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Landsvirkjun

Comparison of methods to utilize CO2 from geothermal gases from Krafla and Þeistareykir

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Authors/Company:	Magnús Þór Arnarson. Mannvit hf.		
Project manager:	Sigurður H. Markússon		
Prepared for:			
Co operators:			

Abstract:

The aim of this report is to find ways to combine processes that are environmentally friendly and require minimal external chemicals for the operation to produce CO2 from the geothermal gases. This pre-feasibility study will focus on the utilization of CO2 from the Krafla and Þeistareykir power plants. In order to find a combination of processes to clean CO2 the pros and cons are listed as well as both OPEX and CAPEX will be compared. The methods described in this report are all well-known processes. Today they are mostly applied in the chemical and oil industries. Most of them have to be adjusted as they have not been used in the geothermal industry before. A comparison was conducted, based on six different processes. For each method different aspects were explored and compared.

Keywords: CO2, geothermal gases, geothermal power plants, Krafla, þeistareykir

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Summary

The aim of this prefeasibility study is to suggest processes to utilise CO_2 from geothermal gases called non-condensable gases (NCG) at Krafla and Þeistareykir geothermal power plants. A comparison was conducted, based on six different processes:

a. Water scrubbing H_2S removal + Pressure swing adsorption (PSA) + catalytic oxidation
b. Water scrubbing H_2S removal + CO_2 amine removal + catalytic oxidation
c. Amine H_2S removal + Amine CO_2 removal
d. Amine H_2S removal + Pressure swing adsorption (PSA)
e. Water scrubbing H_2S removal low purity, CO_2 5000 ton/year
f. Amine H_2S removal low purity, CO_2 5000 ton/year

For each method different aspects were explored and compared: OPEX and CAPEX, production capacity, purity of the CO_2 product. In table 1 and 2 cost overviews for the respective alternatives for Krafla and Þeistareykir are shown.

The main conclusions for each process are

a. Has the highest OPEX and CAPEX. The water scrubbing is already in operation in Hellisheiði power plant. The other processes, PSA and Catalytic oxidation, have not to our knowledge been operated in the geothermal industry. The visual impact is lowest compared to other processes, one column 23 m high other process equipment located inside. Estimated CO_2 production capacity for Krafla is 10.500 ton/year and 3.000 ton/year for Þeistareykir. Estimated cost for CO_2 is 28 kr/kg for Krafla and 82 kr/kg for Þeistareykir. Additional calculations show that if only water scrubbing H_2S removal is used the cost is 11 kr/kg for Krafla and 27 kr/kg for Þeistareykir.

b. Is similar to a, the main difference being that the PSA has been replaced for amine process. One amine process is in operation in Iceland at the Carbon recycling (CRI) plant located close to Svartsengi geothermal power plant. The OPEX and CAPEX is the second highest and the capacity is higher than in process a. The visual impact is higher because the amine system includes two additional columns which are 11 to 16 m high. Estimated CO_2 production capacity for Krafla is 17.462 ton/year and 5.026 ton/year for Þeistareykir. Estimated cost for CO_2 is 22 kr/kg of Krafla and 54 kr/kg for Þeistareykir. Additional calculations show that if only water scrubbing H_2S removal is used the cost is 11 kr/kg for Krafla and 27 kr/kg for Þeistareykir.

c. Amine process is used to remove the H_2S followed by a PSA system. This process has the lowest OPEX and CAPEX in case of Krafla but similar to d in case of Þeistareykir. The visual impact is mostly due to the columns, which are two in this case, 11 to 16 m high. Estimated CO_2 production capacity for Krafla is 13.667 ton/year and 3.500 ton/year for Þeistareykir. Estimated cost for CO_2 is 12 kr/kg of Krafla and 46 kr/kg for Þeistareykir. Additional calculations show that if only Amine H_2S removal is used the cost is 6 kr/kg for Krafla and 15 kr/kg for Þeistareykir.

d. Amine process is used to remove the H_2S then a second amine process is used to remove the CO_2. The visual impact is highest. Each amine process needs two columns which are 11 to 16 m high. Estimated CO_2 production capacity for Krafla is 19.859 ton/year and 5.774 ton/year for Þeistareykir. Estimated cost for CO_2 is 13 kr/kg of Krafla and 29 kr/kg for Þeistareykir. Additional calculations show that if only Amine H_2S removal is used the cost is 6 kr/kg for Krafla and 15 kr/kg for Þeistareykir.

e. Process e, is similar to water scrubbing process in a and b, but without the reboiling system. The capacity is 5000 ton/year of low purity CO_2. This process is only calculated for Krafla. The estimated cost for CO_2 is 22 kr/kg

f. Process f, similar to amine H_2S removal process c and d, but without the H_2S reinjection system. The capacity is 5000 ton/year of low purity CO_2. This process is only calculated for Krafla. The estimated cost for CO2 is 15 kr/kg

In the financial calculation it is assumed that the H_2S removal process is included. If the H_2S removal process is not included in the financial calculation, the production cost of CO_2 in kr/kg would reduce approximately 50% for all processes. The lowest production price of CO_2 is by using process which has most visual impact *c or d*.

Two additional cases were studied for Krafla, process *e* and *f*. The purpose is to estimate the cost for low purity CO_2. Only part of the gas from the power plant is used in the CO_2 production process, 5000 ton/year. H_2S and part of CO_2 is removed from the gas. In process *e*, the water scrubbing process is without reboiling system and process f is without the H_2S reinjection systems. The cost of each kg of CO_2 from *e* and *f* is higher compared to H_2S removal in *a* to *d.* The reason is relatively higher CAPEX and OPEX in case of e and f compared to *a* to *d*.

Other things also need to be considered such as how the process fits into present operation of the power plant. Using PSA and Catalytic oxidation probably has the least visual impact and can also be easy to operate. The PSA system can be operated at the same pressure as the water scrubber system. Catalytic oxidation system can be operated by using almost atmospheric pressure. The concentration of H_2S and SO_2 after PSA and OX in Table 1 and Table 2 are estimated. For that reason OX system is added in process b for Þeistareykir even though the H_2S concentration is slightly below 300 ppm. The next recommended step is to get more information about these two technologies to see if it is possible to increase the efficiency of the PSA system and lower the production cost.

Table 1 Cost overview: combined processes for Krafla

Process technology
Purpose
CO2 ton/year
Cost kr/kg CO2
H_2S/SO_2 ppm/ppb
OPEX
CAPEX

From Power plant
25.007 ton/year

Process technology	WS H_2S	* WS H_2S low
Purpose	H_2S removal	H_2S removal
CO2 ton/year	18.401 ton/year	5.000 ton/year
Cost kr/kg CO2	11 kr/kg	22 kr/kg
H_2S/SO_2 ppm/ppb	373 ppm	373 ppm
OPEX	73.081.000 kr.	36.133.000 kr.
CAPEX	1.406.220.000 kr.	799.296.000 kr.

Process a, flow direction →

Process technology	PSA	OX + WS SO_2	CO_2 feedstock
Purpose	H_2 removal	H_2S residues removal	
CO2 ton/year	11.040 ton/year	10.550 ton/year	10.550 ton/year
Cost kr/kg CO2			28 kr/kg
H_2S/SO_2 ppm/ppb	773 ppm	2 ppm	2 ppm
OPEX	11.919.000 kr.	18.517.000 kr.	103.517.000
CAPEX	362.500.000 kr.	430.588.000 kr.	2.199.308.000

Process b, flow direction →

Process technology	Amine CO_2	OX + WS SO_2	CO_2 feedstock
Purpose	H_2 removal	H_2S residues removal	
CO2 ton/year	18.217 ton/year	17.462 ton/year	17.462 ton/year
Cost kr/kg CO2			22 kr/kg
H_2S/SO_2 ppm/ppb	470 ppm	3 ppm	3 ppm
OPEX	41.057.000 kr.	18.517.000 kr.	132.655.000 kr.
CAPEX	963.623.000 kr.	430.588.000 kr.	2.800.431.000 kr.

From Power plant
25.007 ton/year

Process technology	Amine H_2S	** Amine H_2S low
Purpose	H_2S removal	H_2S removal
CO2 ton/year	19.939 ton/year	5.000 ton/year
Cost kr/kg CO2	6 kr/kg	15 kr/kg
H_2S/SO_2 ppm/ppb	64 ppm	64 ppm
OPEX	36.948.000 kr.	27.830.000 kr.
CAPEX	831.376.000 kr.	531.387.000 kr.

Process c, flow direction →

Process technology	PSA	CO_2 feedstock
Purpose	H_2 removal	
CO2 ton/year	13.667 ton/year	13.667 ton/year
Cost kr/kg CO2		12 kr/kg
H_2S/SO_2 ppm/ppb	217 ppm	217 ppm
OPEX	33.550.000 kr.	70.498.000 kr.
CAPEX	574.000.000 kr.	1.405.376.000 kr.

Process d, flow direction →

Process technology	Amine CO_2	CO_2 feedstock
Purpose	H_2 removal	
CO2 ton/year	19.859 ton/year	19.859 ton/year
Cost kr/kg CO2		13 kr/kg
H_2S/SO_2 ppm/ppb	83 ppm	83 ppm
OPEX	43.191.000 kr.	80.139.000 kr.
CAPEX	1.027.148.000 kr.	1.858.524.000 kr.

Additional processes

* 5000 ton/year low purity CO_2 and without reboiling system

** 5000 ton/year low purity CO_2 and without H_2S reinjection

Table 2 Cost overview: combined processes for Þeistareykir

Process technology
Purpose
CO2 ton/year
Cost kr/kg CO2
H_2S/SO_2 ppm/ppb
OPEX
CAPEX

From Power plant
7.000 ton/year

WS H2S
H_2S removal
5.517 ton/year
27 kr/kg
143 ppm
47.597.000 kr.
1.114.755.000 kr.

Process a, flow direction →

PSA	OX + WS SO2	CO2 feedstock
H_2 removal	H_2S residues removal	
3.243 ton/year	2.996 ton/year	2.996 ton/year
		82 kr/kg
533 ppm	6 ppb	6 ppm
11.919.000 kr.	18.517.000 kr.	78.033.000 kr.
362.500.000 kr.	430.588.000 kr.	1.907.843.000 kr.

Process b, flow direction →

Amine CO2	OX + WS SO2	CO2 feedstock
H_2 removal	H_2S residues removal	
5.242 ton/year	5.026 ton/year	5.026 ton/year
		54 kr/kg
244 ppm	262 ppb	262 ppb
26.284.000 kr.	18.517.000 kr.	92.398.000 kr.
482.154.000 kr.	430.588.000 kr.	2.027.497.000 kr.

From Power plant
7.000 ton/year

Amine H2S
H_2S removal
5.849 ton/year
15 kr/kg
77 ppm
30.507.000 kr.
620.634.000 kr.

Process c, flow direction →

PSA	CO2 feedstock
H_2 removal	
3.500 ton/year	3.500 ton/year
	46 kr/kg
158 ppm	158 ppm
31.705.000 kr.	62.212.000 kr.
512.500.000 kr.	1.133.134.000 kr.

Process d, flow direction →

Amine CO2	CO2 feedstock
H_2 removal	
5.774 ton/year	5.774 ton/year
	29,0 kr/kg
146 ppm	146 ppm
30.152.000 kr.	60.659.000 kr.
609.204.000 kr.	1.229.838.000 kr.

Table of Content

List of Tables

1 Introduction

Inseparable part of the geothermal steam is the geothermal gas, defined as non-condensable gas (NCG). The composition of geothermal gases is very different between geothermal systems and there can also be great difference between two wells in same area. In Iceland the gas consist mainly of three gases, CO_2, H_2S and H_2. Where CO_2 is the component which normally has the highest concentration. Other gases, N_2, Ar and CH_4, are smaller components of the gas. The gas composition between Krafla and Þeistareykir, which are the subjects of this report, are very different, especially regarding the H_2S and H_2 content. Other great difference is the steam condensation technology, which will be discussed further in this report. Krafla (60 MW) has been in operation since February 1978 but Þeistareykir (90 MW) will start power production in the autumn 2017. Up until now the power companies have been focusing on lowering concentration of H_2S emitted to the atmosphere because of stricter regulations. There are many well-known processes used for H_2S abatement of geothermal gases. The product from these processes is normally elementary sulphur or sulphuric acid. These processes are for example LO-CAT, Claus processes, WSA etc. There are limited markets for elementary sulphur and sulphuric acid in Iceland and the annual operation cost is high. These processes are described further in a report (McIntush, o.fl., 2011) and (Gunnarsson, 2011)

The aim of this report is to find ways to combine processes that are environmentally friendly and require minimal external chemicals for the operation to produce CO_2 from the geothermal gases. This pre-feasibility study will focus on the utilization of CO_2 from the Krafla and Þeistareykir power plants. In order to find a combination of processes to clean CO_2 the pros and cons are listed as well as both OPEX and CAPEX will be compared. The methods described in this report are all well-known processes. Today they are mostly applied in the chemical and oil industries. Most of them have to be adjusted as they have not been used in the geothermal industry before.

