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THE HELLISHEIDI GEOTHERMAL PROJECT – FINANCIAL ASPECTS OF GEOTHERMAL DEVELOPMENT

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ABSTRACT

The Hellisheidi power plant is the newest geothermal power plant in Iceland. The power plant is combined heat and power and was built in stages. Production from the first two 45MW$_e$ turbines started 2006. A low pressure 33 MW$_e$ unit was added 2007 and two additional 45 MW$_e$ turbines 2008. The first stage of the heating plant was taken into operation 2010. Last two 45 MW$_e$ turbines were put on line late 2011. The installed power is therefore 303 MW$_e$ and 133 MW$_{th}$. The power plant is described and some cost figures given but due to the collapse of the Icelandic economy in 2008 the values have to be taken with care. The financial result is then used to make a financial model for a new power plant which is now under consideration.

1. INTRODUCTION

Today a total of 2669 MW electrical are installed in Iceland of that 665 MW comes from geothermal or about 25%. The use of geothermal energy to generate electricity has increased significantly over the last years in Iceland. Over 63% of the electricity generated by geothermal energy comes from the power plants at Nesjavellir and Hellisheidi in the Hengill geothermal system. Figure 1 shows the development in geothermal power plants in Iceland from 1969-2011. The picture also shows power plants which are on the planning stage for next years and decades.

2. THE HENGILL GEOTHERMAL SYSTEM

The Hengill geothermal system lies in the middle of the western volcanic zone in Iceland, on the plate boundary between North America and the European crustal plates.

Resistivity measurements, heat distribution and subsurface measurements indicate an area of around 110 km^2 for the Hengill system. It is one of the most extensive geothermal areas in the country. The bedrock in the Hengill area consists mostly of palagonite formed by volcanic eruptions below glaciers during the last ice ages (Franzson et al., 2010). Geothermal activity is associated with three volcanic systems of different age within the complex (Figure 2). Several potential geothermal fields can be distinguished within the Hengill complex. It has been estimated that the Hengill geothermal system can sustain about 700 MW$_e$ power production at several power plants (Icelandic Ministry of Industry, Energy and Tourism, 1994; Ketilsson et al., 2009). So far only Nesjavellir (Gunnarsson et al., 1992, Ballzus et al., 2000a, b) and Hellisheidi (Gunnlaugsson et al., 2010, Geirsson and Hrólfsson, 2010) have been developed.

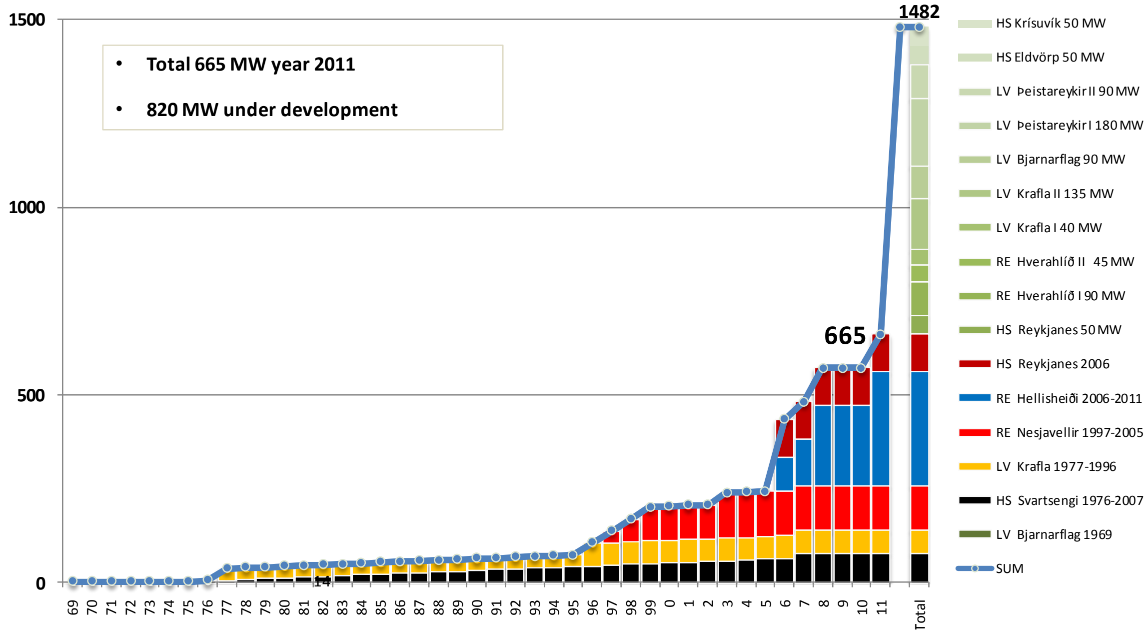

FIGURE 1: Geothermal power plants in Iceland 1969-2011. On the right hand side are also shown power plants on the planning stage.

