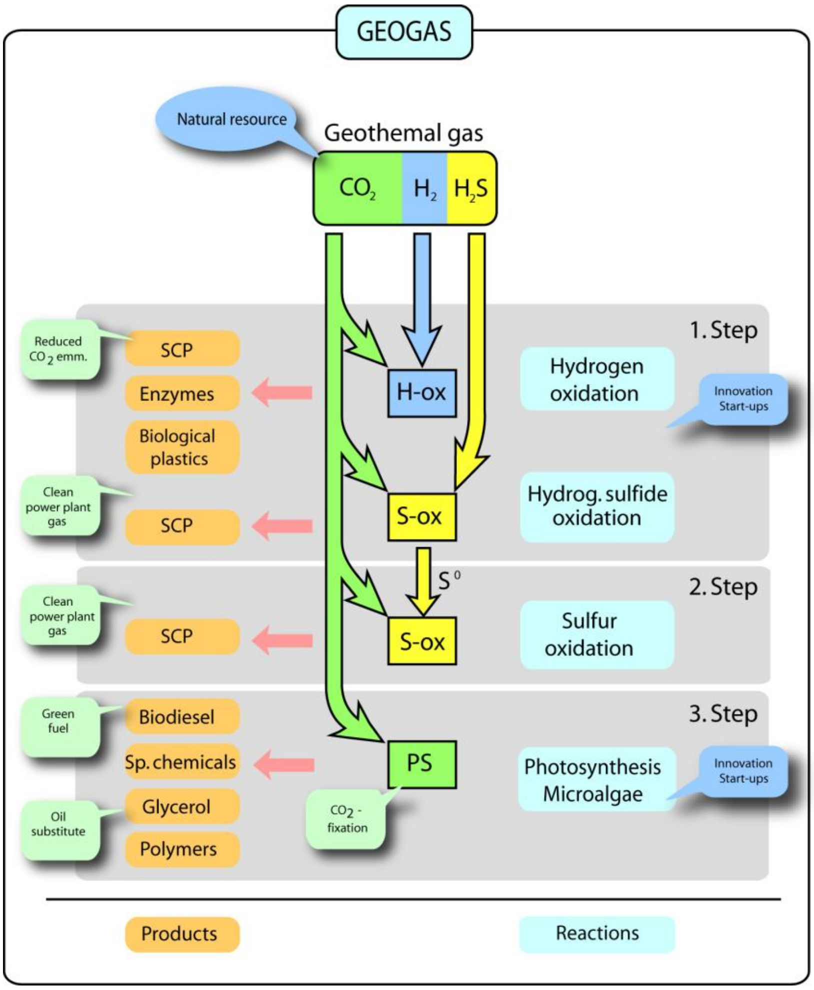

Fig.1. Overview of the GEOGAS project (SCP: Single-cell protein, PS: Photosynthesis)

As shown in the figure, the components of the geothermal gas can be converted to various products including high value specialty chemicals, enzymes, single-cell protein, biodiesel and glycerol. It is becoming apparent that the geothermal gas is a unique and valuable resource for the production of biomass and biofuel. The facilities, experience and competence in the group of collaborating partners provides a strong competitiveness to successfully carry out the research and development needed to commercially exploit his unique natural resource.

The value created by the GEOGAS project can be very substantial. For an average power plant like Nesjavellir about 2000-4000 tones of single-cell protein meal can be produced and in the process about 7000 tones of H_2S and about 5000 tones of CO_2 emission will be eliminated. If all gas in current and planned power plants in the Hengill area will be utilized, these figures can be multiplied by a factor of around 5. Using the remaining CO_2 for biodiesel production might give amount of fuel for 10% of the annual fuel demands for vehicles in Iceland.

The experimental work so far, including the work at the Nesjavellir laboratory, has demonstrated that the non-condensable gas from the power plant can be used in special cultivation vessels in a controlled way for the cultivation of hydrogen-oxidizing and sulfur-oxidizing microorganisms. In this process, the microbes also bind CO_2 in the gas and form protein-rich biomass, comparable to fish-meal, that can be used as feed for animals and fish in agriculture and fish farms. During cultivation, the microbes first form solid elemental sulfur from the H_2S in gas and this solid can be separated from the culture or otherwise let the microorganisms oxidize the sulfur further to sulfuric acid.

The CO_2 emission from geothermal energy utilization is relatively small proportion of the total emission in Iceland, e.g. in year 2004, only 3% came from geothermal energy utilization but potential future CO_2 tax is also of concern for the geothermal industry. However, H_2S emission is already of great concern with 90% of total sulfur compound emission in Iceland originating from geothermal industry and with more and bigger power plants near human habitats this is becoming an urgent issue due to smell, corrosion of metals and potential health risks. As a method to reduce emission, biological utilization of geothermal gas will convert H_2S to solid sulfur or sulfuric acid which is more manageable than the gas but still has to be disposed of or used to produce commercial products.