2 Assumptions

2.1 Gas composition

Gas composition for both power plants, used in this prefeasibility study, is a key issue when evaluating feasible processes. Table 3 is a summary of the composition and mass flow. It is assumed that the gas is saturated at 40°C and that the pressure is close to atmospheric pressure. The reference for gas composition in case of Krafla is taken from a report from Trimeric Corporation (Mamrosh, et al., 2014). The gas composition for Þeistareykir is taken from a new gas analysis provided by Landsvirkjun. For Þeistareykir the gas concentration was given both with an upper limit and lower limit. In this report the upper limit is used for all gases.

It is assumed in the H_2S removal steps, that the H_2S will be separated and re-injected in similar way as is currently done in the Hellisheiði power plant.

Table 3 Gas composition for Krafla and Þeistareykir

	Power plant 1 (Krafla) 60 MW			Power plant 2 (Þeistareykir) 90 MW		
Gas from condenser	**Value**	**Unit**		**Value**	**Unit**	
Temperature	40	°C		40	°C	
Pressure	1,05	bar_a		1,05	bar_a	
Gas flow	0,958	kg/s		0,3703	kg/s	
Humidity	100	%		100	%	
Vapor fraction	100	%		100	%	
Gas composition	**vol %**	**wt %**	**kg/s**	**vol %**	**wt %**	**kg/s**
H_2S	8,72%	7,93%	0,076	25,30%	29,70%	0,11
CO2	70,68%	82,97%	0,793	39,63%	59,95%	0,222
H_2	6,85%	0,37%	0,004	23,39%	1,62%	0,006
N_2	4,11%	3,07%	0,029	4,49%	4,32%	0,016
O_2	2,16%	1,85%	0,020	0,00%	0,00%	0
CH_4	0,05%	0,02%	0,000	0,10%	0,05%	0,0002
H_2O	7,03%	3,38%	0,032	7,03%	4,35%	0,0161
Ar	0,39%	0,41%	0,004	0,00%	0,00%	0
Total	**100%**	**100%**	**0,954**	**100%**	**100%**	**0,3703**

2.2 Fluids

Available fluids are fresh water, geothermal water, condensate and steam. The qualities of these fluids are different and so is the availability between these two power plants. Landsvirkjun is going to publish two reports where the effluent streams are described. In this report it is assumed that all necessary fluids for the discussed processes will be available in the cases of both power plants and also that the purity is good enough to be used in all discussed processes.

2.3 Performance

Guidelines for production capacity for each will be max 30.000 ton/year for Krafla and 6.000 ton/year for Þeistareykir. The CO_2 gas may contain 0 – 300 ppm of H_2S.

2.4 Financial calculation

CAPEX (Capital expenditure) and OPEX (operational expenditure) will be estimated for the processes. The production cost for each kg of CO_2 will be evaluated by using CAPEX, OPEX together with interest on debt and required return on equity. The depreciation is assumed to be 20 years and the project life time is expected to be 25 years. In chapter 5.5 and Table 6 are more details regarding the assumption used in the financial calculation.

3 Technology

3.1 Introduction

The gas compositions are different between the two power plants and so are the technology used when condensing the steam from the turbines. It is assumed that the gas is saturated from both power plants and the pressure is close to atmospheric pressure. In Krafla a direct condenser is used, were the cooling water is sprayed into the condenser. This type of condenser has better performance than closed surface condenser, but one of the great disadvantages is the cooling water that absorbs oxygen when the water goes through the cooling tower. Oxygen desorbs in the condenser at lower pressure. The consequence is increased concentration of oxygen in the geothermal gas coming from the condenser. Furthermore when steam is drawn in at the turbine glands it will be mixed with air leading to increased oxygen concentration of the NCG. In this study it will be assumed that the gland steam is not piped into the condenser according to memorandum (Gunnarsson, 2014), even though that change has not been installed yet. In Þeistareykir there will be a closed surface condenser where the cooling water is not in direct contact with the steam. The gland steam will be piped separately and released to the atmosphere. In this report it is assumed that no oxygen leaks into the condenser. Nonetheless, the oxygen can affect what processes are suitable to use in the CO_2 production. High concentration of oxygen can cause precipitation of elementary sulphur in the scrubber equipment and clog the re-injection well. It can shorten the life time of amine solvents. Mixture of hydrogen and oxygen can be very explosive. These disadvantages will mostly be ignored in this report but in any case they will need to be considered in the next steps. Here below is a brief description of the processes which will be used for the CO_2 production.

3.2 Water scrubbing

Solubility of H_2S in water is relatively low compared to amines. It needs significantly more water and higher operating pressure. The water scrubber system consists of compressor, absorption column, booster pumps and a heat exchanger. The geothermal gas is compressed and piped into the absorption column at the bottom, but the water, which is normally cold condensate from steam turbines, enters at the top. H_2S and CO_2 dissolves in the water but the solubility of H_2S is about four times higher than the solubility of CO_2. The consequence, it is difficult to selectively absorb only H_2S using water scrubbing. The condensate with dissolved gases is piped from the bottom of the absorption column to a re-injection well from where it is pumped to the reservoir. One disadvantage about this technology is the high concentration of dissolved CO_2 in the re-injection fluid. To decrease the concentration of CO_2 in the re-injection fluid, a part of the CO_2 can be removed by using a reboiling system. Approximately ¾ of the CO_2 can be removed from the fluid using that technology (Mamrosh, et al., 2014).

3.2.1 Main equipment

The main items of equipment are compressor, absorption column, two pumps and two heat exchangers.

3.2.2 Stage of development

H_2S removal using water scrubbing has been in operation in Hellisheiði power plant for almost a year. No major issues have been discovered during the operating period. The process is sensitive for oxygen contamination which can cause precipitation of elementary sulphur. The additional part of the water scrubber, the reboiling system has not been proven but will be tested in a pilot plant during 2015.

3.2.3 Utilisation of CO_2 product

Utilisation directly from the water scrubber is not feasible unless the end user can use the hydrogen as well. The concentration of H_2S is below upper limit (300 ppm) see chapter 2.3. The concentration of H_2S will go over the limit if the hydrogen or other gases are removed. In the case of Krafla the volume percentage of H_2 is around 10 % after the scrubber. It would be worth doing a separate study to check if the gas can be used directly for greenhouses.

3.2.4 Chemical usage

No additional chemicals are needed for the process. The process is driven by electricity, condensate and cold water which all are part of the geothermal utilities.

3.2.5 Construction

The process is similar to the water scrubber process in Hellisheiði where the building is around 100 m^2 and the column is 13 m high. Calculated column height for Krafla and Þeistareykir is 23 m and the diameter is 2 m in Krafla but 1 m in Þeistareykir. The reason for the height difference of the columns, are higher demands of low H_2S concentration from the top of the column. If the reboiling system will be added the space needed for the process will increase by approximately 200 m^2. Visual impart is mostly because of the column, which will be located outside.

3.2.6 Foot print

The electricity consumption is higher than in the amine processes. The usage of cold water can be limiting for the technology where there is lack of cold water.

3.3 Amine scrubbing

Amine scrubbing is a well-known technology for gas sweetening (acid gas removal). A typical gas treating process includes an absorber unit and regenerator unit. The regenerator units consist of a deareator, a reboiler and a reflux drum. The amine enters the absorption column at the top but the NCG enters at the bottom. The falling amine solution absorbs H_2S and CO_2 from the up flowing NCG. The concentration of absorbed H_2S and CO_2 depends on what solvent is used. The rich amine solution is piped into the regenerator to regenerate the amine solution, now called the lean amine solution. The lean solution is reused in the absorption column. In this report two amine processes are explored, H_2S removal and CO_2 removal. These processes are similar and contain the same main equipment. The main difference is in different solvent and sizes of components.

3.3.1 Main equipment

The main items of equipment are absorption column, deareator, reboiler, reflux drum, 3 pumps, heat exchangers, gas blower and gas compressor.

3.3.2 Stage of development

This technology is widely used when refining and processing oil and natural gas. One amine process is in operation in Iceland in Carbon recycling (CRI) plant located close to Svartsengi geothermal power plant. Amine process is normally subjected with other processes for example Claus, Liquid redox sulphur recovery (LRSR) (McIntush, o.fl., 2011). High partial pressure of oxygen can cause oxidative degradation of the amine solvent.

3.3.3 Utilisation of CO_2 product

The gas composition after the H_2S removal process is similar to the amine process which is mentioned in chapter 3.2, but mole fraction of the H2S is much lower. Utilisation directly from the H_2S removal system is not feasible unless the end user can use the hydrogen as well. The mole fraction of H_2 is low in the case of Krafla. It would be worth doing separate study to check if the gas can be used directly for greenhouses. To separate the H_2 from the CO_2, a CO_2 removal process is added.

3.3.4 Chemical usage

The most commonly used amines in industrial plants are alkanolamines, Diethanolamine (DEA), Monoethanolamine (MEA) and Methyldiethanolamine (MDEA). Companies as DOW Chemical, BASF, United Oil Product (UOP) and ExxonMobil are producing amine solvents to selectively remove acid gases. These solvents are not produced in Iceland and need to be imported. In normal operation the makeup is annually around 10 % of the total volume of the solvent in the system. In this pre-feasibility study a process simulation was based on using Ucarsol HS 102 and AP 814 solvents from Dow Chemicals.

3.3.5 Construction

The amine process is more complex than the water scrubber system. Each amine process includes two columns which are between 11 to 16 m high. The diameter is average 1 m. A necessary space for the process is not accurately known but is estimated to be at least 250 m^2. Process design and layout is needed for estimating the house space requirement. Visual impact is mostly because of the columns, which will be located outside.

3.3.6 Footprint

The use of electricity is lower in the amine possesses than the water scrubber system. The need of makeup of solvents is highly dependent on the design of the process and the operation of the plant. The process needs hot fluid for the re-boiler as well as cold water for cooling of the solvent. Product safety assessment documents are available for Ucarsol HS 102 solvent which is used in H_2S removal[1] and Ucarsol AP 814[2].

3.4 Pressure swing adsorption (PSA)

The PSA process works at constant temperature and uses the effect of both alternating pressure and partial pressure to perform adsorption and desorption. Operation pressure is normally between 10

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[1] For more information about product safety assessment go to http://msdssearch.dow.com/PublishedLiteratureDOWCOM/dh_040a/0901b8038040a5e3.pdf?filepath=productsafety/pdfs/noreg/233-00620.pdf&fromPage=GetDoc

[2] For more information about product safety assessment go to http://msdssearch.dow.com/PublishedLiteratureDOWCOM/dh_03e3/0901b803803e381d.pdf?filepath=productsafety/pdfs/noreg/233-00621.pdf&fromPage=GetDoc

and 40 bar, can be adjusted to other pressure until equilibrium loading is reached. The changes in the temperature are caused only by heat of adsorption, desorption and pressurization. The most important part is the adsorbent, which is essential to the PSA technology. All properties, operating conditions and operating modes depend on the initial choice of adsorbent. The PSA process has four basic steps, adsorption, depressurization, regeneration and pressurization. The typical gas treating process consists of three or four columns, to secure continuous flow.

3.4.1 Main equipment

The main items of equipment are adsorption columns and control valves.

3.4.2 Stage of development

The PSA technology is widely used in the gas industry, where it is used to separate CO_2 from CH_4, hydrogen purification and production of clean nitrogen. The PSA process has probably not been used in the geothermal industry before and it will be necessary to customize the technology according to the gas composition.

3.4.3 Utilisation of CO_2 product

According to PSA vendor, around 60 %, of CO_2 will be adsorbed, other gases such H_2S and H_2O are also adsorbed but H_2 and part of the CO_2 goes through. The purity of CO_2 is approximately 95 % vol, the rest is H_2O, O_2 and H_2S.

3.4.4 Chemical usage

The adsorbent material can be a combination of activated carbon, silica gel alumina, carbon molecular sieves and zeolites.

3.4.5 Construction

The PSA system consists of columns which contains the adsorbent. It is assumed that the process equipment can be inside. Estimated area needed for the process is 110 m^2. Visual impart is mostly due to the building where the columns will be located.

3.4.6 Footprint

The process will be operated at the same pressure as the water scrubber column. When the PSA is added after the amine system it is necessary to add a compressor. The adsorbent is replaced every two years. In case of molecular sieve the adsorbent is considered non-hazardous for the purpose of disposal in fresh unused state. However the adsorbed material on the spent adsorbent may change the classification for purpose of disposal[3].

3.5 Catalytic oxidation

Haldor Topsøe provides technology were H_2S <2 % vol gas steam is oxidized to SO_2. The advantage of the technology is that up to 99.999% H_2S is converted to SO_2 and low oxidation of SO_2 to SO_3. The sulphur monolith catalyst SMC™ selectively oxidizes the H_2S to SO_2 and also oxidizes any higher hydrocarbons and CO to CO_2. A typical process includes heater to increase the temperature in the start-up, cross exchanger for the heat recovery and oxidation reactor. The SO_2 is removed by using a

[3] For more information about MSDS for molecular sieve (13X) go to http://ccsdsdocs.com/1/en/vdat/datas/CC-MUKLSX-5118.pdf

scrubber system. A typical wet scrubber is operated by using sodium hydroxide (NaOH) or calcium hydroxide $Ca(OH)_{2,}$ in the case of dry scrubbing. The main disadvantage of using these scrubber media is the operation cost. The solubility of SO_2 in the water is much higher than H_2S at 20 °C and with atmospheric pressure. In this pre-feasibility study it will be assumed that condensate is used as a solvent. The condensate from the scrubber unit will be used further in the H_2S scrubber system.

