FINAL REPORT

GeoChem

Project ID: 10-03-005

Coordinator: Bernhard Pálsson / Sigurður Brynjólfsson

Start date: May 1st 2011

Duration: 3 years

Partners:

1 Project summary

<Explain the projects achievements during whole project period, milestones and goal achieve. Inform about possible delays and complications and explain who it was handled. >

The overall goal of this project was to design and build a photobioreactor-based algae factory that utilizes geothermal energy in an efficient manner to fix CO_2 into valuable chemicals that are produced from algae. We designed a new photobioreactor (PBR) that combines light-emitting diode (LED) technology and algal biotechnology to produce algae from electrical energy and CO_2 emitted from geothermal wells in Iceland. Many of the fundamental design parameters of such a factory have already been determined through experimentation with a fully functional prototype operated at the Center for Systems Biology at the University of Iceland. The initial prototype is a 10 liter working volume for the purpose of investigating the feasibility of the design at industrial scale. The work has been focused on the control system, controlling the flow of chemicals, the gas flow and composition, power and energy consumption of the LED's.

The work related to the biology of algae continues. We still have a PhD student working on growth of diatoms, financed by the Technical Development Fund. The adaptive laboratory evolution is a tool that us used to increase the production rate of the algae in the given environment of the photo-bioreactor. Our main species are Chlorella vulgaris and Dunaliella salina. Chlorella is a common fresh water algae and cultivated as a food suppliment and Dunaliella is a salt water algae and is grown for it carotenoid content. It was grown in the photo-bioreactor using adaptive laboratory evolution and its metabolism investigated. The effect of light intensity, color (red/blue combinations) salinity and type of nitrogen source in the medium. The light combination, ratio of red/blue light, does affect the content of cartenoids in the biomass. This information is used to optimize the economy of the production process.

We have started to grow diatom, Phaeodactylum tricornutum, in the experimental setup. That organism is promising for producing lipids. It also produce fucoxanthin that is used as food suppliment. This organism has been sequenced and therefore it is possible to make a metabolic model that can be used to investigate how applicable it is for production of valuable chemicals and for metabolic engineering. Preliminary results are promishing.

It has not been possible to test the equipment with geothermal gas. The Center for Systems Biology is located at Sturlugata 8, same building as Decode Genetics. It is not possible to work with geothermal gases in the same facilities as human genetics work is on going. It is necessary to work with geothermal gases closer to or in geothermal area. That has not been done due to increased cost. We are trying to resolve that issue in collaboration with other research labs.

This project has resulted in 6 scientific journal articles, one Master thesis and one final project at The Technical College (Vélskólinn). Sindri Freyr Ólafsson defended his MS thesis that focused on the final products of chemicals or biomass. Several alternative produciton lines were analysed. That work was in collaboration with Matis (Sigurjón Arason, Hörð Kristinsson, Björn Margeirsson and Sindra Frey Ólafssonar). Final products are lipids and dry biomass. It is possible to produce consumer products

later. Kristinn Arnar Ormarsson, a student from Vélskólinn built a prototype that was supposed to be testes at the geothermal power plant at Hellisheiði. He did an excellent work but it was not possible to install it at the site due to the control system that was unstable. Two engineering summer students worked on the control system during the summer but where not able to stabilize the flow rates and CO_2 concentrations sufficiently.

There were two people working on the project most of the time, Dr. Weiqi Fu, biochemical engineer and Elín Adda Steinarsdóttir, a mechanical engineer. We spent more time on the biology and biotechnology than anticipated in the beginning and less on the design issues. That shows on the publication list. It was difficult for us to test the equipment with real geothermal gases for several reasons. Our lab is located in the same building as Decode Genetics so it is not possible to do experiments with "real geothermal gases" that include H_2S. We also had problems with the stability of the control systems of the photo-bioreactor. It is necessary to work on that to finish the prototype. We are still using our lab system to investigate the growth of diatoms. A PhD student, Zhiqian Yi, is working on that project which is funded by the Technical Development Fund. There will be two students working on the prototype this summer, one mechanical engineering student, an exchange student from Yale, and one graduate student in biotechnology, Birkir Reynisson.

2 Project Management

<Explain the management of the project, how decisions were made and how the project is organized. Inform about possible problems or unforeseen incidents and how it was tackled.>

The project was conducted in collaboration between the Center for Systems Biology at the University of Iceland and Controlant ehf. Dr. Bernhard Palsson, Dr. Sigurður Brynjólfsson and Gisli Herjolfsson supervised the project in the beginning. The control engineering design is carried out by Controlant ehf, an Icelandic startup company with extensive knowledge on control systems, hardware and software design. Growth characteristics of the various algal species are done at the Center. In addition the Center is capable of carrying out genome-scale metabolic models and to generate metabolomic data that characterizes the metabolic state and performance of the algal strains used. Weiqi Fu, biochemical engineer and post doc at CSB (Center for Systems Biology) performed the physiological experiments with algae. Sigurjon Arason will participate in the design of the drying process and supervised Sindri Freyr Ólafsson. Another engineer was to work on the development and the design of the design process. The role of Controlant and Matis were less in the last year than the previous years. Sigurdur Brynjolfsson ran the project on a daily bases.

3 Student involvement

< if applicable, inform about the student involvement in the project. Are graduate students involved in the and in so what are their names and degrees?>

Several students worked on the project over the years. Two of them did their final projects as mentioned previously, Sindri Freyr his MS thesis at the University of Iceland and Kristinn Arnar his final project in the Technical College Reykjavík (Vélskólinn). Daníel Eldjárn student in electrical engineering worked with Controllant on the control system. Freyr Jóhannson and Kristófer Þór Magnússon worked on the gas flow system during one summer.