Both elemental sulfur and sulfuric acid are being used in large amounts in industrial applications and for example is sulfuric acid the chemical substance that is being produced in greatest amounts in the world today and often used as indicator of the industrialization of the corresponding country. Both these substances are also being formed as waste products during mining, processing of fuels etc. but then the elemental sulfur for example is often polluted by heavy metals and is therefore not usable and has to be disposed of. Elemental sulfur is otherwise used for production of sulfuric acid but also used for many other purposes such as a fertilizer.

Pure sulfur is harmless to animals by digestion. Sulfur as a component in cosmetics is still the main method for treatment of acne and other skin problems. Sulfur has a well-known fungicidal effect and is finding increased use since it is approves for use in ecological cultivation of vegetables both as a fungicide and as an insecticide. Sulfur is normally included in fertilizer since it is essential element for plants and 15-50 kg/Ha/year are required for growing common crops. Inorganic sulfur is hydrophobic whereas sulfur produced by biological oxidation is hydrophilic and more easily solubilized and works better as fertilizer and fungicide. In the project, the potential use and commercialization of sulfur formed by biological oxidation of H_2S in geothermal gas will be evaluated, including experiments using the produced sulfur as fertilizer and fungicide.

Education / Infrastructure quality

Previous and present work within the GEOGAS framework has been based on collaboration between academia and the industry. Several students have been involved from Univ. of Iceland, Univ. of Akureyri, RES and Chalmers Technical Univ. in Sweden. The applicants and cooperating partners are active in providing education within the Universities and RES. Special emphasis will be put on scientific merits and the education of young scientists and engineers with publications of scientific papers and with patent applications as required. A Masters student, Guðný Inga Ófeigsdóttir, will be working under the supervision of the applicant on the proposed project. A grant has been also been awarded to the applicant from Reykjavik Energy Research fund (UOOR) for part of this work.

The aim of the GEOGAS project is to acquire the knowledge and develop the technology and infrastructure needed for future utilization of geothermal gas. The cooperation of academic groups and start-up companies will be based on production of valuable products ranging from single-cell protein for use in feed to specialty chemicals, enzymes and biofuels from microalgae. The research and development program is a unique addition to the development of the geothermal industry in Iceland and provides an important resource for continued development of the industry in Iceland but also in bringing the technology and competence to other geothermal energy projects overseas.

1.1 Objectives and GEORG WP relevance

Specify the main objectives of the project and explain the relevance it has to GEORG WP. Please also explain how the project will help GEORG achieving its main objectives

The main objectives of the project is to develop an economically feasible biological method and technology to utilize and treat geothermal gas that is released from geothermal power plants. The gas typically consisting mainly of CO2, H2 and H2S will be led into a bioreactor where bacteria will be grown and thereby removing to H2 and H2S as energy sources and fixing the CO2 as carbon source. By the growth of the bacteria, biomass and solid sulphur will be formed, followed by removal from the bioreactor and separation. Final goals are then to sell the biomass as a protein rich ingredient for fish- and animal feed. The sulphur will also be exported and sold for use in fertilisers or for conversion into sulphuric acid, used in chemical and mining industries.

These objectives match perfectly with the GEORG main goals, particularly WP5, Task 5.4. concerning the treatment and utilisation of gases and WP6, tasks 6.2 concerning diminished greenhouse gas emission and task 6.3 concerning novel biproducts that can be produced and used in other unrelated fields.

2 Work plan and time schedule:

Provide a short work plan broken down into subtasks which should follow the logical phases of the implementation of the project. A timeline should be presented as well as list of deliverables and milestones. Please keep in mind the submission of progress- and annual reports to GEORG, while planning the deliverables and milestones.

Short description of the work plan

Subtask 1. Pilot plant at Hellisheiði
Main emphasis is put on building a several thousand liter pilot plant at the Hellisheiði power plant. The pilot plant will obtain geothermal gas directly from the power plant and the gas will be processed by a biological process for the production of biomass (single-cell protein) and solid sulfur and sulfuric acid. The pilot plant will be run for 1-2 years and is estimated that during the operation of the facility, up to 50 tones of biomass and 100-300 tones of sulfur / sulfuric acid will be produced. The operation will be a feasibility study for a future full-scale factory.

Subtask 2. Use of Biomass for Feed
There is much interest in the availability of new protein sources for feed due to shortage of fish meal for feed. We will collaborate with the Norwegian feed producer Ewos to evaluate by analysis and testing the use of our single-cell protein in feed for animals and fish farming. We will also collaborate with Matís ohf and the Icelandic company Arctic Tilapia ehf for experiments using the single-cell protein for cultivation of the tropical Tilapia fish which is a species with characteristics suitable for experiments of this kind.

Subtask 3. Utilization of Sulfur
Previous studies have indicated that soil in Iceland is generally deficient in sulfur and is a limiting factor in growing grass and vegetables. Currently, the fertilizer imported to Iceland annually contains over 1000 tones of sulfur and indications are that agriculture could benefit form even larger amounts of sulfur. Potential use of the biological sulfur produced at the pilot plant as a fertilizer will be investigated in this project. Contacts have been established with the Agricultural Univ. of Iceland and the Soil Conservation Service of Iceland (Landgræðsla ríkisins) for collaborations regarding experiments for use of the biological sulfur as fertilizer and protective agent mainly as a fungicide. Plans have been made for experiments regarding the use of sulfur as fungicide in the growth of barley plants by the Icelandic biotech company Orf Genetics Special and emphasis will be put on working with farmers of organic agriculture.