3.5.1 Main equipment

The main items of equipment are Heater, cross exchanger, reactor and water scrubber.

3.5.2 Stage of development

This technology is used in different industry and for variety of components such as Hydrogen Sulphide, Hydrocarbons, Hydrogen and Carbon Monoxide etc. Representatives from Haldor Topsøe have shown interest to establish pilot plant where the technology will be proven on geothermal gases. Oxidation process itself is well known and widely used.

3.5.3 Utilisation of CO_2 product

The oxidation step is the last step in the cleaning process of CO_2 and is necessary when the water scrubber is used in H_2S removal. The CO_2 after the SO_2 water scrubber can be sent to an end-user.

3.5.4 Chemical usage

The catalyst is guaranteed to last for two years. The gas has already been pre-cleaned for dust and particles in the water scrubber system, therefore the expected lifetime would be higher than 2 years. The usage of catalysts modules is approximately 1000 l for each power plant.

3.5.5 Construction

The oxidation technology will be a part of other processes. Process equipment will be located indoors. Estimated space needed for the process equipment is 25 – 30 m^2. Visual impact is mainly because of buildings needed for processing.

3.5.6 Footprint

Energy use is small compared to other processes. In the start-up process a heater is used to increase the temperature of the gas. Estimated steam consumption is 92 kg/h for Krafla and 38 kg/h for Þeistareykir. The SMC^{TM} catalyst does not include any harmful components but it cannot be regenerated. There are companies in Europe which reclaiming catalysts but that is up to the user if he uses that service.

4 Methodology

4.1 Process combination

In order to extract CO_2 from the NCG it is not sufficient to utilize only one of the processes described in chapter 3. Six combination of processes are compared and named a to f. Each process is split into 3 to 4 steps as is described in Table 4. In the case of process *a* and *b,* 3 steps are necessary to lower the H_2S so it will be under the upper limit given in chapter 2 (300 ppm). The combination of the processes is the same for both power plants but the gas composition and mass flow is very different. Table 5 explains the acronyms in Table 4. Tables, which include the gas composition for each step, are in Appendix D. The gas compositions are estimated and for information only, but not to use as an assumption for designing or construction.

Table 4 Type and orders of processes for Krafla and Þeistareykir

Process steps for Krafla and Þeistareykir				
Process	**Steps, gas flow direction →**			
	1	2	3	4
a	WS H_2S	PSA	OX+WS SO_2	CO_2 feedstock
b	WS H_2S	Amine CO_2	OX+WS SO_2	CO_2 feedstock
c	Amine H_2S	PSA	CO_2 feedstock	
d	Amine H_2S	Amine CO_2	CO_2 feedstock	
e	WS H_2S low			
f	Amine H_2S low			

- Process *a*, starts with water scrubbing where most of the H_2S is removed (1). The next step (2) is pressure swing adsorption were the H_2 is separated from other gases. In step (3) the remaining trace of H_2S is oxidised to SO_2 and the SO_2 is removed by water scrubbing. After step (3) the CO_2 is sent to feedstock (4). In step (4) the CO_2 is saturated and the pressure is close to atmospheric pressure.

- Process *b*, starts with water scrubbing where most of the H_2S is removed (1). The next step (2) is separating CO_2 from the remaining H_2 using amine solvent which is selective for CO_2. These gases are almost perfectly separated but the remaining trace of H_2S follows the CO_2 stream. In step (3) the trace of H_2S is oxidised to SO_2 and the SO_2 is removed by water scrubbing. After step (3) the CO_2 is sent to feedstock (4). In step (4) the CO_2 is saturated and the pressure is close to atmospheric pressure.

- Process *c*, amine solvent is used to remove the H_2S (1). After the first step the concentration of H_2S is very low, below the upper limit, see chapter 2 . The next step (2) is PSA which removes the H_2 from CO_2. After step (2) the CO_2 is sent to feedstock (3). In step (3) the CO_2 is saturated and the pressure is close to atmospheric pressure.

- Process d, amine solvent is used to remove the H_2S (1). After the first step the concentration of H_2S is very low, below the upper limit, see chapter 2. The next step is a second amine step, now for CO_2 removal (2). The amine is selective for CO_2 and separates it from the H_2. Only two steps are needed before the CO_2 gas is sent to the customer. After step (2) the CO_2 is sent to feedstock (3). In step (3) the CO_2 is saturated and the pressure is close to atmospheric pressure.

- Process e, is similar to process a and b, step (1), but without the reboiling system. The capacity is 5000 ton/year of low purity CO_2. This process is only calculated for Krafla.

- Process f, is similar to process c and d, step (1), but without the H_2S reinjection system. The capacity is 5000 ton/year of low purity CO_2. This process is only calculated for Krafla.

Table 5 Acronyms

Process technology	**Acronym**
Water scrubbing H_2S removal	WS H_2S
Water scrubbing H_2S removal low purity CO_2	WS H_2S low
Water scrubbing SO_2 removal	WS SO_2
Amine H2S removal	Amine H_2S
Amine H2S removal low purity CO_2	Amine H_2S low
Amine CO2 removal	Amine CO_2
Pressure swing adsorption	PSA
H_2S Oxidation	OX
CO_2 feedstock	CO_2 feedstock
Power Plant	PP

4.2 Process performance

Each process is different from the performance point of view. In the H_2S removal processes, there is not a considerable difference between water scrubbing and using amine. On the other hand a considerable difference is evident in step number 2, when comparing Amine CO_2 and PSA. Here the difference is usually between 30 and 40 % where the Amine CO_2 has much higher efficiency but the cost is also considerably higher. According to a vendor of PSA systems, around 60 % of CO_2 will be adsorbed. This is one of the critical parts, because with higher efficiency the PSA system can become more competitive to Amine CO_2. In step 3 the dissolved CO_2 in the water scrubber system is roughly 5 % depending on the demands of the purity of the CO_2. The concentration of H_2S and SO_2 after PSA and OX in Table 1 and Table 2 are estimated and can therefore varies.

5 Cost estimation

5.1 Cost estimate classification

The cost estimation is in Class 5 as defined in AACE international guidelines “Cost Estimate Classification System” 17R-97 as well as “Cost Estimation Classification System – As applied in Engineering and Construction for the Process Industries,” 18R-97. According to AACE the estimate is in the range -50% on the lower side and +100% on the higher side.

5.2 Operational expenditure (OPEX)

OPEX was calculated from off the shelf process flow diagrams. There are operational cost differences between processes. In case of the water scrubber system, electricity, cold water and condensate are the main operating cost items. Other processes are not dependent on the water as much as the water scrubber system but amine systems needs hot water, cold water, steam and amine for makeup. The cost of hot water, cold water and steam is not rated in the variable cost, was according to Landsvirkjun´s decision. In case of the water scrubbing the water pricing has great effect on the variable cost for the process.

Labour cost is different between processes. In the combination of water scrubbing, PSA and oxidation the annual labour cost is 0,7 full-time equivalent unit. Maintenance cost is assumed to be 3 % of the total installed cost (TIC) for each process, on average. The maintenance cost includes the cost of repairing and replacing as well as the cost of labour needed to carry out the maintenance work. In Appendix A are tables showing the itemised variable cost for each process.

5.3 Major equipment cost

The estimation of equipment cost is different depending on what approach has been used. In case of the water scrubbing system Trimeric used Aspen Capital Cost Estimator (ACCE) to calculate the equipment cost for both power plants (Douglas, o.fl., 2015) (Mamrosh, et al., 2014). A budgetary quotation was received from Haldor Topsøe A/S for the oxidation systems for both power plants. The amine systems were calculated by using historical data, both for the columns and heat exchangers. In case of the PSA system a very rough estimation was given from one vendor. The water scrubber system has been built in Hellisheiði Power plant, and most cost parameters are known. In Appendix C there are tables showing itemised cost for the major equipment for each process.

5.4 Capital expenditure (CAPEX)

In this pre-feasibility study no design cost has been counted for. In Appendix C are tables showing the segmentation of CAPEX cost for each process. The cost of the main equipment is estimated and the installation cost is calculated as a function (installation factor) of the equipment cost. The installation factor varies between different types of equipment (Tower, o.fl., 2013). The total contingency is 20 % and design and engineering cost is estimated 20 %. The sum of the equipment cost, installation cost, engineering cost and contingency is the CAPEX. The location of the process buildings are not known, therefore pipelines, cables and buildings supporting the process, located outside the process building are not a part of this cost estimation. There are two exceptions of this in cost estimation, for both water scrubbing H_2S removal and amine H_2S removal systems. One 1000 m pipe line for water from the water scrubber system to the re-injection well, and a pipeline inside the re-injection well for both power plants are included. The length of the pipelines is not known but well number 26 will be used in Krafla. In reports from Trimeric (Douglas, o.fl., 2015) (Mamrosh, et al., 2014), where the water scrubber system for Krafla and Þeistareykir is simulated the main items equipment are sized and the installation cost estimated by using Aspen Capital Cost Estimator (ACCE). The calculation includes contingency and engineering cost.

5.5 Financial estimation

Table 6 shows assumptions used in the financial estimation for both power plants. The terms of the projects are 25 years but the first year is a construction period. The interests on debt was assumed to be 6 %, the LTV value 80% and required to be returned on equity 8 % and fees 0,5%. Changes on these parameters can affect the price of produced kg of CO_2. Appendix A consists of tables with detailed results of financial calculation for processes *a* to *d.*

Table 6 Assumptions for the financial estimations

Interest on debt	6%
Loan to value (LTV)	80%
Required return on equity	8%
Fees	0,5%
Depreciation	20 year
Term	25 year
Fluid cost water, steam	0 kr/kg
Electricity	5 kr/kWh

Conclusion

Krafla

For different combinations of processes, OPEX and CAPEX were calculated. The estimated production cost of CO_2 for each process combination is shown in Table 1. The table shows the processes *a and c,* the PSA system is a major bottleneck and affects the cost of CO_2.The system can only adsorb 60% of the CO_2. If the efficiency of the PSA system would be similar to the amine CO_2 removal system, the production cost of CO_2 would be much lower. It is most profitable to use amine system, process *c* and *d* but on the other hand the most uncertainty is in these processes both regarding variable and capital cost. The amine processes have the most visual impact because each step needs two columns that can be up to 16 m high.

Þeistareykir

In Table 2 variable and capital costs are shown. The cost of CO_2 production is high compared to Krafla. The reason is that both the OPEX and the CAPEX are very similar between these power plants but the capacity at Þeistareykir is less. A vendor for the PSA system assumed that the cost difference between power plants would be insignificant, and the same goes for the catalytic oxidation systems.

Summary

There is great difference of estimated cost of production of CO_2 between processes. The cost varies from 12 to 28 kr/kg in the case of Krafla and Þeistareykir from 29 to 82 kr/kg. In the financial calculation it is assumed the H_2S removal system is included. If only steps 2 to 4 in Table 4 are taken into account, the cost of CO_2 kr/kg would reduce about 50%. The lowest production price of CO_2 is by using the processes *c* and *d* which has most visual impact. The concentration of H_2S and SO_2 after PSA and OX in Table 1 and Table 2 are estimated and can therefore vary. For that reason OX system is added in process *b* for Þeistareykir even though the H_2S concentration is below 300 ppm. Calculations show that if only water scrubbing H_2S removal is used the cost is 6 to 11 kr/kg for Krafla and 15 to 27 kr/kg for Þeistareykir.

Two additional cases were studied for Krafla, process *e* and *f.* The purpose is to estimate the cost for low purity CO_2, only part of the gas from the power plant is used in the CO_2 production process that is 5000 ton/year. H_2S and part of CO_2 is removed from the gas. Process *e*, the water scrubbing process is without the reboiling system and process f is without the H_2S reinjection systems. The cost of each kg of CO_2 from *e* and *f* is higher compared to H_2S removal in *a* to *d.* The reason is relatively higher CAPEX and OPEX in the cases of e and f compared to *a* to *d*. The estimated cost is 22 kr/kg in case *e* and 15 kr/kg in case *f*.

Other things also have to be considered such as how the process fits into the present operation of the power plant. Using PSA and Catalytic oxidation are likely to have the least visual impact and can also be easy to operate. The PSA system can be operated at the same pressure as the water scrubber system. Catalytic oxidation system can be operated using almost atmospheric pressure. The next recommended step is to get more information about these two technologies and to see if it is possible to increase the efficiency of the PSA system and lower the production cost.