3. THE HELLISHEIDI POWER PLANT

The Hellisheidi power plant is located on the southern side of the Hengill Mountain about 20 km from the capital. The plant is a cogeneration plant of heat and power and is built up in modular units. Figure 3 shows the main dates for the development at the Hellisheidi power plant. Research drilling started in 2001 by drilling 2 wells. In 2002 the board of the company decided to continue with the preparation for a power plant by obtaining all relevant permits for the project. Environmental impact assessment was carried out in two steps. First for a 120 MW_e power production and a 400 MW_{th} thermal production. That was finalized in 2003. By extending the field towards the Hengill Mountain the size of the development area had almost doubled. Then the second stage of environmental impact assessment was undertaken. This part was finalized in late 2005. The construction started in early 2005. The installed power at the Hellisheidi power plant is now 303 MW_e and 133 MW_{th}. The thermal plant can be extended to 400 MW.

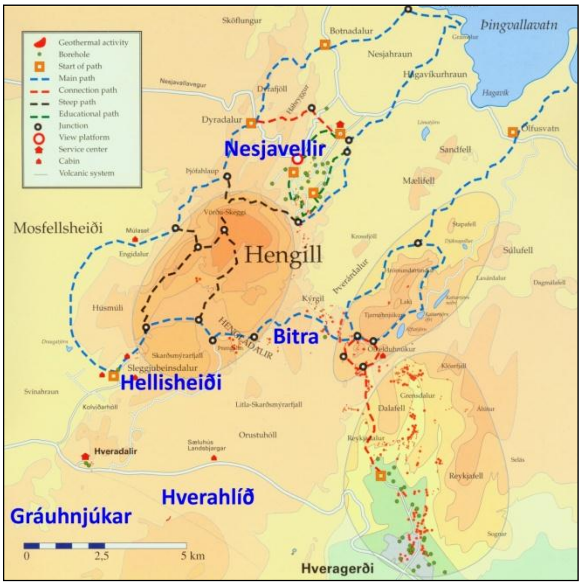

FIGURE 2: Volcanic systems of the Hengill complex. The map shows the Nesjavellir and Hellisheidi power plants as well as three other locations for possible new power plants

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Beginning of research drilling	X										
Prepare powerplant - permits		X									
Environmental Impact Assessment			X		X						
Beginning of construction					X						
1st phase 90 MW_e						X					
2nd phase low pressure unit 33 MW_e							X				
3rd phase 90 MW_e								X			
4th phase thermal plant 133 MW_{th}										X	
5th phase 90 MW_e											X

FIGURE 3: The main dates for the development at the Hellisheidi power plant

The total development area of Hellisheidi power plant is 820 ha. The development consists of geothermal utilisation, access roads, service roads, production wells, water supply system, steam transmission pipes, steam separator stations, power houses, cooling towers, steam exhaust stacks, a fresh groundwater supply system, water tanks, hot-water transmission pipe, quarrying, discharge system, injection areas and connection to the power grid. A simplified flow diagram of the Hellisheidi power plant is shown on Figure 4. This flow diagram is interactive on the OR-web site (http://www.or.is/flash/framl/index.html). The following chapters will briefly describe the main sectors of the power plant.

