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How to Make a New Geothermal Power Plant More Environmentally Friendly

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ABSTRACT

The Hengill area in SW-Iceland is one of the most extensive geothermal areas in the country. Orkuveita Reykjavíkur (OR) operates two power plants in the Hengill area, Nesjavellir and Hellisheiði, and is planning to build two new power plants in the same area; Hverahlíð and Bitra. OR's commitment to the environment has motivated a search for measures that will reduce the environmental impact of these new geothermal power plants. These measures include grouping boreholes on drilling sites, adjusting drilling sites to their surroundings, minimize the effect of the steam collection pipelines in the landscape, design the main power house in harmony with its surroundings, using hybrid cooling towers, reducing emission of geothermal gasses and reducing noise level from the power plant.

This paper describes the main ideas for minimizing the effect of a new geothermal power plant on its surroundings.

1. INTRODUCTION

The Hengill area in SW-Iceland is one of the most extensive geothermal areas in the country. It is located 25 km east of Reykjavík, Fig. 1. It is approximately 110 km² and it is estimated to sustain 700 MW_{el} power production through several power plants, Iðnaðarrráðuneytið (1994).

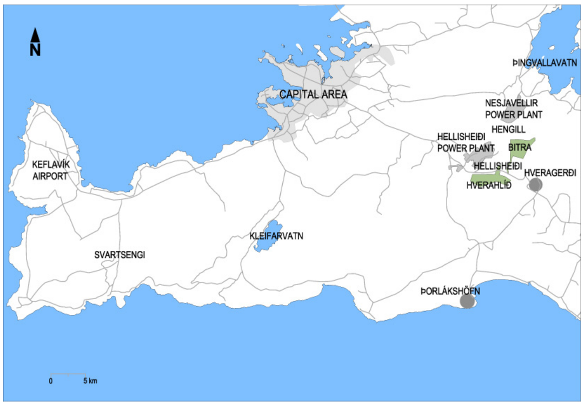

Figure 1: The locations of OR's power plants in the Hengill area.

Research drilling started in 1965 at Nesjavellir in north Hengill area, see Fig. 1. The Nesjavellir power plant was build in several stages. In 1990 hot water production for the district heating in Reykjavík started in the Nesjavellir power plant and power production started there in 1998. Today Nesjavellir power plant produces 120 MW_{el} and 300 MW_{th}.

OR is currently building a geothermal power plant at Hellisheiði, see Fig. 1. The Hellisheiði power plant is built in stages like was done at Nesjavellir. Today Hellisheiði power plant produces 213 MW_{el}. The completed power plant at Hellisheiði will produce at least 300 MW_{el} and 400 MWt_{h}.

To meet increasing demand for electricity, especially in the industrial sector, OR is planning two new geothermal power plants in the Hengill area, at Hverahlíð and Bitra, see Fig. 1. Due to the importance of environmental issues to OR, the company has put a great emphasis on finding ways to reduce the environmental impact of new power plants. In 2008 OR published Environmental Impact Assessment (EIA) for Hverahlíð and Bitra, VSÓ (2008a) and VSÓ (2008b). In those EIA's, OR published an environmental policy and design basis for future power plants.

2. ENVIRONMENTAL POLICY AND DESIGN BASIS

OR 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. To ensure this police a design basis is defined for each process factor, such as:

- drill sites
- steam collection
- roads
- buildings
- finishing of the landscape

In preparation for construction of a new power plant a great emphasis is put on minimizing the effect of the power plant on its surroundings and minimizing visibility from established viewpoints, such as nearby hiking routes, roads and popular tourist zones.

3. BOREHOLES AND DRILL SITES

Most of the boreholes at Hellisheiði power plant are drilled directional, see Fig 2. With directional drilling a boreholes can reach more than 1.000 m from the perpendicular. Therefore, the boreholes can be grouped together on a drill site. Grouping boreholes on to a drill site leads to a more economical steam supply system and it also minimizes the impact of drilling on the surroundings.

At Hellisheiði power plant there is a mean of 4 holes on each platform, but it is estimated that up to 8 boreholes can be grouped on each drill site. To minimize the impact of the drill sites on their surroundings they are situated in pre-defined areas. Directional drilling establishes freedom in placing the drill sites since it is not necessary to place the boreholes directly above the target.