Appendix A

Table 7 Summary of cost of WS H_2S + PSA + Ox + WS SO_2 at Krafla

Krafla

WS H_2S + PSA + Ox+WS SO_2

Capital Expenditure (CAPEX)		**Income**	
CAPEX	2.199.308.000	Price kr/kg CO_2	28
		Production kg/year CO_2	10.550.117
Operating Expenses (OPEX)		Sales as % of production	100%
x	103.517.000	Sales	10.550.117
x			
x		**Project Facility**	
x		Loan to value (LTV)	80%
Total	**103.517.000**	Total amount	1.759.446.400
		Fees	0,5%
Other		Term (years)	25
Corporate tax	20,0%	Type of loan	Even Principal Payments
Receivables (days)			
Short term liabilities (days)		**Cost of Capital**	
Depreciation (years)	20	Interest on debt	6,0%
		Required return on equity	8,0%
		WACC	**5,5%**

Results

Project		**Equity**	
Net present value (NPV)	279.491.817	Net present value (NPV)	13.604.664
Internal rate of return (IRR)	6,9%	Internal rate of return (IRR)	8,3%
Uses of Capital		**Sources of Capital**	
Capital expenditure	2.199.308.000	Project facility	1.759.446.400
Interest & fees	61.580.624	Equity	501.442.224
Total	**2.260.888.624**	**Total**	**2.260.888.624**
Debt-Service Coverage Ratio (DSCR)			
Year 2	1,1		
Year 3	1,1		
Year 4	1,2		

Table 8 Summary of cost of WS H_2S + Amine CO_2 + Ox + WS SO_2 at Krafla

Krafla

WS H_2S + Amine CO_2 + Ox+WS SO_2

Capital Expenditure (CAPEX)		**Income**	
CAPEX	2.800.431.000	Price kr/kg CO_2	22
		Production kg/year CO_2	17.462.209
Operating Expenses (OPEX)		Sales as % of production	100%
x	132.655.000	Sales	17.462.209
x			
x		**Project Facility**	
x		Loan to value (LTV)	80%
Total	**132.655.000**	Total amount	2.240.344.800
		Fees	0,5%
Other		Term (years)	25
Corporate tax	20,0%	Type of loan	Even Principal Payments
Receivables (days)			
Short term liabilities (days)		**Cost of Capital**	
Depreciation (years)	20	Interest on debt	6,0%
		Required return on equity	8,0%
		WACC	**5,5%**

Results

Project		**Equity**	
Net present value (NPV)	432.277.165	Net present value (NPV)	78.087.217
Internal rate of return (IRR)	7,2%	Internal rate of return (IRR)	9,2%
Uses of Capital		**Sources of Capital**	
Capital expenditure	2.800.431.000	Project facility	2.240.344.800
Interest & fees	78.412.068	Equity	638.498.268
Total	**2.878.843.068**	**Total**	**2.878.843.068**
Debt-Service Coverage Ratio (DSCR)			
Year 2	1,1		
Year 3	1,2		
Year 4	1,2		

Table 9 Summary of cost of Amine H_2S + Amine CO_2 at Krafla

Krafla

Amine H_2S + Amine CO_2

Capital Expenditure (CAPEX)		**Income**	
CAPEX	1.858.524.000	Price kr/kg CO_2	13
		Production kg/year CO_2	19.858.720
Operating Expenses (OPEX)		Sales as % of production	100%
x	80.139.000	Sales	19.858.720
x			
x		**Project Facility**	
x		Loan to value (LTV)	80%
Total	**80.139.000**	Total amount	1.486.819.200
		Fees	0,5%
Other		Term (years)	25
Corporate tax	20,0%	Type of loan	Even Principal Payments
Receivables (days)			
Short term liabilities (days)		**Cost of Capital**	
Depreciation (years)	20	Interest on debt	6,0%
		Required return on equity	8,0%
		WACC	**5,5%**

Results

Project		**Equity**	
Net present value (NPV)	402.735.786	Net present value (NPV)	143.290.474
Internal rate of return (IRR)	7,8%	Internal rate of return (IRR)	11,3%
Uses of Capital		**Sources of Capital**	
Capital expenditure	1.858.524.000	Project facility	1.486.819.200
Interest & fees	52.038.672	Equity	423.743.472
Total	**1.910.562.672**	**Total**	**1.910.562.672**
Debt-Service Coverage Ratio (DSCR)			
Year 2	1,2		
Year 3	1,2		
Year 4	1,3		

Table 10 Summary of cost of Amine H_2S + PSA at Krafla

Krafla

Amine H_2S + PSA

Capital Expenditure (CAPEX)		**Income**	
CAPEX	1.405.376.000	Price kr/kg CO_2	12
		Production kg/year CO_2	17.462.209
Operating Expenses (OPEX)		Sales as % of production	100%
x	70.498.000	Sales	17.462.209
x			
x		**Project Facility**	
x		Loan to value (LTV)	80%
Total	**70.498.000**	Total amount	1.124.300.800
		Fees	0,5%
Other		Term (years)	25
Corporate tax	20,0%	Type of loan	Even Principal Payments
Receivables (days)			
Short term liabilities (days)		**Cost of Capital**	
Depreciation (years)	20	Interest on debt	6,0%
		Required return on equity	8,0%
		WACC	**5,5%**

Results

Project		**Equity**	
Net present value (NPV)	350.096.503	Net present value (NPV)	144.071.724
Internal rate of return (IRR)	8,2%	Internal rate of return (IRR)	12,3%
Uses of Capital		**Sources of Capital**	
Capital expenditure	1.405.376.000	Project facility	1.124.300.800
Interest & fees	39.350.528	Equity	320.425.728
Total	**1.444.726.528**	**Total**	**1.444.726.528**
Debt-Service Coverage Ratio (DSCR)			
Year 2	1,3		
Year 3	1,3		
Year 4	1,3		

Table 11 Summary of cost of WS H_2S at Krafla

Krafla

WS H_2S

Capital Expenditure (CAPEX)		**Income**	
CAPEX	1.406.220.000	Price kr/kg CO_2	11
		Production kg/year CO_2	18.400.602
Operating Expenses (OPEX)		Sales as % of production	100%
x	73.081.000	Sales	18.400.602
x			
x		**Project Facility**	
x		Loan to value (LTV)	80%
Total	**73.081.000**	Total amount	1.124.976.000
		Fees	0,5%
Other		Term (years)	25
Corporate tax	20,0%	Type of loan	Even Principal Payments
Receivables (days)			
Short term liabilities (days)		**Cost of Capital**	
Depreciation (years)	20	Interest on debt	6,0%
		Required return on equity	8,0%
		WACC	**5,5%**

Results

Project		**Equity**	
Net present value (NPV)	248.910.976	Net present value (NPV)	64.435.665
Internal rate of return (IRR)	7,4%	Internal rate of return (IRR)	9,9%
Uses of Capital		**Sources of Capital**	
Capital expenditure	1.406.220.000	Project facility	1.124.976.000
Interest & fees	39.374.160	Equity	320.618.160
Total	**1.445.594.160**	**Total**	**1.445.594.160**
Debt-Service Coverage Ratio (DSCR)			
Year 2	1,2		
Year 3	1,2		
Year 4	1,2		

Table 12 Summary of cost of Amine H_2S at Krafla

Krafla

Amine H_2S

Capital Expenditure (CAPEX)		**Income**	
CAPEX	831.376.000	Price kr/kg CO_2	6
		Production kg/year CO_2	19.939.200
Operating Expenses (OPEX)		Sales as % of production	100%
x	36.948.000	Sales	19.939.200
x			
x		**Project Facility**	
x		Loan to value (LTV)	80%
Total	**36.948.000**	Total amount	665.100.800
		Fees	0,5%
Other		Term (years)	25
Corporate tax	20,0%	Type of loan	Even Principal Payments
Receivables (days)			
Short term liabilities (days)		**Cost of Capital**	
Depreciation (years)	20	Interest on debt	6,0%
		Required return on equity	8,0%
		WACC	**5,5%**

Results

Project		**Equity**	
Net present value (NPV)	211.516.745	Net present value (NPV)	88.679.388
Internal rate of return (IRR)	8,2%	Internal rate of return (IRR)	12,5%
Uses of Capital		**Sources of Capital**	
Capital expenditure	831.376.000	Project facility	665.100.800
Interest & fees	23.278.528	Equity	189.553.728
Total	**854.654.528**	**Total**	**854.654.528**
Debt-Service Coverage Ratio (DSCR)			
Year 2	1,3		
Year 3	1,3		
Year 4	1,3		

Table 13 Summary of cost of WS H_2S low purity at Krafla

Krafla

WS H_2S low purity

Capital Expenditure (CAPEX)		**Income**	
CAPEX	799.296.000	Price kr/kg CO_2	22
		Production kg/year CO_2	4.999.812
Operating Expenses (OPEX)		Sales as % of production	100%
x	36.133.000	Sales	4.999.812
x			
x		**Project Facility**	
x		Loan to value (LTV)	80%
Total	**36.133.000**	Total amount	639.436.800
		Fees	0,5%
Other		Term (years)	25
Corporate tax	20,0%	Type of loan	Even Principal Payments
Receivables (days)			
Short term liabilities (days)		**Cost of Capital**	
Depreciation (years)	20	Interest on debt	6,0%
		Required return on equity	8,0%
		WACC	**5,5%**

Results

Project		**Equity**	
Net present value (NPV)	145.183.146	Net present value (NPV)	39.551.174
Internal rate of return (IRR)	7,5%	Internal rate of return (IRR)	10,1%
Uses of Capital		**Sources of Capital**	
Capital expenditure	799.296.000	Project facility	639.436.800
Interest & fees	22.380.288	Equity	182.239.488
Total	**821.676.288**	**Total**	**821.676.288**
Debt-Service Coverage Ratio (DSCR)			
Year 2	1,2		
Year 3	1,2		
Year 4	1,2		

Table 14 Summary of cost of Amine H_2S low purity at Krafla

Krafla

Amine H_2S low purity

Capital Expenditure (CAPEX)		**Income**	
CAPEX	531.387.000	Price kr/kg CO_2	15
		Production kg/year CO_2	4.999.992
Operating Expenses (OPEX)		Sales as % of production	100%
x	27.830.000	Sales	4.999.992
x			
x		**Project Facility**	
x		Loan to value (LTV)	80%
Total	**27.830.000**	Total amount	425.109.600
		Fees	0,5%
Other		Term (years)	25
Corporate tax	20,0%	Type of loan	Even Principal Payments
Receivables (days)			
Short term liabilities (days)		**Cost of Capital**	
Depreciation (years)	20	Interest on debt	6,0%
		Required return on equity	8,0%
		WACC	**5,5%**

Results

Project		**Equity**	
Net present value (NPV)	76.140.656	Net present value (NPV)	10.142.204
Internal rate of return (IRR)	7,1%	Internal rate of return (IRR)	8,8%
Uses of Capital		**Sources of Capital**	
Capital expenditure	531.387.000	Project facility	425.109.600
Interest & fees	14.878.836	Equity	121.156.236
Total	**546.265.836**	**Total**	**546.265.836**
Debt-Service Coverage Ratio (DSCR)			
Year 2	1,1		
Year 3	1,2		
Year 4	1,2		

Table 15 Summary of cost of WS H_2S + PSA + Ox + WS SO_2 at Þeistareykir

Þeistareykir

WS H_2S + PSA + Ox+WS SO_2

Capital Expenditure (CAPEX)		**Income**	
CAPEX	1.907.843.000	Price kr/kg CO_2	82
		Production kg/year CO_2	2.995.983
Operating Expenses (OPEX)		Sales as % of production	100%
x	78.033.000	Sales	2.995.983
x			
x		**Project Facility**	
x		Loan to value (LTV)	80%
Total	**78.033.000**	Total amount	1.526.274.400
		Fees	0,5%
Other		Term (years)	25
Corporate tax	20,0%	Type of loan	Even Principal Payments
Receivables (days)			
Short term liabilities (days)		**Cost of Capital**	
Depreciation (years)	20	Interest on debt	6,0%
		Required return on equity	8,0%
		WACC	**5,5%**

Results

Project		**Equity**	
Net present value (NPV)	255.079.863	Net present value (NPV)	21.860.649
Internal rate of return (IRR)	7,0%	Internal rate of return (IRR)	8,5%
Uses of Capital		**Sources of Capital**	
Capital expenditure	1.907.843.000	Project facility	1.526.274.400
Interest & fees	53.419.604	Equity	434.988.204
Total	**1.961.262.604**	**Total**	**1.961.262.604**
Debt-Service Coverage Ratio (DSCR)			
Year 2	1,1		
Year 3	1,1		
Year 4	1,2		

Table 16 Summary of cost of WS H_2S + Amine CO_2 + Ox + WS SO_2 at Þeistareykir

Þeistareykir

WS H_2S + Amine CO_2 + Ox+WS SO_2

Capital Expenditure (CAPEX)		Income	
CAPEX	2.027.497.000	Price kr/kg CO_2	54
		Production kg/year CO_2	5.026.203
Operating Expenses (OPEX)		Sales as % of production	100%
x	92.398.000	Sales	5.026.203
x			
x		**Project Facility**	
x		Loan to value (LTV)	80%
Total	**92.398.000**	Total amount	1.621.997.600
		Fees	0,5%
Other		Term (years)	25
Corporate tax	20,0%	Type of loan	Even Principal Payments
Receivables (days)			
Short term liabilities (days)		**Cost of Capital**	
Depreciation (years)	20	Interest on debt	6,0%
		Required return on equity	8,0%
		WACC	**5,5%**

Results

Project		Equity	
Net present value (NPV)	280.306.321	Net present value (NPV)	30.577.135
Internal rate of return (IRR)	7,0%	Internal rate of return (IRR)	8,6%
Uses of Capital		**Sources of Capital**	
Capital expenditure	2.027.497.000	Project facility	1.621.997.600
Interest & fees	56.769.916	Equity	462.269.316
Total	**2.084.266.916**	**Total**	**2.084.266.916**
Debt-Service Coverage Ratio (DSCR)			
Year 2	1,1		
Year 3	1,1		
Year 4	1,2		

