

# Orkusjóður

## Lokaskýrsla

**Vistvænt eldsneyti úr afgasi jarðvarmavirkjana**

Project ID: 201530029

Coordinator: Guðmundur Gunnarsson

Start date: May 2015

Duration: 12 months

Partners: Innovation Center Iceland, Orka náttúrunnar, Landsvirkjun and HS Orka

## 1 Project summary

Below are the results of work on the different work packages in the project is summarised. Reference is made to previously released documents related to this final report such as thesis, report and memos, a full list of these can be found in Chapter 4.

### WP 1: Geothermal gas separation

#### 1.1 Water scrubbing of geothermal gas

Results from running the Sulfix II plant (first water washing step) at Hellisheiði have showed that the hydrogen content in the gas to the plant was somewhat lower than previously measured, thus decreasing the quantity of hydrogen that can be obtained from the gas, see **Report**. It was also found that the content of  $N_2$  and  $O_2$  was much more variable and often higher than previously assumed, mainly due to leakage of air into the vacuum system. This demonstrates that in the design of geothermal power plants it is important to limit leakage of air into the of gas system since this limits the use of the gas.

The possibility of increasing the capacity of the Sulfix II plant by changing process conditions, pressure (from 5 to 6 bara), water temperature (from 20 °C to 15 °C), water flow rate and column internals was studied, see **Report**. The results showed that it is be possible double the  $H_2S$  removal capacity of the Sulfix II plant by changing the process conditions. The Sulfix II plant has now been modified to achieve the capacity increase. The penalty is however that the gas from water washing will contain more  $H_2S$  than before, making any utilisation of the gas more difficult.

The possibility to use a second water scrubbing step to treat the hydrogen rich gas from the first water scrubbing test so that gas with high ratio of  $H_2/CO_2$  (4 and above) and low  $H_2S$  content is obtained was investigated by performing simulations. The results showed that it is possible to use water washing to obtain gas with a  $H_2/CO_2$  ratio, but also of high nitrogen content, see **Report**.

#### 1.2 Residual/low level $H_2S$ removal from geothermal gas

For removal of 0,1 – 4 %  $H_2S$  from geothermal gas it could come into consideration to use microbial desulphurisation, see **Memo 5**. Another possibility, when the gas has very low content of hydrogen is to used catalytic oxidation with the method developed by Haldor Topsoe and tested in the Svartsengi power plant of HS Orka.

#### 1.3 Separation of $CO_2$ by reboiling $H_2S/CO_2$ solution before injection.

The possibility of separating the  $CO_2$  from the solution from enhanced capacity Sulfix plant was simulated. The results show that by flashing the pressurised solution at 1 bara and 85°C it is possible to obtain gas with consisting mainly of  $CO_2$  with some  $H_2S$  and very low content of  $H_2$ ,  $N_2$  and  $O_2$ . After  $H_2S$  removal, for example with microbial desulphurisation, it could be possible to use the  $CO_2$  in greenhouses or for production of methane, see **Report**.

#### 1.4 Final gas polishing

For removal of 10 – 100 ppmv of  $H_2S$  from geothermal gas containing some  $O_2$  and water activated carbon can be used. The cost of activated carbon for  $H_2S$  removal from gas with 50 ppmv has been estimated, see **Memo 12**. After removal of  $H_2S$  the gas can be used for greenhouses (if mainly  $CO_2$ ) or if the gas has sufficiently high  $H_2$  content for production of fuel cell grade  $H_2$  with pressure swing adsorption (PSA), see **Memo 11**.

#### WP 2: Use of purified gas

##### 2.1 Methane production

Microbial methanation (see **Memo 6**) was found to be the methanation best suited to geothermal gas because it can tolerate considerable  $H_2S$  in the gas (up to 6000 ppmv), whereas the catalytic methanation method requires gas with very low  $H_2S$  content ( $< 0,1$  ppmv). Process flow sheets for production of methane from different gas stream that could be available by processing gas from enhanced capacity Sulfix II were developed for different cases, see **Report**. In developing the processes care was taken to select process step so the methane produced would meet the requirements of standards, see **Memo 3**.

##### 2.2 Liquefaction of methane

The cost of liquefying methane on small scale has been estimated, see **Memo 2**. For methane capacity of  $73 \text{ Nm}^3/\text{h}$  the cost of liquefaction is estimated to be about  $0,1 \text{ €/Nm}^3$ . For larger capacities the cost is estimated to be smaller.