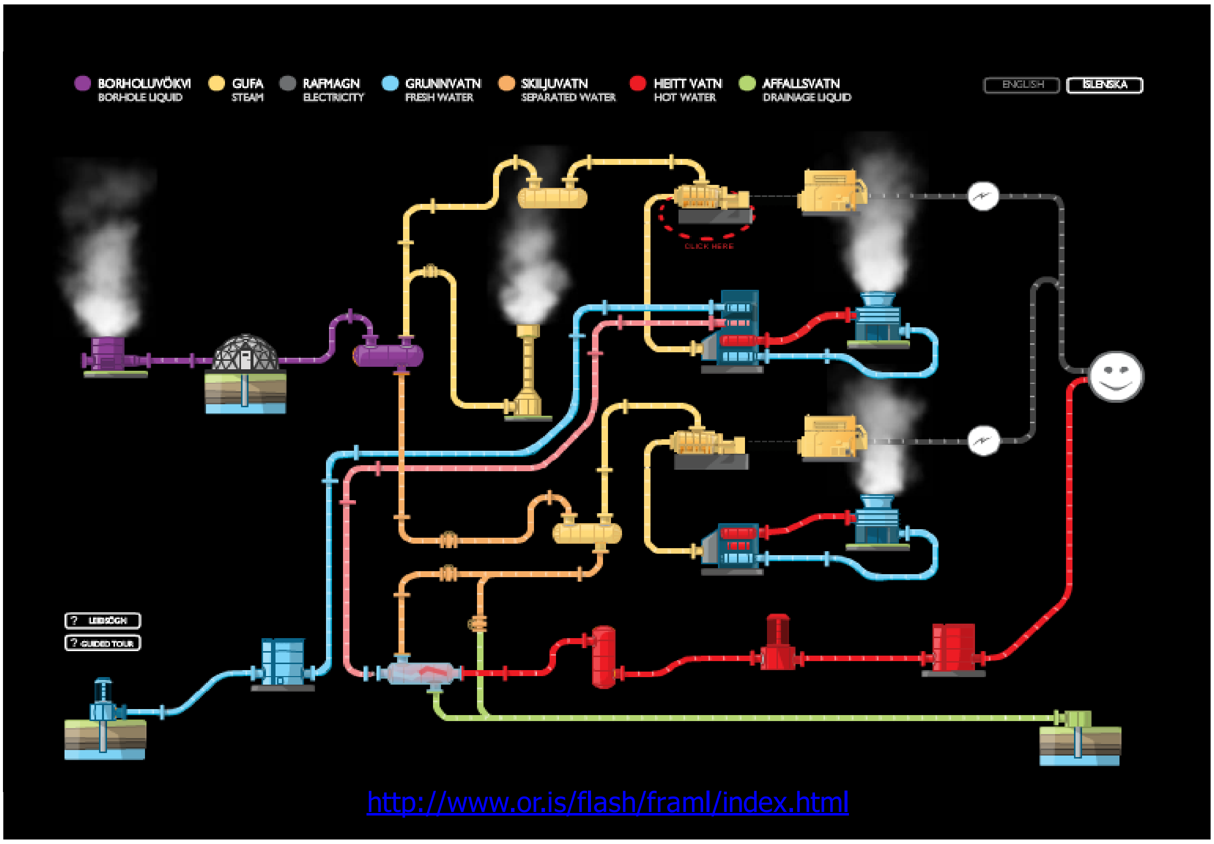

FIGURE 4: Simplified flow diagram of the Hellisheidi power plant

3.1 Production drillholes

TABLE 1: Production wells

Total number of production wellls	47	
Vertical wells	8	
Directional wells	39	
Number of platforms	14	
Wells connected to the power plant	21	
Average output of a well	7.5	MW_e
Average enthalpy	1750	kJ/kg

Production wells are drilled both vertical and directional (Table 1). Up to five wells can be sited from each platform. Directional drilling makes it is possible to reach under environmentally sensitive areas and under valleys and mountains. Drillholes can be up to 3.000-4000 m deep and with directional drilling it is possible to reach up to 1.200 m from the vertical. On average four drillholes are on a platform and the size of the platform is about 1200 m^2. To site a drillhole geological and geophysical information are used as well as information from previously drilled holes. An effort is made to minimize the environmental effects taking into account the landscape and visualization of drillholes. The minimum distance between production wells on a platform is around 10 m. Well head silencers and borehole housings are installed at each well.

3.2 Steam gathering system and separation stations

From the drillholes a mixture of steam and water is piped to separation stations where water and steam are separated. The steam gathering system is about 15 km long. This is a steel pipe insulated with rock wool and covered with aluminium sheets. There are three separation stations with 21 water-steam separators. From the separation stations steam and separated water is transported in separate pipelines to the power station, where electricity is generated and fresh groundwater heated in heat exchangers. Before the steam enters the turbines it flows through mist eliminators in front of the power station to drain of the last remaining of droplets from the steam.