Table 17 Summary of cost of Amine H_2S + Amine CO_2 at Þeistareykir

Þeistareykir

Amine H_2S + Amine CO_2

Capital Expenditure (CAPEX)		**Income**	
CAPEX	1.229.838.000	Price kr/kg CO_2	29
		Production kg/year CO_2	5.773.572
Operating Expenses (OPEX)		Sales as % of production	100%
x	60.659.000	Sales	5.773.572
x			
x		**Project Facility**	
x		Loan to value (LTV)	80%
Total	**60.659.000**	Total amount	983.870.400
		Fees	0,5%
Other		Term (years)	25
Corporate tax	20,0%	Type of loan	Even Principal Payments
Receivables (days)			
Short term liabilities (days)		**Cost of Capital**	
Depreciation (years)	20	Interest on debt	6,0%
		Required return on equity	8,0%
		WACC	**5,5%**

Results

Project		**Equity**	
Net present value (NPV)	150.638.876	Net present value (NPV)	3.102.066
Internal rate of return (IRR)	6,8%	Internal rate of return (IRR)	8,1%
Uses of Capital		**Sources of Capital**	
Capital expenditure	1.229.838.000	Project facility	983.870.400
Interest & fees	34.435.464	Equity	280.403.064
Total	**1.264.273.464**	**Total**	**1.264.273.464**
Debt-Service Coverage Ratio (DSCR)			
Year 2	1,1		
Year 3	1,1		
Year 4	1,2		

Table 18 Summary of cost of Amine H_2S + PSA at Þeistareykir

Þeistareykir

Amine H_2S + PSA

Capital Expenditure (CAPEX)		**Income**	
CAPEX	1.133.134.000	Price kr/kg CO_2	46
		Production kg/year CO_2	3.500.496
Operating Expenses (OPEX)		Sales as % of production	100%
x	62.212.000	Sales	3.500.496
x			
x		**Project Facility**	
x		Loan to value (LTV)	80%
Total	**62.212.000**	Total amount	906.507.200
		Fees	0,5%
Other		Term (years)	25
Corporate tax	20,0%	Type of loan	Even Principal Payments
Receivables (days)			
Short term liabilities (days)		**Cost of Capital**	
Depreciation (years)	20	Interest on debt	6,0%
		Required return on equity	8,0%
		WACC	**5,5%**

Results

Project		**Equity**	
Net present value (NPV)	143.427.937	Net present value (NPV)	6.552.848
Internal rate of return (IRR)	6,9%	Internal rate of return (IRR)	8,2%
Uses of Capital		**Sources of Capital**	
Capital expenditure	1.133.134.000	Project facility	906.507.200
Interest & fees	31.727.752	Equity	258.354.552
Total	**1.164.861.752**	**Total**	**1.164.861.752**
Debt-Service Coverage Ratio (DSCR)			
Year 2	1,1		
Year 3	1,1		
Year 4	1,2		

Table 19 Summary of cost of WS H_2S at Þeistareykir

Þeistareykir

WS H_2S

Capital Expenditure (CAPEX)		Income	
CAPEX	1.114.755.000	Price kr/kg CO_2	27
		Production kg/year CO_2	5.517.456
Operating Expenses (OPEX)		Sales as % of production	100%
x	47.597.000	Sales	5.517.456
x			
x		**Project Facility**	
x		Loan to value (LTV)	80%
Total	**47.597.000**	Total amount	891.804.000
		Fees	0,5%
Other		Term (years)	25
Corporate tax	20,0%	Type of loan	Even Principal Payments
Receivables (days)			
Short term liabilities (days)		**Cost of Capital**	
Depreciation (years)	20	Interest on debt	6,0%
		Required return on equity	8,0%
		WACC	**5,5%**

Results

Project		Equity	
Net present value (NPV)	185.304.923	Net present value (NPV)	41.573.728
Internal rate of return (IRR)	7,3%	Internal rate of return (IRR)	9,6%
Uses of Capital		**Sources of Capital**	
Capital expenditure	1.114.755.000	Project facility	891.804.000
Interest & fees	31.213.140	Equity	254.164.140
Total	**1.145.968.140**	**Total**	**1.145.968.140**
Debt-Service Coverage Ratio (DSCR)			
Year 2	1,2		
Year 3	1,2		
Year 4	1,2		

Table 20 Summary of cost for Amine H_2S at Þeistareykir

Þeistareykir

Amine H_2S

Capital Expenditure (CAPEX)		**Income**	
CAPEX	620.634.000	Price kr/kg CO_2	15
		Production kg/year CO_2	5.849.052
Operating Expenses (OPEX)		Sales as % of production	100%
x	30.507.000	Sales	5.849.052
x			
x		**Project Facility**	
x		Loan to value (LTV)	80%
Total	**30.507.000**	Total amount	496.507.200
		Fees	0,5%
Other		Term (years)	25
Corporate tax	20,0%	Type of loan	Even Principal Payments
Receivables (days)			
Short term liabilities (days)		**Cost of Capital**	
Depreciation (years)	20	Interest on debt	6,0%
		Required return on equity	8,0%
		WACC	**5,5%**

Results

Project		**Equity**	
Net present value (NPV)	111.439.066	Net present value (NPV)	29.690.473
Internal rate of return (IRR)	7,4%	Internal rate of return (IRR)	10,0%
Uses of Capital		**Sources of Capital**	
Capital expenditure	620.634.000	Project facility	496.507.200
Interest & fees	17.377.752	Equity	141.504.552
Total	**638.011.752**	**Total**	**638.011.752**
Debt-Service Coverage Ratio (DSCR)			
Year 2	1,2		
Year 3	1,2		
Year 4	1,2		

Appendix B

Table 21 Operational expenditure (OPEX) for WS H_2S at Krafla

Krafla					
Operational expenditure (OPEX) for WS H_2S					
Energy usage	**Value**	**Unit**	**Unit price**	**Total price**	**Annual**
Electricity	591	[kW]	5,00 kr/kWh	2.956 kr.	25.894.560 kr.
Condensate	121,0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Ground water	100	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Amine	0	kg/s	725,00 kr/kg	0,00 kr.	0 kr.
Steam	0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Geothermal water	0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Maintenance cost 3%	1	kr/year	42.186.600 kr.	42.186.600 kr.	42.186.600 kr.
labor cost	0,5	annual	10.000.000 kr.	5.000.000 kr.	5.000.000 kr.
Total Operational Cost	**Rounded up to nearest 1000**			**47.190.000 kr.**	**73.081.000 kr.**

Table 22 Operational expenditure (OPEX) for PSA, after WS H_2S at Krafla

Krafla					
Operational expenditure (OPEX) for PSA, after WS H_2S					
Energy usage	**Value**	**Unit**	**Unit price**	**Total price**	**Annual**
Electricity	1	[kW]	5,00 kr/kWh	5 kr.	43.800 kr.
Condensate	0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Ground water	0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Amine	0	kg/s	725,00 kr/kg	0,00 kr.	0 kr.
Steam	0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Geothermal water	0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Maintenance cost 3%	1	kr/year	10.875.000 kr.	10.875.000 kr.	10.875.000 kr.
labor cost	0,1	annual	10.000.000 kr.	1.000.000 kr.	1.000.000 kr.
Total Operational Cost	**Rounded up to nearest 1000**			**11.875.000 kr.**	**11.919.000 kr.**

Table 23 Operational expenditure (OPEX) for Amine H_2S at Krafla

Krafla					
Operational expenditure (OPEX) for Amine H_2S					
Energy usage	**Value**	**Unit**	**Unit price**	**Total price**	**Annual**
Electricity	158	[kW]	5,00 kr/kWh	788 kr.	6.900.690 kr.
Condensate	3,0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Ground water	8	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Amine	146	kg/year	725,00 kr/kg	106.002 kr.	106.002 kr.
Steam	1	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Geothermal water	5,5	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Maintenance cost 3%	1	kr/year	24.941.280 kr.	24.941.280 kr.	24.941.280 kr.
labour cost	0,5	annual	10.000.000 kr.	5.000.000 kr.	5.000.000 kr.
Total Operational Cost	**Rounded up to nearest 1000**			**30.048.000 kr.**	**36.948.000 kr.**

Table 24 Operational expenditure (OPEX) for Amine CO_2, after Amine H_2S at Krafla

Krafla					
Operational expenditure (OPEX) for Amine CO_2, after Amine H_2S					
Energy usage	**Value**	**Unit**	**Unit price**	**Total price**	**Annual**
Electricity	163	[kW]	5,00 kr/kWh	816 kr.	7.148.160 kr.
Condensate	3,0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Ground water	25	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Amine	315	kg/year	725,00 kr/kg	228.023 kr.	228.023 kr.
Steam	2	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Geothermal water	5,5	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Maintenance cost 3%	1	kr/year	30.814.440 kr.	30.814.440 kr.	30.814.440 kr.
labor cost	0,5	annual	10.000.000 kr.	5.000.000 kr.	5.000.000 kr.
Total Operational Cost	**Rounded up to nearest 1000**			**36.043.000 kr.**	**43.191.000 kr.**

Table 25 Operational expenditure (OPEX) for PSA, after Amine H_2S at Krafla

Krafla					
Operational expenditure (OPEX) for PSA, after Amine H_2S					
Energy usage	**Value**	**Unit**	**Unit price**	**Total price**	**Annual**
Electricity	350	[kW]	5,00 kr/kWh	1.750 kr.	15.330.000 kr.
Condensate		kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Ground water	2	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Amine	0	kg/s	725,00 kr/kg	0,00 kr.	0 kr.
Steam	0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Geothermal water	0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Maintenance cost 3%	1	kr/year	17.220.000 kr.	17.220.000 kr.	17.220.000 kr.
labor cost	0,1	annual	10.000.000 kr.	1.000.000 kr.	1.000.000 kr.
Total Operational Cost	**Rounded up to nearest 1000**			**18.222.000 kr.**	**33.550.000 kr.**

Table 26 Operational expenditure (OPEX) Amine CO_2 removal, after WS H_2S at Krafla

Krafla					
Operational expenditure (OPEX) Amine CO_2 removal, after WS H_2S					
Energy usage	**Value**	**Unit**	**Unit price**	**Total price**	**Annual**
Electricity	163	[kW]	5,00 kr/kWh	816 kr.	7.148.160 kr.
Condensate	3,0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Ground water	25	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Amine	0	kg/s	725,00 kr/kg	0,00 kr.	0 kr.
Steam	2	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Geothermal water	5,5	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Maintenance cost 3%	1	kr/year	28.908.690 kr.	28.908.690 kr.	28.908.690 kr.
labor cost	0,5	annual	10.000.000 kr.	5.000.000 kr.	5.000.000 kr.
Total Operational Cost	**Rounded up to nearest 1000**			**33.910.000 kr.**	**41.057.000 kr.**

Table 27 Operational expenditure (OPEX) for OX + WS SO_2, after PSA or Amine CO_2 at Krafla

Krafla					
Operational expenditure (OPEX) for OX + WS SO_2, after PSA or Amine CO_2					
Energy usage	**Value**	**Unit**	**Unit price**	**Total price**	**Anual**
Electricity	105	[kW]	5,00 kr/kWh	525 kr.	4.599.000 kr.
Condensate	10	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Ground water	2	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Amine	0	kg/s	725,00 kr/kg	0,00 kr.	0 kr.
Steam	0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Geothermal water	0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Maintenance cost 3%	1	kr/year	12.917.640 kr.	12.917.640 kr.	12.917.640 kr.
labor cost	0,1	annual	10.000.000 kr.	1.000.000 kr.	1.000.000 kr.
Total Operational Cost	**Rounded up to nearest 1000**			**13.918.000 kr.**	**18.517.000 kr.**

Table 28 Operational expenditure (OPEX) for WS H_2S low purity at Krafla

Þeistareykir					
Operational expenditure (OPEX) for WS H_2S low					
	Value	**Unit**	**Unit price**	**Total price**	**Annual**
Electricity	209	[kW]	5,00 kr/kWh	1.045 kr.	9.154.200 kr.
Condensate	42,0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Ground water	40	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Amine	0	kg/s	725,00 kr/kg	0,00 kr.	0 kr.
Steam	0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Geothermal water	0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Maintenance cost 3%	1	kr/year	23.978.880 kr.	23.978.880 kr.	23.978.880 kr.
labor cost	0,3	annual	10.000.000 kr.	3.000.000 kr.	3.000.000 kr.
Total Operational Cost	**Rounded up to nearest 1000**			**26.980.000 kr.**	**36.133.000 kr.**

Table 29 Operational expenditure (OPEX) for Amine H_2S low purity at Krafla

Þeistareykir					
Operational expenditure (OPEX) for Amine H_2S low					
Energy usage	**Value**	**Unit**	**Unit price**	**Total price**	**Anual**
Electricity	156	[kW]	5,00 kr/kWh	780 kr.	6.828.420 kr.
Condensate	3,0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Ground water	10	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Amine	82	kg/year	725,00 kr/kg	59.624 kr.	59.624 kr.
Steam	0,5	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Geothermal water	5,5	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Maintenance cost 3%	1	kr/year	15.941.610 kr.	15.941.610 kr.	15.941.610 kr.
labor cost	0,5	annual	10.000.000 kr.	5.000.000 kr.	5.000.000 kr.
Total Operational Cost	**Rounded up to nearest 1000**			**21.002.000 kr.**	**27.830.000 kr.**