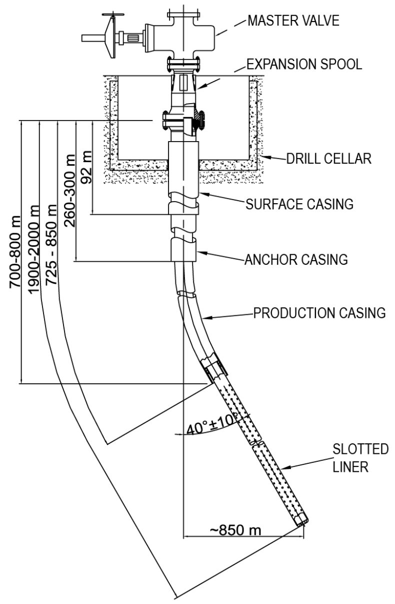

Figure 2: Example of a directional drilled borehole.

To minimize the area of a drill site, distance between boreholes on the site must be as short as possible. Accessibility to each borehole must be ensured and the drill rig must be able to work on the site. Other key elements in minimizing the distance between boreholes is the deflection of the vertical on the vertical part of the borehole. According to measurements of the deflection of the vertical at the depth of 300 m in boreholes in Iceland, the deflection has a mean of 2,5 m, with a maximum deflection of 7 m, Jónnson (2009). Fig. 3 shows a box plot for the deflection of the vertical for boreholes at 300 m depth.

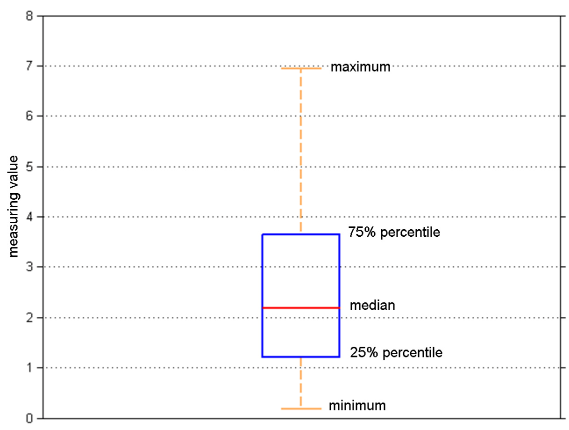

Figure 3: Box plot for deflection of the vertical for boreholes at 300 m depth.

If the direction of the deflection of the vertical on the vertical part of the boreholes is unknown, then it is possible to ensure with 95 % probability, based on gamma distribution, that two boreholes will not intersect if the distance between them at the top is 12 m or more, Jónsson (2009).

The lineup of the boreholes on a drill site is important to make a layout of the site. Therefore it is necessary to have an estimate for the direction of the boreholes. Fig. 4 shows three drill sites and the sector containing the estimated direction of the boreholes from each site is. With this information the lineup of the boreholes on the drill site can be done in advance.

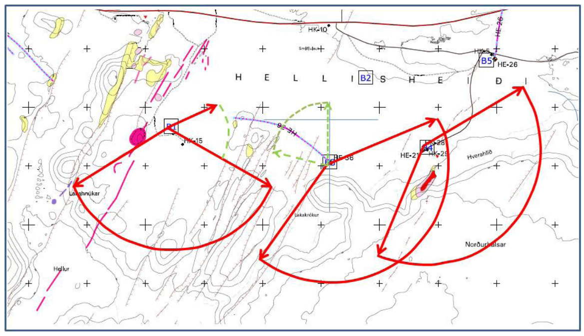

Figure 4: Estimated direction of boreholes from three drill sites at Hverahlíð.

By minimizing the distance between boreholes and aligning them according to their estimated direction the drill site can be adjusted to its surroundings, thereby minimizing its impact. Other design considerations that can minimize the impact of a drill site on its surroundings include placement of steam transmission pipes on the site in underground ducts, placement of the wellhead in a semi-hidden building and the use of one to two well head silencers on each drill site while the drill site is in operation instead of one for each borehole.

4. STEAM COLLECTION SYSTEM

Steam collection pipes, which connect drill sites to the separation stations and the power plant, impact their surroundings since. To prevent corrosion and because of thermal expansions in the pipes it's usually required that pipelines lay above ground. Three kinds of steam collection pipes that reduce aesthetic affects are defined:

- Hidden steam pipes, which are buried. The pipeline must be in a duct or in steel-in-steel pipe to ensure thermal expansions and prevent corrosion, see Fig. 5.

- Semi hidden steam pipes are normal steam pipes on the surface, but mounted earthen barriers are used to minimize the effect of the pipelines on the landscape, see Fig. 5.