3.3 Power stations

TABLE 2: Power stations

Item	**Producer**	
Number of power stations		2
High pressure turbines	Mitsubishi	6 x 45 MW_e
Low pressure turbine	Toshiba	1 x 33 MW_e
Number of condensers	Balcke Dürr	7
Number of cooling towers		7
Control system	Siemens	

At the Hellisheidi power plant there are two power stations. Buildings are re-enforced concrete or steel frame constructions. Principal information is given in Table 2. Power station 1 is the main building. It contains four high pressure turbines, the low pressure turbine, the heating plant and a visitor centre. The two latest turbines are located in power station 2 (Sleggjan) due to lack of space in the main power station. The visitor centre is open to the public every day. There tourists can learn about geology and geothermal energy and how this green energy is used for different applications in Iceland and elsewhere. The number of visitors has reached over 100 thousand a year.

3.4 Cold water supply and heating plant

The cold water supply is mainly for the thermal plant. There cold water is heated in heat exchangers the water boiled at low pressure before it is pumped to Reykjavík to be used to heat up buildings. The cold water supply consists of ground water drillholes, pumping station, a pipeline to the power station and a cold water storage tank. The basic information regarding the cold water is given in Table 3.

The heating plant consists of two lines of tube heat exchangers each line with two heat exchangers. Two deareators are used to remove dissolved oxygen from the heated water to prevent corrosion. After removing dissolved oxygen minor content of steam is mixed with the water to adjust pH and add some hydrogen sulphide (H_2S) to the water. The H_2S reacts with the dissolved oxygen which may enter the water on the way to consumers. The water is then free of dissolved oxygen and not corrosive when it flows through radiators in houses.

3.5 Disposal of separated water – re-injection

After energy has been extracted from the separated water it is re-injected into the reservoir. Two sites for re-injection are in use, 3.5 km and 1 km distance respectively, from the power station. The main information regarding re-injection is shown in Table 4.

3.6 Distribution of electricity and hot water

An underground cable connects the power plant to a transformer station. From there the electricity is distributed along the national grid. A special distribution company distributes all electricity in Iceland. On the other hand the hot water transmission is by the producer. The main information regarding the hot water pipeline to Reykjavík is given in Table 5.

TABLE 3: Cold water supply

Number of drillholes	6	
Depth of drillholes	250-300	m
Pumping capacity	960	l/s
Size of pumping station	412	m^2
Length of cold water pipeline	5.5	km
Diameter of pipeline	DIN 900	mm
Total capacity of pipeline	2200	l/s

TABLE 4: Re-injection

Total number of re-injection wells	17
Vertical wells	2
Directional wells	15
Average length	1968 m
Average depth	1753 m

TABLE 5: Hot water pipeline

Length of pipeline to Reykjavík	19.5	km
Diameter DN 1000/Ø1200	14.5	km
Diameter DN 900/Ø1100	5.0	km
Capacity of pipeline	1450	l/s
Temperature of water	80-105	°C

4. FINANCIAL PARAMETERS

There are many factors influencing the cost of a geothermal power plant. In general, geothermal plants are affected by the cost of steel, other metals and labour. The cost of steel and metals for power production are mostly international but the cost of labour may be variable. Cost of drilling may vary as well as the cost depends on material and labour cost. Geothermal projects are always site specific. The cost is therefore dependant on the size of the plant and the technology used. The knowledge of the reservoir such as temperature, chemistry, depth and permeability also affects the cost. Environmental policies and taxes have to be taken into account. The financial options, the cost of financing as well as the market influence the cost of a power plant.

In the following an attempt is made to summarize the cost of the Hellisheidi power plant. It have to be kept in mind that during the construction time the Icelandic economy collapsed and that may have some influence on the outcome.

The total cost has been estimated to be in the range of 800 to 810 Million US$. In Table 6 the construction cost has been divided after development stages. Table 7 shows the cost distribution after categories.

The drilling cost is affected by the number of drillholes which have to be drilled and their average output. The cost of drilling includes all cost related to the drillhole. It includes the preparation of the platform, water supply, moving of the rig as well as master valve silencer, connections and shelter for the well head.

The price of drilling is based on tender where each activity is listed with a price list. The total cost of a drillhole is 2.8 to 3.5 Million US$ depending on depth, diameter and method used for drilling.