Table 30 Operational expenditure (OPEX) for WS H_2S at Þeistareykir

Þeistareykir					
Operational expenditure (OPEX) for WS H_2S					
	Value	**Unit**	**Unit price**	**Total price**	**Annual**
Electricity	209	[kW]	5,00 kr/kWh	1.045 kr.	9.154.200 kr.
Condensate	42,0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Ground water	40	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Amine	0	kg/s	725,00 kr/kg	0,00 kr.	0 kr.
Steam	0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Geothermal water	5,3	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Maintenance cost 3%	1	kr/year	33.442.650 kr.	33.442.650 kr.	33.442.650 kr.
labor cost	0,5	annual	10.000.000 kr.	5.000.000 kr.	5.000.000 kr.
Total Operational Cost	**Rounded up to nearest 1000**			**38.444.000 kr.**	**47.597.000 kr.**

Table 31 Operational expenditure (OPEX) for PSA, after WS H_2S at Þeistareykir

Þeistareykir					
Operational expenditure (OPEX) for PSA, after WS H_2S					
Energy usage	**Value**	**Unit**	**Unit price**	**Total price**	**Annual**
Electricity	1	[kW]	5,00 kr/kWh	5 kr.	43.800 kr.
Condensate	0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Ground water	2	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Amine	0	kg/s	725,00 kr/kg	0,00 kr.	0 kr.
Steam	0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Geothermal water	0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Maintenance cost 3%	1	kr/year	10.875.000 kr.	10.875.000 kr.	10.875.000 kr.
labor cost	0,1	annual	10.000.000 kr.	1.000.000 kr.	1.000.000 kr.
Total Operational Cost	**Rounded up to nearest 1000**			**11.875.000 kr.**	**11.919.000 kr.**

Table 32 Operational expenditure (OPEX) for Amine H_2S at Þeistareykir

Þeistareykir					
Operational expenditure (OPEX) for Amine H_2S					
Energy usage	**Value**	**Unit**	**Unit price**	**Total price**	**Anual**
Electricity	156	[kW]	5,00 kr/kWh	780 kr.	6.828.420 kr.
Condensate	3,0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Ground water	10	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Amine	82	kg/year	725,00 kr/kg	59.624 kr.	59.624 kr.
Steam	0,5	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Geothermal water	5,5	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Maintenance cost 3%	1	kr/year	18.619.020 kr.	18.619.020 kr.	18.619.020 kr.
labor cost	0,5	annual	10.000.000 kr.	5.000.000 kr.	5.000.000 kr.
Total Operational Cost	**Rounded up to nearest 1000**			**23.679.000 kr.**	**30.507.000 kr.**

Table 33 Operational expenditure (OPEX) for Amine CO_2, after Amine H_2S at Þeistareykir

Þeistareykir					
Operational expenditure (OPEX) for Amine CO_2, after Amine H_2S					
Energy usage	**Value**	**Unit**	**Unit price**	**Total price**	**Anual**
Electricity	156	[kW]	5,00 kr/kWh	779 kr.	6.819.660 kr.
Condensate	3,0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Ground water	10	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Amine	77	kg/year	725,00 kr/kg	55.901,34 kr.	55.901 kr.
Steam	0,5	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Geothermal water	5,5	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Maintenance cost 3%	1	kr/year	18.276.120 kr.	18.276.120 kr.	18.276.120 kr.
labour cost	0,5	annual	10.000.000 kr.	5.000.000 kr.	5.000.000 kr.
Total Operational Cost	**Rounded up to nearest 1000**			**23.333.000 kr.**	**30.152.000 kr.**

Table 34 Operational expenditure (OPEX) for PSA, after Amine H_2S at Þeistareykir

Þeistareykir					
Operational expenditure (OPEX) for PSA, after Amine H_2S					
Energy usage	**Value**	**Unit**	**Unit price**	**Total price**	**Annual**
Electricity	350	[kW]	5,00 kr/kWh	1.750 kr.	15.330.000 kr.
Condensate	0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Ground water	2	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Amine	0	kg/s	725,00 kr/kg	0,00 kr.	0 kr.
Steam	0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Geothermal water	0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Maintenance cost 3%	1	kr/year	15.375.000 kr.	15.375.000 kr.	15.375.000 kr.
labor cost	0,1	annual	10.000.000 kr.	1.000.000 kr.	1.000.000 kr.
Total Operational Cost	**Rounded up to nearest 1000**			**16.377.000 kr.**	**31.705.000 kr.**

Table 35 Operational expenditure (OPEX)t for Amine CO_2 removal, after WS H_2S at Þeistareykir

Þeistareykir					
Operational expenditure (OPEX)t for Amine CO_2 removal, after WS H_2S					
Energy usage	**Value**	**Unit**	**Unit price**	**Total price**	**Anual**
Electricity	156	[kW]	5,00 kr/kWh	779 kr.	6.819.660 kr.
Condensate	3,0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Ground water	10	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Amine	0	kg/s	725,00 kr/kg	0,00 kr.	0 kr.
Steam	0,5	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Geothermal water	5,5	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Maintenance cost 3%	1	kr/year	14.464.620 kr.	14.464.620 kr.	14.464.620 kr.
labor cost	0,5	annual	10.000.000 kr.	5.000.000 kr.	5.000.000 kr.
Total Operational Cost	**Rounded up to nearest 1000**			**19.465.000 kr.**	**26.284.000 kr.**

Table 36 Operational expenditure (OPEX) for OX process and WS SO_2, after PSA or Amine CO_2 at Þeistareykir

Þeistareykir					
Operational expenditure (OPEX) for OX + WS SO_2, after PSA or Amine CO_2					
Electricity	105	[kW]	5,00 kr/kWh	525 kr.	4.599.000 kr.
Condensate	5	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Ground water	0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Amine	0	kg/s	725,00 kr/kg	0,00 kr.	0 kr.
Steam	0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Geothermal water	0	kg/s	0,00 kr/kg	0,00 kr.	0 kr.
Maintenance cost 3%	1	kr/year	12.917.640 kr.	12.917.640 kr.	12.917.640 kr.
labor cost	0,1	annual	10.000.000 kr.	1.000.000 kr.	1.000.000 kr.
Total Operational Cost	**Rounded up to nearest 1000**			**13.918.000 kr.**	**18.517.000 kr.**

Appendix C

Table 37 Capital expenditure (CAPEX) for WS H_2S at Krafla

Krafla			
Capital expenditure (CAPEX) for WS H_2S			
Item no	**Description**	**Equipment cost ISK**	**Design detail**
1	Column	73.968.000 kr.	Diameter 2 m Height 23 m. PN16 material 1.4404
2	Cross exchanger	81.144.000 kr.	Type plate, Size 3340 m2, PN16 material SMO 254
3	Reboiler	16.422.000 kr.	Type Shell and tube, Size 311 m2, PN16 material SMO 254
4	LRVP water pump	2.235.600 kr.	Pressure head 10,3 m 0,8 kg/s material 1.4404
5	LRVP separator	6.596.400 kr.	Diameter 1 m Height 3 m. PN16 material 1.4404
6	Compressor	103.776.000 kr.	Type liquid ring compressor material 1.4404
7	Bottoms pump	6.486.000 kr.	Pressure head 18,5 m 140,8 kg/s material 1.4404
8	Boilup separator	20.355.000 kr.	Diameter 2,5 m Height 7 m PN16 material SMO 254
9	Ground water pump	3.588.000 kr.	Pressure head 62 m 40 kg/s material 1.4404
10	Heat exchanger	5.000.000 kr.	Plate size 200 m2 PN16 material 1.4404
11	Re-injection pipeline 1000 m	15.000.000 kr.	PE ø315 SDR17,6
12	Pipeline in re-injection well	26.000.000 kr.	DN150 pipe 750 m material 1.4404
	Total Equipment Cost	**360.571.000 kr.**	
	Total Installed Cost (TIC)	**1.171.835.723 kr.**	
	Contingency 20% of TIC	**234.367.145 kr.**	
	Capital Expenditure	**1.406.220.000 kr.**	**Designing incl. Rounded up to nearest 1000**

Table 38 Capital expenditure (CAPEX) for PSA, after WS H_2S at Krafla

Krafla			
Capital expenditure (CAPEX) for PSA, after WS H_2S			
Item no	**Description**	**Equipment cost ISK**	**Design detail**
1	PSA system total	145.000.000 kr.	Approx floor area 8x13 m
	Total Equipment Cost	**145.000.000 kr.**	
	Total Installed Cost (TIC)	**290.000.000 kr.**	
	Engineering Cost 5% of TiC	**14.500.000 kr.**	No designing only construction supervision and service
	Contingency 20% of TIC	**58.000.000 kr.**	
	Capital Expenditure	**362.500.000 kr.**	**Rounded up to nearest 1000**

Table 39 Capital expenditure (CAPEX) for Amine H_2S at Krafla

Krafla			
Capital expenditure (CAPEX) for Amine H_2S			
Item no	**Description**	**Equipment cost ISK**	**Design detail**
1	Absorption column (ABS column)	36.174.576 kr.	Diameter 0,9 m Height 11 m. PN6 material 1.4404
2	Deariator (Reg column)	48.716.031 kr.	Diameter 0,9 m Height 15 m. PN6 material 1.4404
3	Reboiler (shell/tube)	1.660.289 kr.	Type Shell and tube, Size 14 m2, PN10 material 1.4404
4	Condenser (shell/tube)	652.257 kr.	Type Shell and tube, Size 5,5 m2, PN10 material 1.4404
5	Lean pump	2.000.000 kr.	Pressure head 17 m 8,2 kg/s material 1.4404
6	Rich pump	2.000.000 kr.	Pressure head 26 m 7,7 kg/s material 1.4404
7	Cooler (shell/tube)	4.743.684 kr.	Type Shell and tube, Size 40 m2, PN10 material 1.4404
8	L/R Hex (HTXR - shell/tube)	8.538.631 kr.	Type Shell and tube, Size 72 m2, PN10 material 1.4404
9	Gas Blower	36.300.000 kr.	Gas blower 1986 Nm3/h
10	Gas compressor	20.778.000 kr.	Gas compressor 500 Nm3/h @ 5 bar_a
11	Re-injection pipeline 1000 m	15.000.000 kr.	PE ø315 SDR17,6
12	Pipeline in re-injection well	26.000.000 kr.	Same design as in Hellisheiði
	Total Equipment Cost	**202.563.000 kr.**	
	Total Installed Cost (TIC)	**593.839.912 kr.**	
	Engineering Cost 20% of TiC	**118.767.982 kr.**	
	Contingency 20% of TIC	**118.767.982 kr.**	
	Capital Expenditure	**831.376.000 kr.**	**Rounded up to nearest 1000**

Table 40 Capital expenditure (CAPEX) for Amine CO_2, after Amine H_2S at Krafla

Krafla			
Capital expenditure (CAPEX) for Amine CO_2, after Amine H_2S			
Item no	**Description**	**Equipment cost ISK**	**Design detail**
1	Absorption column (ABS column)	58.279.646 kr.	Diameter 1,2 m Height 16 m. PN6 material 1.4404
2	Deariator (Reg column)	69.425.209 kr.	Diameter 1,3 m Height 16 m. PN6 material 1.4404
3	Reboiler (shell/tube)	3.320.579 kr.	Type Shell and tube, Size 28 m2, PN10 material 1.4404
4	Condenser (shell/tube)	652.257 kr.	Type Shell and tube, Size 5,5 m2, PN10 material 1.4404
5	Lean pump	4.000.000 kr.	Pressure head 17 m 18,5 kg/s material 1.4404
6	Rich pump	4.000.000 kr.	Pressure head 26 m 17,8 kg/s material 1.4404
7	Cooler (shell/tube)	22.532.499 kr.	Type Shell and tube, Size 190 m2, PN10 material 1.4404
8	L/R Hex (HTXR - shell/tube)	15.061.197 kr.	Type Shell and tube, Size 127 m2, PN10 material 1.4404
9	Gas Blower	18.150.000 kr.	Gas blower 1986 Nm3/h
	Total Equipment Cost	**195.421.386 kr.**	
	Total Installed Cost (TIC)	**733.677.280 kr.**	
	Engineering Cost 20% of TiC	**146.735.456 kr.**	
	Contingency 20% of TIC	**146.735.456 kr.**	
	Capital Expenditure	**1.027.148.000 kr.**	**Rounded up to nearest 1000**

Table 41 Capital expenditure (CAPEX) for PSA, after Amine H_2S at Krafla

Krafla			
Capital expenditure (CAPEX) for PSA, after Amine H_2S			
Item no	**Description**	**Equipment cost ISK**	**Design detail**
1	PSA system total	145.000.000 kr.	Approx floor area 8x13 m
2	Compressor	60.000.000 kr.	
	Total Equipment Cost	**205.000.000 kr.**	
	Total Installed Cost (TIC)	**410.000.000 kr.**	
	Engineering Cost 5% of TiC	**82.000.000 kr.**	No designing only construction supervision and service
	Contingency 20% of TIC	**82.000.000 kr.**	
	Capital Expenditure	**574.000.000 kr.**	**Rounded up to nearest 1000**