4 Publications and disseminations

<list up all publications and dissemination activities that can be linked to the project>

- Tommaso Pacini, Weiqi Fu, Steinn Gudmundsson, Antonio Eugenio Chiaravalle, Sigurdur Brynjolfson, Bernhard Ø. Palsson, Giuseppe Astarita, and Giuseppe Paglia, *A multidimensional analytical approach based on UHPLC-UV-ion mobility-MS for the screening of natural pigments*, Anal. Chem., Just Accepted Manuscript, DOI: 10.1021/ac504707n, Publication Date (Web): February 3, 2015

- Wichuk K, Brynjólfsson S, Fu W. *Biotechnological production of value-added carotenoids from microalgae: Emerging technology and prospects*. Bioengineered 2014; 5:10 - 9; http://dx.doi.org/10.4161/bioe.28720

- Weiqi Fu, Giuseppe Paglia, Manuela Magnúsdóttir, Elín A Steinarsdóttir, Steinn Gudmundsson, Bernhard Ø Palsson, Ólafur S Andrésson and Sigurður Brynjólfsson; *Effects of abiotic stressors on lutein production in the green microalga Dunaliella salina*, Microbial Cell Factories 2014, 13:3 doi:10.1186/1475-2859-13-3, (2014)

- Kristinn Arnar Ormsson, *Tilfærsla þörungaverksmiðju frá tilraunastigi yfir á frumstig framleiðslu. Búnaður til að vinna verðmæt efni úr koltvísýringi frá jarðvarmavirkjunum*, Lokaverkefni til VD vélstjórnarréttinda, Véltækniskólinn Tækniskólinn, Leiðbeinandi: Sigurður Brynjólfsson, PhD Maí 2014

- From Waste to Value, 4th Seminar: Value creation from chemicals/gases. GeoChem, Presentation Sigurður Brynjólfsson, 24. april 2013 Reykjavík University

- Sindri Freyr Ólafsson *Downstream process design for microalgae*, MS verkefni í Iðnaðarverkfræði, Háskóla Íslands, 2013. http://skemman.is/handle/1946/16441

- Fu, W., Guðmundsson, Ó., Paglia, G., Herjólfsson, G., Andrésson, O.S., Palsson, B.Ø., Brynjólfsson, S., *Enhancement of carotenoid biosynthesis in the green microalga Dunaliella salina with light-emitting diodes and adaptive laboratory evolution*, Applied Microbiology and Biotechnology, 97(6), pp 2395-2403, (2013) DOI 10.1007/s00253-012-4502-5

- Fu, W., Magnusdottir, M., Brynjolfson, S., Palsson, B.Ø., Paglia, G., *UPLC-UV-MSE method for quantification and identification of major carotenoid and chlorophyll species in algae*, Anal Bioanal Chem, 404:3145-3154 (2012).

- Fu, W., Gudmundsson, O., Feist A. M., Herjolfsson, G., Brynjolfsson, S., Palsson, B. O., *Maximizing biomass productivity and cell density of Chlorella vulgaris by using light-emitting diode-based photobioreactor*, Journal of Biotechnology. Volume 161, Issue 3, 31 October 2012, Pages 242-249.

5 Cost statement

<explain and justify the cost of the project, also fill in the GOERG - cost statement excel sheet provided by GEORG>

Most of the cost is salaries of the staff and operational cost of the experiments and equipment as can bee seen in the table.

Consortium:	CSB Matís Controllant													
Name of Project:	GeoChem													
ISK 1000	Year	Year 2013/2014												
	Month	1	2	3	4	5	6	7	8	9	10	11	12	Total 1
Financing														
GEORG funding		425	425	425	425	425	425	425	425	425	425	425	425	5.100
Participants own contributions		280	280	280	280	280	690	280	280	280	280	280	280	3.770
Participants, in kind costs														0
Facilites, equipm. & other resources														0
Other national compet. grants		750	750	750	750	750	750	750	750	750	750	750	750	9.000
Other intern. Grants, e.g. FP7														0
Other sources (e.g. Philanthropic)														0
Total other financing		1030	1030	1030	1030	1030	1440	1030	1030	1030	1030	1030	1030	12.770
														71%
Total financing														17.870
Operational Costs														
Average Personnel Costs	**Unit cost**													Man-months
Participant:														
														0 / 0,0
CSB UI		1.090	1.090	1.090	1.090	1.090	1.090	1.090	1.090	1.090	1.090	1.090	1.090	13.080 / 24,0
CSB UI														0 / 0,0
														0 / 0,0
														0 / 0,0
														0 / 0,0
Add lines if needed														0 / 0,0
														0 / 0,0
														0 / 0,0
Total		1.090	1.090	1.090	1.090	1.090	1.090	1.090	1.090	1.090	1.090	1.090	1.090	13.080 / 24
Operational exp.														
CSB UI		270	270	270	270	270	270	270	270	270	270	270	270	3.240
														0
														0
Total		270	270	270	270	270	270	270	270	270	270	270	270	3.240
Contracted Services														
														0
														0
														0
Total		0	0	0	0	0	0	0	0	0	0	0	0	0
Travel expenses														
CSB UI						350								350
														0
														0
Total		0	0	0	0	350	0	0	0	0	0	0	0	350
Others														
overhead		100	100	100	100	100	100	100	100	100	100	100	100	1.200
														0
														0
Total		100	100	100	100	100	100	100	100	100	100	100	100	1.200
Total operational cost		1.460	1.460	1.460	1.460	1.810	1.460	1.460	1.460	1.460	1.460	1.460	1.460	17.870