The Hellisheidi power plant is a CHP plant and the cost of drillholes and the steam supply system have to be divided between the electrical power plant and the thermal power plant in order to calculate the price of hot water and electricity. Other general cost is divided equally between the electrical power plant and the thermal power plant. The operational cost is estimated to be about 2.75% of the investment cost. The largest operational cost is drilling of make-up wells during the live time of the power plant.

TABLE 6: Construction cost after stages

Stage	**% of cost**
1. Stage (2 x 45 MW_e)	23.8
2. Stage (1 x 33 MW_e low pressure unit)	4.9
3. Stage (2 x 45 MW_e)	23.8
4. Stage (thermal plant)	11.2
5. Stage (2 x 45 MW_e)	27.5
Exhibition area	0.6
Investment cost (Banking cost)	8.1

In the calculations the investment has to sustain a weighted average cost of capital (WACC) of 6.3% before tax. The investment payback time is 18 years and the power plant is discounted in 36 years.

The Hellisheidi power plant is located about 20 km from the city of Reykjavík. Smell of hydrogen sulphide can be found in Reykjavík in cold calm winter days. Although Icelandic people are used to the geothermal smell people have been complaining and in 2010 a strong regulation regarding H_2S concentration was adopted. According to this H_2S have to be cleaned from the exhaust of the power plant to some extent. This cost is not included in the cost of the power plant listed above. It has been estimated that the cost of cleaning H_2S from the emission would be near 12.2 million US$ per 90 MW_e production. This will increase the cost of the power plant considerably.

5. NEW POWER PLANT AT HVERAHLÍD

TABLE 7: Construction cost after categories

Category	**% of cost**
General	6.7
Drilling and steam supply system	36.7
Electrical power plant	36.7
Thermal power plant	11.2
Exhibition area	0.6
Investment cost (Banking cost)	8.1

To meet increasing demand for electricity, especially in the industrial sector, Orkuveita Reykjavíkur has started researching and planning for a new power plant in the Hengill area. The location is some 3-5 km SE of the Hellisheidi power plant. Five research drill holes have been drilled. From the size of the area it was estimated to sustain 90 MW_e power production. Further study and drilling is however needed to determine the size of the field. Geothermal power plants are subject to Environmental Impact Assessment (EIA) according to Icelandic lows. Preliminary EIA proposal for the Hverahlíd project was presented in August 2007. The EIA was published in March 2008 and finally accepted in May 2008.

Due to the importance of environmental issues the company has put a great emphasis on finding ways to reduce the environmental impact of new power plants and has issued an environmental policy regarding its future geothermal power plant projects. The aim is to customize each project to its surroundings so that its impact on the environment will be minimized. It has been estimated that environmental issues will increase the cost by 11%.

Important figures for the Hverahlíd power plant are listed in Table 8.

TABLE 8: Key figures for Hverahlíd power plant

Power	90	MW_e
Steam use	~180	kg/s
Project area	400	ha
Road and tracks		
Main road	4-4.5	km
Work tracks	11-12	km
Drilling		
Number of drilling sites	12	
Size of drilling sites	12	ha
Number of drillholes	18	
Number of maintenance holes	7-15	
Depth	2000-4000	m
Steam gathering system		
Pipe lines	11-13	km
Number of separation stations	2	
Base level of each separation station	600-700	m^2
Power station		
Base level	5000	m^2
Height	15	m
Cooling towers (hybrid towers)		
Number	2	
Base level of each cooling tower	900	m^2
Height	20	m
Disposal of waste water		
Injection pipe line	3-4	km
Number of re-injection wells	9	
Depth of re-injection wells	1000-2000	m

The financial model for Hverahlíd is based on data and experience from the Hellisheidi power plant. The Hverahlíd power plant will only be generating electricity but not hot water for district heating. Figure 5 shows the estimated construction cost of 90 MW power plant at Hverahlíd. The colours of the bars on the picture indicate how accurate the values are. It especially shows that the cost of drilling is not very well known but the drilling cost depends on how many well have to be drilled to ensure the steam needed for 90 MW_e production. Estimated cost of a borehole is near 3.5 million US$.

The investment cost is 2.65 to 3 million US$/$MW_e$ is used. The financial model is based on 33% equity, no subsidence or grants, depreciation time of 25 years, repayment of loans in 30 years and repayment of equity in 50 years. The calculated tariff of 40 mills or 4 US cents/kWh is needed. The main results are shown in Table 9.