##### 2.3 Production cost estimates

The production cost of methane for the cases developed in 2.1 was estimated, where it was assumed that additional hydrogen needed would be produced with alkaline electrolysis, see **Memo 1**. The results are summarised in Table 1.

Table 1. Manufacturing cost of methane in the different cases, see **Report**.

	Power for water electrolysis (MW)	Methane capacity ( $\text{Nm}^3/\text{h}$ )	Manufacturing cost ( $\text{€/Nm}^3$ )
Case 1	3.68	263	1.25
Case 2	0	72	1.81
Case 3	1.13	132	1,64
Case 4	3.13	162	1,69

The reason for the high cost in Cases 2 – 3 is that it is mainly the high cost of gas processing, including water washing, membrane treatment, desulphurisation as well as cost of water electrolysis. For comparison it can be mentioned that cost of manufacturing  $625 \text{ Nm}^3/\text{h}$  of methane from  $H_2$  from 11.5 MW water electrolysis and relatively pure zero cost  $CO_2$  is estimated to be about  $1,1 \text{ €/Nm}^3$ . This can in turn be compared to the retail price of methane in Iceland, which is about  $0,81 \text{ €/Nm}^3$ .



In the above Case 1 it was assumed that the gas would be desulphurised before methanation. The microbial methanation process is very tolerant to high levels of  $H_2S$ . It could therefore be interesting to study if methanation could be carried out in gas with high levels of  $H_2S$  (1 – 4%), if possible this could decrease the cost of methane production. ON is now planning to test this together with a supplier of microbial methanation technology.

The possibility of lowering the  $H_2$  production cost by water electrolysis by taking part in Landsnet's market for regulating power was investigated (see **Thesis** and **Memo 8**). This is a subject that is now being investigated in Europe and elsewhere because increasing part of electricity generation is coming from intermittent energy source (wind and solar). Water electrolysis can then be used for load balancing and frequency stabilisation of the electric grid, see **Memo 7**.

The results in **Thesis** and **Memo 8** show that it is possible to lower the  $H_2$  manufacturing cost by taking part in the Landsnet's market for regulating power, especially when taking part in the down regulating market. In this case it may be possible to lower the  $H_2$  manufacturing cost by about 40 – 50% when the electricity price is 40€/MWh, see **Memo 8**. This is also expected to make an impact when hydrogen is used for methane production, although not as large because of the investment for methane production.

### **2.4 Other use of purified gas**

This part was cut out of the work plan due to the limited grant from Orkusjóður (1 million ISK, instead of the 4 million ISK applied for).

## **WP 3: Market for methane and purified gas**

### **3.1 Market for methane**

The work on this task was reduced because of limited grant from Orkusjóður (1 million ISK, instead of the 4 million ISK applied for). The work done is described in **Memo 10** where it was concluded that electricity could supply much the energy need for short distance transport (private cars, buses, goods distribution, etc.) in Iceland. For long distance heavy transport biofuels or fuels like methane and possibly hydrogen will be needed. Renewable methane produced in Iceland may become attractive in some years if it can still be counted twice as a sustainable fuel as now allowed in Icelandic law no. 40, 2013, see **Memo 9**.

### **3.2 Market for purified $CO_2$**

This part was cut out of the work plan due to the limited grant from Orkusjóður (1 million ISK, instead of the 4 million ISK applied for).

### **Future work**

As a result of this project ON is planning to develop and pilot the microbial methanation method for application in the geothermal environment, but  $H_2S$  content in the feed gas can be much higher than in the biogas and landfill gas the method has been piloted for.

## 2 Project Management

Several project meeting were held where representatives of Georg and the project partners participated. To finance the work on the project a grant application was also sent to Orkusjóður. The amount applied for was 4 million ISK, but Orkusjóður only granted 1 million to the project. Therefore it was necessary to cut down work on some WP's, mainly WP's 2.4, 3.1 and 3.2 as mentioned above.

## 3 Student involvement

A MS student at Reykjavik University, Jeffrey Jacobs, studied the economics of hydrogen production when the hydrogen production units takes part in the Landsnet's market for regulating power. The title of his thesis (submitted in January 2016) was "Economic Modelling of Cost Effective Hydrogen Production from Water Electrolysis by Utilising Iceland's Regulating Power Market". The results showed that it could be possible to lower the cost of hydrogen by participating in the regulating power market. Hydrogen from the production can be used to produce methane and other fuels from geothermal CO<sub>2</sub>.