Deliverables and Milestones indicating progress:

The submission of a Progress report:

Milestone 1: Construction of 2000 L pilot bioreactor tank finished.

Milestone 2: Report on sulphur market situation and main uses of sulphur prepared.

The submission of an Annual report:

Milestone 3: Bioreactor has been put in operation and at Hellisheiði power plant and tested with real geogas on site.

3 Project Management

Make a short description of the applicants involved in the project, inform about the resources that will be assigned to the project. Also specify in clear and simple manner who is resposible for what and how that will be managed.

The project will be managed by the coordinator and his cooperation partners, primarily Prokatin ehf, which mission is the same as the objectives of this project and concentrating all its efforts on this problem in close cooperation with Orkuveita Reykjavíkur.

The cooperation between Univ. of Iceland and the partners involves supervision of students involved in the project by the applicant Dr. Guðmundur Ó. Hreggviðsson. The daily operations of the laboratory at Nesjavellir and the pilot plant at Hellisheiði will be under responsibility of Dr. Arnþór Ævarsson, CEO of Prokatin and Dr. Jakob Kristjánsson. The board of Prokatin, including representatives from Reykjavik Energy, Mannvit Engineering and Arkea, the mother company of Prokatin, take part in major decisions in the progress of the project. Chemical engineer Ásgeir Ívarsson at Mannvit Engineering supervises the operations of engineers in the projects. Progress in the project is regularly review by all involved parties for further decision making. Reykjavik Energy has allocated up to 50 millions ISK for construction of the pilot plant at Hellisheiði power plant and other share-holders of Prokatin are also contributing to the GEOGAS projects. Effort will be made to establish international collaborations, especially EU funded programs. The project partners have extensive experience of participation in research programs within the EU research framework.

Cooperative partners

University of Iceland,
Dr. Guðmundur Óli Hreggviðsson, Ph.D. in molecular biology from Edinburg Univ., UK. Docent in Microbiology at Univ. of Iceland. Department manager at Matís/Prokaria.
M.Sc. student: *Guðný Inga Ófeigsdóttir*, B.S. Biochemistry Univ. of Iceland.

Prokatin ehf
Dr. Arnþór Ævarsson CEO, Ph.D. educated in Biotechnology and Biophysics at Univ. of Lund, Sweden and Univ. of Washington, USA. Previously director of intellectual property and business development at Prokaria. Published about 20 scientific papers and a number of issued patents.
Dr. Jakob Kristjánsson, Chairman, Ph.D. in biochemistry from Brandeis Univ. USA. Previously docent and research professor and Univ. of Iceland. Founder and president of Prokaria. Published over 100 scientific papers and a number of issued patents.

Mannvit Engineering
Ásgeir Ívarsson, M.Sc. Chemical engineering, Chalmers Univ. of Technology, Sweden.
Rúnólfur Maack, M.Sc. Mechanical eng. Denmark Univ. Of Technology. Deputy CEO foreign operations.

Reykjavik Energy
Hólmfríður Sigurðardóttir, Cand Scient Soil Biology Univ. of Aarhus, MBA from Univ. of Reykjavik. Manager of innovation and development.

4 Budget overview

Insert the "Costs" spreadsheet from the application documents. Explain the basic cost structure of the project. If it's assumed informative an additional budget summary can be included here, that, however, should not exclude the standard forms. Please justify, in simple *terms, how the criterias of chapter 6, Section I in the „Proposal & Award Policies & Procedures Guide“ are fulfilled.*

Financing:

(Copy and paste (as picture) the budget summary table from the attached excel document)

	Cost item	Requested funding		Other financing		Total
2009/2010	Salaries					5.600
	Operational expenses					3.472
	Travel expenses					500
	Total 2009/2010:	1.250	13%	8.072	84%	9.572
2010/2011	Salaries					3.680
	Operational expenses					2.282
	Travel expenses					300
	Total 2010/2011:	1.250	20%	5.262	84%	6.262
2011/2012	Salaries					0
	Operational expenses					0
	Travel expenses					0
	Total 2010/2012:	0	N/A	0	N/A	0
Grand Total		**2.500**	**16%**	**13.334**	**84%**	**15.834**

Explanation of cost:

If necessary, explain the cost structure of the project in more detail. If it’s assumed informative an additional budget summary can be included here, that, however, should not exclude the standard forms.

Requested funding of ISK 2.500.000.- from GEORG is only for part of the salary costs for the applicant’s Masters student. The rest of the cost for the student, i.e. remaining salary and expenses for the student’s work, excluding overhead, is covered by a grant from the Reykjavik Energy Research Fund (UOOR, Umhverfis- og Orkurannsóknasjóður Orkuveitu Reykjavíkur).

Contributions for the remaining costs in the budget have been secured from the involved partners.