Table 42 Capital expenditure (CAPEX) for Amine CO_2 removal, after WS H_2S at Krafla

Krafla			
Capital expenditure (CAPEX) for Amine CO_2, after WS H_2S			
Item no	**Description**	**Equipment cost ISK**	**Design detail**
1	Absorption column (ABS column)	58.279.646 kr.	Diameter 1,2 m Height 16 m. PN6 material 1.4404
2	Deariator (Reg column)	69.425.209 kr.	Diameter 1,3 m Height 16 m. PN6 material 1.4404
3	Reboiler (shell/tube)	3.320.579 kr.	Type Shell and tube, Size 28 m2, PN10 material 1.4404
4	Condenser (shell/tube)	652.257 kr.	Type Shell and tube, Size 5,5 m2, PN10 material 1.4404
5	Lean pump	4.000.000 kr.	Pressure head 17 m 18,5 kg/s material 1.4404
6	Rich pump	4.000.000 kr.	Pressure head 26 m 17,8 kg/s material 1.4404
7	Cooler (shell/tube)	22.532.499 kr.	Type Shell and tube, Size 190 m2, PN10 material 1.4404
8	L/R Hex (HTXR - shell/tube)	15.061.197 kr.	Type Shell and tube, Size 127 m2, PN10 material 1.4404
	Total Equipment Cost	**177.271.386 kr.**	
	Total Installed Cost (TIC)	**688.302.280 kr.**	
	Engineering Cost 20% of TiC	**137.660.456 kr.**	
	Contingency 20% of TIC	**137.660.456 kr.**	
	Capital Expenditure	**963.623.000 kr.**	**Rounded up to nearest 1000**

Table 43 Capital expenditure (CAPEX) for OX, after amine CO_2 or PSA at Krafla

Krafla			
Capital expenditure (CAPEX) for OX + WS SO_2, after amine CO_2 or PSA			
item no	**Description**	**Equipment cost ISK**	**Design detail**
1	Catalytic oxidation system	101.500.000	
2	Gas blower	36.300.000	
3	Column	30.435.138	
4	booster pump	4.000.000	
	Total Equipment Cost	**172.235.138 kr.**	
	Total Installed Cost (TIC)	**344.470.277 kr.**	
	Engineering Cost 5% of TiC	**17.223.514 kr.**	No designing only construction supervision and service
	Contingency 20% of TIC	**68.894.055 kr.**	
	Capital Expenditure	**430.588.000 kr.**	**Rounded up to nearest 1000**

Table 44 Capital expenditure (CAPEX) for WS H_2S low at Krafla

Krafla			
Capital expenditure (CAPEX) for WS H_2S low			
Item no	**Description**	**Equipment cost ISK**	**Design detail**
1	Column	33.534.000 kr.	Diameter 1 m Height 23 m. PN16 material 1.4404
6	Compressor	35.880.000 kr.	Type liquid ring compressor material 1.4404
7	Bottoms pump	14.214.000 kr.	Pressure head 18,5 m 40,8 kg/s material 1.4404
9	Ground water pump	3.588.000 kr.	Pressure head 86 m 40 kg/s material 1.4404
10	Heat exchanger	5.000.000 kr.	Plate size 200 m2 PN16 material 1.4404
11	Re-injection pipeline 1000 m	15.000.000 kr.	PE ø315 SDR17,6
12	Pipeline in re-injection well	26.000.000 kr.	DN150 pipe 750 m material 1.4404
	Total Equipment Cost	**133.216.000 kr.**	
	Total Installed Cost (TIC)	**666.080.000 kr.**	
	Contingency 20% of TIC	**133.216.000 kr.**	
	Capital Expenditure	**799.296.000 kr.**	**Designing cost included. Rounded up to nearest 1000**

Table 45 Capital expenditure (CAPEX) for Amine H_2S low at Krafla

Krafla			
Capital expenditure (CAPEX) for Amine H_2S low purity			
Item no	**Description**	**Equipment cost ISK**	**Design detail**
1	Absorption column (ABS column)	29.023.205 kr.	Diameter 0,6 m Height 11 m. PN6 material 1.4404
2	Deariator (Reg column)	42.481.503 kr.	Diameter 0,7 m Height 15 m. PN6 material 1.4404
3	Reboiler (shell/tube)	830.145 kr.	Type Shell and tube, Size 7m2, PN10 material 1.4404
4	Condenser (shell/tube)	652.257 kr.	Type Shell and tube, Size 5,5 m2, PN10 material 1.4404
5	Lean pump	2.000.000 kr.	Pressure head 17 m 5,2 kg/s material 1.4404
6	Rich pump	2.000.000 kr.	Pressure head 26 m 5 kg/s material 1.4404
7	Cooler (shell/tube)	2.253.250 kr.	Type Shell and tube, Size 19 m2, PN10 material 1.4404
8	L/R Hex (HTXR - shell/tube)	5.455.237 kr.	Type Shell and tube, Size 46 m2, PN10 material 1.4404
9	Gas blower	18.150.000 kr.	1000 Nm3/h
	Total Equipment Cost	**102.845.596 kr.**	
	Total Installed Cost (TIC)	**379.561.940 kr.**	
	Engineering Cost 20% of TiC	**75.912.388 kr.**	
	Contingency 20% of TIC	**75.912.388 kr.**	
	Capital Expenditure	**531.387.000 kr.**	**Rounded up to nearest 1000**

Table 46 Capital expenditure (CAPEX) for WS H_2S at Þeistareykir

Þeistareykir			
Capital expenditure (CAPEX) for WS H_2S			
Item no	**Description**	**Equipment cost ISK**	**Design detail**
1	Column	33.534.000 kr.	Diameter 1 m Height 23 m. PN16 material 1.4404
2	Cross exchanger	29.394.000 kr.	Type Shell and tube, Size 1200 m2, PN16 material SMO 254
3	Reboiler	3.864.000 kr.	Type Shell and tube, Size 40 m2, PN16 material SMO 254
4	LRVP water pump	2.208.000 kr.	Pressure head 10,3 m 0,20 kg/s material 1.4404
5	LRVP separator	6.348.000 kr.	Diameter 1 m Height 3 m. PN16 material 1.4404
6	Compressor	35.880.000 kr.	Type liquid ring compressor material 1.4404
7	Bottoms pump	14.214.000 kr.	Pressure head 18,5 m 40,8 kg/s material 1.4404
8	Boilup separator	13.800.000 kr.	Diameter 2 m Height 6 m PN16 material SMO 254
9	Ground water pump	3.588.000 kr.	Pressure head 86 m 40 kg/s material 1.4404
10	Heat exchanger	5.000.000 kr.	Plate size 200 m2 PN16 material 1.4404
11	Re-injection pipeline 1000 m	15.000.000 kr.	PE ø315 SDR17,6
12	Pipeline in re-injection well	26.000.000 kr.	DN150 pipe 750 m material 1.4404
	Total Equipment Cost	**188.830.000 kr.**	
	Total Installed Cost (TIC)	**928.962.361 kr.**	
	Contingency 20% of TIC	**185.792.472 kr.**	
	Capital Expenditure	**1.114.755.000 kr.**	**Designing cost included. Rounded up to nearest 1000**

Table 47 Capital expenditure (CAPEX) cost for PSA, after WS H_2S at Þeistareykir

Þeistareykir			
Capital expenditure (CAPEX) cost for PSA, after WS H_2S			
Item no	**Description**	**Equipment cost ISK**	**Design detail**
1	PSA system total	145.000.000 kr.	
	Total Equipment Cost	**145.000.000 kr.**	
	Total Installed Cost (TIC)	**290.000.000 kr.**	
	Engineering Cost 5% of TiC	**14.500.000 kr.**	No designing only construction supervision and service
	Contingency 20% of TIC	**58.000.000 kr.**	
	Capital Expenditure	**362.500.000 kr.**	**Rounded up to nearest 1000**

Table 48 Capital expenditure (CAPEX) for Amine H_2S at Þeistareykir

Þeistareykir			
Capital expenditure (CAPEX) for Amine H_2S			
Item no	**Description**	**Equipment cost ISK**	**Design detail**
1	Absorption column (ABS column)	27.629.605 kr.	Diameter 0,6 m Height 11 m. PN6 material 1.4404
2	Deariator (Reg column)	40.904.534 kr.	Diameter 0,7 m Height 15 m. PN6 material 1.4404
3	Reboiler (shell/tube)	830.145 kr.	Type Shell and tube, Size 7m2, PN10 material 1.4404
4	Condenser (shell/tube)	652.257 kr.	Type Shell and tube, Size 5,5 m2, PN10 material 1.4404
5	Lean pump	2.000.000 kr.	Pressure head 17 m 5,2 kg/s material 1.4404
6	Rich pump	2.000.000 kr.	Pressure head 26 m 5 kg/s material 1.4404
7	Cooler (shell/tube)	2.253.250 kr.	Type Shell and tube, Size 19 m2, PN10 material 1.4404
8	L/R Hex (HTXR - shell/tube)	5.455.237 kr.	Type Shell and tube, Size 46 m2, PN10 material 1.4404
9	Gas Blower	18.150.000 kr.	Gas blower 1000 Nm3/h
10	Gas compressor	13.852.000 kr.	Gas compressor 500 Nm3/h @ 5 bar_a
11	Re-injection pipeline 1000 m	15.000.000 kr.	PE ø315 SDR17,6
12	Pipeline in re-injection well	26.000.000 kr.	Same design as in Hellisheiði
	Total Equipment Cost	**154.727.027 kr.**	
	Total Installed Cost (TIC)	**443.309.663 kr.**	
	Engineering Cost 20% of TiC	**88.661.933 kr.**	
	Contingency 20% of TIC	**88.661.933 kr.**	
	Capital Expenditure	**620.634.000 kr.**	**Rounded up to nearest 1000**

Table 49 Capital expenditure (CAPEX) for Amine CO_2 after Amine H_2S at Þeistareykir

Þeistareykir			
Capital expenditure (CAPEX) for Amine CO_2, after Amine H_2S			
Item no	**Description**	**Equipment cost ISK**	**Design detail**
1	Absorption column (ABS column)	34.524.260 kr.	Diameter 0,6 m Height 16 m. PN6 material 1.4404
2	Deariator (Reg column)	41.124.576 kr.	Diameter 0,7 m Height 16 m. PN6 material 1.4404
3	Reboiler (shell/tube)	1.185.921 kr.	Type Shell and tube, Size 10,2 m2, PN10 material 1.4404
4	Condenser (shell/tube)	217.419 kr.	Type Shell and tube, Size 1,8 m2, PN10 material 1.4404
5	Lean pump	1.000.000 kr.	Pressure head 17 m 4,9 kg/s material 1.4404
6	Rich pump	1.000.000 kr.	Pressure head 26 m 4,7 kg/s material 1.4404
7	Cooler (shell/tube)	4.269.316 kr.	Type Shell and tube, Size 36 m2, PN10 material 1.4404
8	L/R Hex (HTXR - shell/tube)	3.984.695 kr.	Type Shell and tube, Size 34 m2, PN10 material 1.4404
9	Gas Blower	36.300.000 kr.	Gas blower 1000 Nm3/h
	Total Equipment Cost	**123.606.186 kr.**	
	Total Installed Cost (TIC)	**435.146.069 kr.**	
	Engineering Cost 20% of TiC	**87.029.214 kr.**	
	Contingency 20% of TIC	**87.029.214 kr.**	
	Capital Expenditure	**609.204.000 kr.**	**Rounded up to nearest 1000**

Table 50 Capital expenditure (CAPEX) for PSA, after Amine H_2S at Þeistareykir

Þeistareykir			
Capital expenditure (CAPEX) for PSA, after Amine H_2S			
Item no	**Description**	**Equipment cost ISK**	**Design detail**
1	PSA system total	145.000.000 kr.	
2	Compressor	60.000.000 kr.	
	Total Equipment Cost	**205.000.000 kr.**	
	Total Installed Cost (TIC)	**410.000.000 kr.**	
	Engineering Cost 5% of TiC	**20.500.000 kr.**	No designing only construction supervision and service
	Contingency 20% of TIC	**82.000.000 kr.**	
	Capital Expenditure	**512.500.000 kr.**	**Rounded up to nearest 1000**

Table 51 Capital expenditure (CAPEX) for Amine CO_2 removal, after WS H_2S at Þeistareykir