The total construction cost in Iceland based on values from 2011 is 2.7 to 3.1 US$/W or < 50 US$/MWh. This is 77-78% of international average cost (Maack and Ingason, 2011).

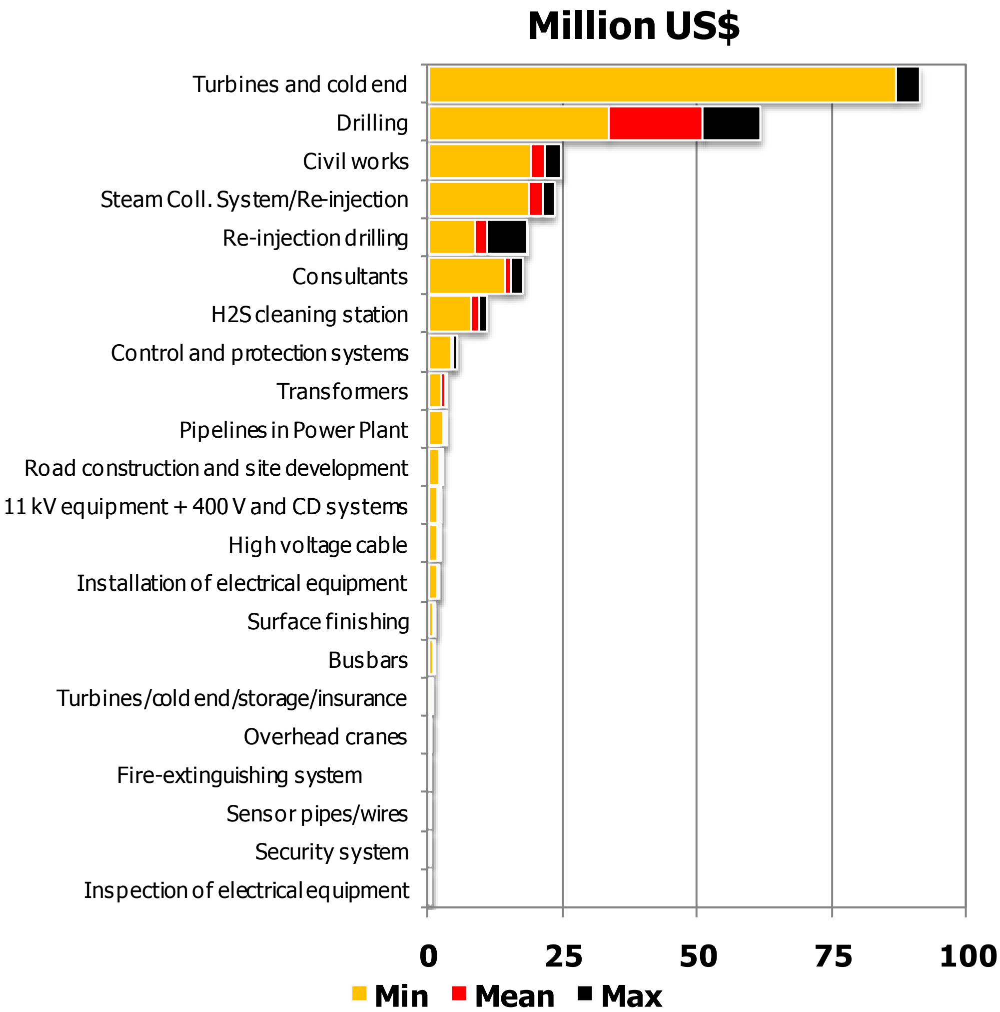

FIGURE 5: First estimated cost for 90 MW_e power plant at Hverahlíd

TABLE 9: Financial model for Hverahlíd power plant

Power	90	MW_e
Construction time	4-5	years
Construction cost	2.75	million US$ /MW_e
Operational cost per year as % of construction cost	2	%
Make up wekks per year as % of construction cost	0.4	%
Equity share	33	%
Required return of equity (ROE)	10-15	%
Interest rates on long term loans	5	%
Soft loans and / or grants	NO	
Ownership	Municipality	
Financing	Equity financing	
Total construction cost and funding cost	247.5 + 30.5 = 278	million US$
Total construction cost and funding cost	2.75 + 0.3 = 3.1	million US$/$MW_e$
Operational years in financial calculations	50	years
Levelized tariff from power plant	30-40	mills

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