## 4 Publications and disseminations and other deliverables

### **Presentations**

Guðmundur Gunnarsson, "From Emissions to Fuels" (In Icelandic), presented at Reykjavik Energy Science Days, March 14, 2016.

[https://www.or.is/sites/or.is/files/12\\_gudmundur\\_fra\\_utblaestri\\_til\\_eldsneytis.pdf](https://www.or.is/sites/or.is/files/12_gudmundur_fra_utblaestri_til_eldsneytis.pdf)

### **Thesis**

Jeffrey Jacobs, "Economic Modelling of Cost Effective Hydrogen Production from Water Electrolysis by Utilising Iceland's Regulating Power Market". MS Thesis, Reykjavik University, January 2016.

<http://skemman.is/search/simple?q=Jeffrey+jacobs>.

### **Report**

Guðmundur Gunnarsson, "Production of methane from off gas from Hellisheiði power plant", Innovation Center Iceland, June 2016.

### **Presentation of the project in a TV program**

The project was also presented in the TV program "Maðurinn og umhverfið", shown on RUV on April 5, 2016.

### **Memos (to be kept confidential)**

Memo 1. Production of hydrogen with water electrolysis.

Memo 2. Liquefaction of methane with Sterling Cryogenerators.

Memo 3. Specification of methane for automotive applications.

Memo 4. Upgrading of gas from Sulfix II with membranes.

Memo 5. Removal of H<sub>2</sub>S from geothermal gas with the Thiopaq process.

Memo 6. Status of technology for microbial methanation.

*Memo 7. Water electrolyzers and frequency stabilisation of the electrical power grid.*

*Memo 8. Er hægt að lækka kostnað við framleiðslu vetnis með rafgreiningu með því að taka þátt í markaði Landsnets fyrir reglunarorku 29.3.16.*

*Memo 9. Er hægt að telja eldsneyti sem framleitt er úr kolsýru og rafgreiningarvetni tvöfalt eða jafnvel fjórfalt.*

*Memo 10. Market for methane.*

*Memo 11. Purification of geothermal hydrogen with PSA.*

*Memo 12. Removal of H<sub>2</sub>S from geothermal gas with activated carbon.*

## 5 Cost statement

### **Contracted services**

*Contracted services include amongst other things the work of engineers in simulation and design of water washing of geothermal gas, both in connection capacity increase of the Sulfix II plant and for the simulations of the second water washing step. Design and simulation of the reboiling process are also included. Only part of the cost is accounted for here. The cost of this is shared by the power companies as a part of their cooperation on treatment of geothermal gas.*

### **Travel expenses**

*Two representatives of ON and one of ICI to Germany, Belgium and Denmark to visited companies providing technology for microbial methanation and electrolysis. Part of the travel cost of the ICI representative was paid by ON and Landsvirkjun.*

### **Other expenses**

*Other expenses are mainly for the pilot facilities constructed to test the reboiling process. Only part of the cost is accounted for here. Cost paid by ON.*



## Vistvænt eldsneyti úr afgangi jarðvarmavirkjana

Consortium:	Innovation Center Iceland, Orka Náttúrunnar, Landsvirkjun, HS Orka		
Name of Project:	Vistvænt eldsneyti úr afgangi jarðvarmavirkjana		
ISK '000	Year	Total 2015/2016	
	Month		
Financing			
Orkusjóður		1.000	3%
Participants own contributions		32.832	85%
Participants, in kind costs			
Facilities, equipm. & other resources			
GEORG Grant		5.000	13%
Other intern. Grants, e.g. FP7			
Other sources (e.g. Philanthropic)			
Total other financing		37.832	97%
Total financing		38.832	100%
Operational Costs			
Average Personnel Costs		Unit cost	Man-months
Participant:			
Innovation Center Iceland	1.645	11.351	6,9
ON	1.645	4.935	3,0
Landsvirkjun	1.645	823	0,5
HS Orka	1.645	823	0,5
Total		17.931	11
Operational exp.			
Innovation Cener		68	
Total		68	
Contracted services			
ON		4.000	
Landsvirkjun		4.000	
HS Orka		2.000	
Total		10.000	
Travel expenses			
Innovation Center Iceland		131	
ON		600	
Landsvirkjun		102	
HS Orka			
Total		833	
Others			
ON		10.000	
Total		10.000	
Total operational cost			
		38.832	