Þeistareykir			
Capital expenditure (CAPEX) for for Amine CO_2 removal, after WS H_2S			
Item no	**Description**	**Equipment cost ISK**	**Design detail**
1	Absorption column (ABS column)	34.524.260 kr.	Diameter 0,6 m Height 16 m. PN6 material 1.4404
2	Deariator (Reg column)	41.124.576 kr.	Diameter 0,7 m Height 16 m. PN6 material 1.4404
3	Reboiler (shell/tube)	1.185.921 kr.	Type Shell and tube, Size 10,2 m2, PN10 material 1.4404
4	Condenser (shell/tube)	217.419 kr.	Type Shell and tube, Size 1,8 m2, PN10 material 1.4404
5	Lean pump	1.000.000 kr.	Pressure head 17 m 4,9 kg/s material 1.4404
6	Rich pump	1.000.000 kr.	Pressure head 26 m 4,7 kg/s material 1.4404
7	Cooler (shell/tube)	4.269.316 kr.	Type Shell and tube, Size 36 m2, PN10 material 1.4404
8	L/R Hex (HTXR - shell/tube)	3.984.695 kr.	Type Shell and tube, Size 34 m2, PN10 material 1.4404
	Total Equipment Cost	**87.306.186 kr.**	
	Total Installed Cost (TIC)	**344.396.069 kr.**	
	Engineering Cost 20% of TiC	**68.879.214 kr.**	
	Contingency 20% of TIC	**68.879.214 kr.**	
	Capital Expenditure	**482.154.000 kr.**	**Rounded up to nearest 1000**

Table 52 Capital expenditure (CAPEX) for OX, after amine CO_2 or PSA at Þeistareykir

Þeistareykir			
Capital expenditure (CAPEX) for OX + WS SO_2, after amine CO_2 or PSA			
item no	**Description**	**Equipment cost ISK**	**Design detail**
1	Catalytic oxidation system	101.500.000	
2	Gas blower	36.300.000	
3	Column	30.435.138	
4	booster pump	4.000.000	
	Total Equipment Cost	**172.235.138**	
	Total Installed Cost (TIC)	**344.470.277**	
	Engineering Cost 5% of TiC	**17.223.514**	No designing only construction supervision and service
	Contingency 20% of TIC	**68.894.055**	
	Capital Expenditure	**430.588.000**	**Rounded up to nearest 1000**

Appendix D

Table 53 Gas composition and mass flow for WS H_2S at Krafla

Krafla				
WS H_2S				
Gas flow	**kg/s**	**ton/year**	**Vol %**	**wt%**
Water	0,002	78	0,82%	0,39%
CO_2	0,583	18.401	79,05%	91,60%
H2S	2,130E-04	7	0,04%	0,03%
H_2	0,004	112	10,46%	0,56%
N_2	0,029	926	6,25%	4,61%
O_2	0,018	557	3,29%	2,77%
CH_4	2,395E-04	8	0,09%	0,04%
Ar	0,000	0	0,00%	0,00%
Total mass flow	0,637			
Concentration H_2S	373	ppm		
CO_2 production	**18.401**	**ton/year**		

Table 54 Gas composition and mass flow for PSA, after WS H_2S at Krafla

Krafla				
PSA, after WS H_2S				
Gas flow	**kg/s**	**ton/year**	**Vol %**	**wt%**
Water	0,003	88	1,66%	0,69%
CO_2	0,350	11.040	95,38%	97,30%
H2S	2,199E-04	7	0,08%	0,06%
N_2	0,005	158	2,14%	1,39%
O_2	0,002	63	0,75%	0,56%
Total mass flow	0,360			
Concentration H_2S	773,452	ppm		
CO_2 production	**11.040**	**ton/year**		

Table 55 Gas composition and mass flow for Amine H_2S at Krafla

Krafla				
Amine H_2S				
Gas flow	**kg/s**	**ton/year**	**Vol %**	**wt%**
Water	0,028	879	7,92%	3,83%
CO_2	0,632	19.939	73,51%	86,78%
H2S	4,290E-05	1	0,01%	0,01%
H_2	0,003	86	6,95%	0,38%
N_2	0,049	1551	8,98%	6,75%
O_2	0,016	518	2,63%	2,26%
CH_4	0,000	0	0,00%	0,00%
Ar	0,000	0	0,00%	0,00%
Total mass flow	0,729			
Concentration H_2S	64	ppm		
CO_2 production	**19.939**	**ton/year**		

Table 56 Gas composition and mass flow for Amine CO_2 after Amine H_2S at Krafla

Krafla				
Amine CO_2, after Amine H_2S				
Gas flow	**kg/s**	**ton/year**	**Vol %**	**wt%**
Water	0,018	568	6,53%	2,78%
CO_2	0,630	19859	93,46%	97,21%
H2S	4,323E-05	1	0,01%	0,01%
H_2	1,243E-06	0	0,00%	0,00%
N_2	1,472E-05	0	0,00%	0,00%
O_2	0,000	0	0,00%	0,00%
CH_4	0,000	0	0,00%	0,00%
Ar		0	0,00%	0,00%
Total mass flow	0,648			
ConcentrationH_2S	83	ppm		
CO_2 production	**19.859**	**ton/year**		

Table 57 Gas composition and mass flow for PSA after Amine H_2S at Krafla

Krafla				
PSA, after Amine H_2S				
Gas flow	**kg/s**	**ton/year**	**Vol %**	**wt%**
Water	0,004	118	2,02%	0,84%
CO_2	0,433	13.667	95,58%	97,56%
H2S	0,000	2	0,02%	0,02%
N_2	0,005	152	1,70%	1,09%
O_2	0,002	70	0,68%	0,50%
Total mass flow	0,444			
ConcentrationH_2S	217	ppm		
CO_2 production	**13.667**	**ton/year**		

Table 58 Gas composition and mass flow for Amine CO_2 after WS H_2S at Krafla

Krafla				
Amine CO_2, after WS H_2S				
Gas flow	**kg/s**	**ton/year**	**Vol %**	**wt%**
Water	0,002	78	1,04%	0,43%
CO_2	0,578	18.217	98,73%	99,49%
H2S	2,130E-04	7	0,05%	0,04%
H_2	1,768E-05	1	0,07%	0,00%
N_2	0,000	0	0,00%	0,00%
O_2	0,000	0	0,00%	0,00%
CH_4	0,000	8	0,11%	0,04%
Ar	0,000	0	0,00%	0,00%
Total mass flow	0,581			
ConcentrationH_2S	470	ppm		
CO_2 production	**18.217**	**ton/year**		

Table 59 Gas composition and mass flow for OX + WS SO_2 after PSA at Krafla

Krafla				
OX + WS SO_2, after PSA				
Gas flow	**kg/s**	**ton/year**	**Vol %**	**wt%**
Water	0,003	107	2,34%	0,98%
CO_2	0,335	10.550	94,66%	96,99%
SO_2	9,615E-07	0	2 ppm	3 ppm
N_2	0,005	158	2,20%	1,45%
O_2	0,002	63	0,78%	0,58%
Total mass flow	0,345			
Concentration SO_2	2	ppm		
CO_2 production	**10.550**	**ton/year**		

Table 60 Gas composition and mass flow for WS H_2S low at Krafla

Krafla				
WS H_2S low				
Gas flow	**kg/s**	**ton/year**	**Vol %**	**wt%**
Water	0,001	21	0,82%	0,39%
CO_2	0,159	5.000	79,05%	91,60%
H2S	0,000	2	0,04%	0,03%
H_2	0,001	30	10,46%	0,56%
N_2	0,008	252	6,25%	4,61%
O_2	0,005	151	3,29%	2,77%
CH_4	0,000	2	0,09%	0,04%
Ar	0,000	0	0,00%	0,00%
Total mass flow	0,173			
Concentration H_2S	373	ppm		
CO_2 production	**5.000**	**ton/year**		

Table 61 Gas composition and mass flow for Amine H2S low at Krafla

Krafla				
Amine H_2S low				
Gas flow	**kg/s**	**ton/year**	**Vol %**	**wt%**
Water	0,007	221	7,92%	3,83%
CO_2	0,159	5.000	73,51%	86,78%
H2S	0,000	0	0,01%	0,01%
H_2	0,001	22	6,95%	0,38%
N_2	0,012	389	8,98%	6,75%
O_2	0,004	130	2,63%	2,26%
CH_4	0,000	0	0,00%	0,00%
Ar	0,000	0	0,00%	0,00%
Total mass flow	0,183			
Concentration H_2S	64	ppm		
CO_2 production	**5.000**	**ton/year**		

Table 62 Gas composition and mass flow for WS H_2S at Þeistareykir

Þeistareykir				
WS H_2S				
Gas flow	**kg/s**	**ton/year**	**Vol %**	**mass%**
Water	0,001	18	0,41%	0,28%
CO_2	0,175	5.517	52,55%	88,48%
H2S	3,687E-05	1	0,01%	0,02%
H_2	0,006	189	39,33%	3,03%
N_2	0,016	505	7,55%	8,09%
O_2	0,000	0	0,00%	0,00%
CH_4	0,000	6	0,15%	0,09%
Total mass flow	0,198			
Concentration H_2S	143	ppm		
CO_2 production	**5.517**	**ton/year**		

Table 63 Gas composition and mass flow for PSA, after WS H_2S at Þeistareykir

Þeistareykir				
PSA, after WS H_2S				
Gas flow	**kg/s**	**ton/year**	**Vol %**	**mass%**
Water	4,320E-04	14	0,01%	0,27%
CO_2	0,153	3.243	94,46%	96,54%
H2S	6,691E-05	1	0,05%	0,04%
N_2	0,005	57	4,84%	3,15%
Total mass flow	0,159			
Concentration H_2S	533	ppm		
CO_2 production	**3.243**	**ton/year**		

Table 64 Gas composition and mass flow for Amine H_2S at Þeistareykir

Þeistareykir				
Amine H_2S				
Gas flow	**kg/s**	**ton/year**	**Vol %**	**wt%**
Water	0,011	354	7,41%	5,13%
CO_2	0,185	5.849	50,17%	84,70%
H2S	2,213E-05	1	0,01%	0,01%
H_2	0,006	189	35,43%	2,74%
N_2	0,016	505	6,81%	7,32%
O_2	0,000	0	0,00%	0,00%
CH_4	2,227E-04	7	0,16%	0,10%
Ar	0,000	0	0,00%	0,00%
Total mass flow	0,219			
Concentration H_2S	77	ppm		
CO_2 production	5.849	**ton/year**		

Table 65 Gas composition and mass flow for Amine CO_2, after Amine H_2S at Þeistareykir

Þeistareykir				
Amine CO_2, after Amine H_2S				
Gas flow	**kg/s**	**ton/year**	**Vol %**	**wt%**
Water	0,005	163	6,45%	2,75%
CO_2	0,183	5774	93,51%	97,24%
H2S	2,213E-05	1	0,01%	0,01%
H_2	1,571E-06	0	0,02%	0,00%
N_2	2,722E-06	0	0,00%	0,00%
O_2	0,000	0	0,00%	0,00%
CH_4	1,575E-07	0	0,00%	0,00%
Ar	0,000	0	0,00%	0,00%
Total mass flow	0,18828			
ConcentrationH_2S	146	ppm		
CO_2 production	**5.774**	**ton/year**		

Table 66 Gas composition and mass flow for PSA, after Amine H_2S at Þeistareykir

Þeistareykir				
PSA, after Amine H_2S				
Gas flow	**kg/s**	**ton/year**	**Vol %**	**wt%**
Water	0,001	29	1,91%	0,81%
CO_2	0,111	3.500	95,00%	98,76%
H2S	2,680E-05	1	0,02%	0,02%
N_2	0,000	6	2,41%	0,16%
CH_4	2,720E-04	9	0,64%	0,24%
Total mass flow	0,112			
ConcentrationH_2S	158	ppm		
CO_2 production	**3.500**	**ton/year**		

Table 67 Gas composition and mass flow for Amine CO_2, after WS H_2S at Þeistareykir

Þeistareykir				
Amine CO_2, after WS H_2S				
Gas flow	kg/s	ton/year	Vol %	mass%
Water	0,001	18	0,70%	0,31%
CO_2	0,166	5242	85,04%	90,78%
H2S	0,000	1	0,02%	0,02%
H_2	0,000	3	1,11%	0,05%
N_2	0,016	505	12,86%	8,74%
O_2	0,000	0	0,00%	0,00%
CH_4	0,000	6	0,25%	0,10%
Total mass flow	0,183			
Concentration H_2S	244	ppm		
CO_2 production	**5242**	**ton/year**		

Table 68 Gas composition and mass flow for OX + WS SO_2, after PSA at Þeistareykir

Þeistareykir				
OX + WS SO_2, after PSA				
Water	0,002	30	2,339%	0,991%
CO_2	0,145	2.996	92,66%	95,720%
SO_2	1,300E-09	0	6 ppb	9 ppb
N_2	4,990E-03	57	5,00%	3,290%
Total mass flow	0,152			
Concentration SO_2	6	ppb		
CO_2 production	**2.996**	**ton/year**		

Table 69 Gas composition and mass flow for OX + WS SO_2, after Amine CO_2 at Þeistareykir

Þeistareykir				
OX + WS SO_2, after amine CO_2				
Gas flow	kg/s	ton/year	Vol %	mass%
Water	0,002	57	2,41%	1,02%
CO_2	0,159	5026	83,70%	89,81%
SO_2	7,299E-08	0	0,00%	0,00%
N_2	0,016	509	13,61%	9,10%
O_2	0,000	0	0,00%	0,00%
CH_4	1,792E-04	6	0,26%	0,10%
Total mass flow	0,177			
Concentration H_2S	262	ppb		
CO_2 production	**5026**	**ton/year**		

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Landsvirkjun

Háaleitisbraut 68
103 Reykjavík
landsvirkjun.is
landsvirkjun@lv.is
Sími: 515 90 00