- Normal steam pipes are on the surface. No surface work is done around the steam pipes, but their color and polish will be chosen according to the landscape, see Fig. 5.

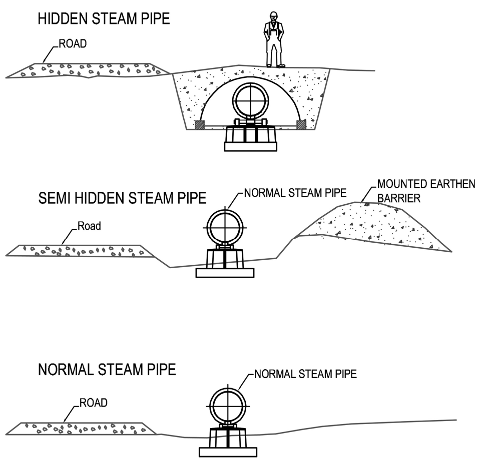

Figure 5: Types of steam pipes.

It is necessary to plan the route of the steam transmission pipelines as soon as possible and estimate which type of pipeline can be adapted most closely to the landscape. Sometimes it can cause more dislocation of the environment if an unnecessary barrier or trench is made.

5. CIVIL WORKS

When Hellisheiði power plant was in the planning stage it was decided that the power plant would be grand building which would serve as a tourist center as well as a power plant. The power plant has been built on those premises. Access roads must fulfill regulation from the Icelandic Road Administration regarding access since the public can visit the power plant, VGK (2003). Fig.. 6 shows Hellisheiði power plant.

Figure 6: Hellisheiði power plant. The tourist center is in the middle of the building.

Future power plants will be designed so that their effect on their environment is minimal. New power plants in the Hengill area will be operated as sub-stations from Hellisheiði power plant and no extra service will be on site. Therefore access road must be built up to standard while other service roads within the area can be kept as trails. The buildings will be designed in harmony with their surroundings and painted in colors that will meld with their environment. However it is important in the process that all safety regulations are fulfilled. To hide the buildings from pre-defined viewpoints a mounted earthen barrier will be built up around them. Fig. 7 shows a preliminary design of the power plant at Hverahlíð.

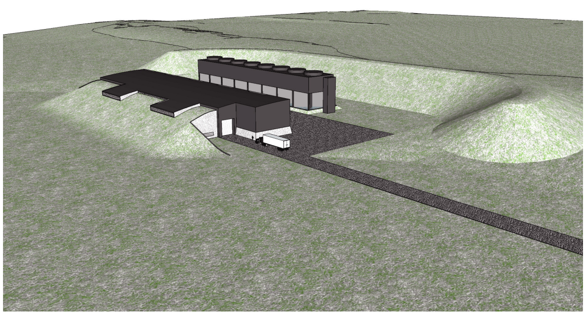

Figure 7: A computerized picture of a preliminary design of the power plant at Hverahlíð.

The power plant at Hverahlíð is located about 500 m south of the highway which crosses Hellisheiði. In the design basis for Hverahlíð it is stated that the power plant will be concealed from the highway as much as possible. Therefore the power plant is situated behind a low hill. To ensure that the power plant is kept out of sight from the highway mounted earthen barriers will be built up around the power plant. These actions ensure that the effect of the power plant on its surroundings will be slight.

6. EQUIPMENT

For OR's geothermal power plants, the piece of equipment that has the most considerable effect on the environment is the cooling tower due to its inherent plume of steam. To minimize the effect on the environment from the cooling tower the visibility of the plume must be minimized.

In addition to the aesthetic impact of the plume, the emission of geothermal gases from a power plant, especially hydrogen sulphide (H_2S) can have an effect on the environment. To reduce the emission of H_2S from its power plants OR is currently building an experimental H_2S cleaning station with the aim of separating H_2S from the gas an re-inject it into the ground.

6.1 Hybrid cooling towers

One of the characteristics of Hellisheiði power plant is the plume that the cooling towers emit. To minimize the effect of a power plant on its surroundings it is necessary to minimize the visibility of the plume. It is also a safety issue since the plume can have effect on traffic if a power plant is close to a highway. The visibility of the plume in a hybrid cooling tower can be controlled according to weather conditions and time of the day.

One way to minimize the plume is to use a hybrid cooling system, which combines open wet cooling and closed dry cooling components. Fig. 8 shows a simplified schematic drawing of a hybrid cooling tower.

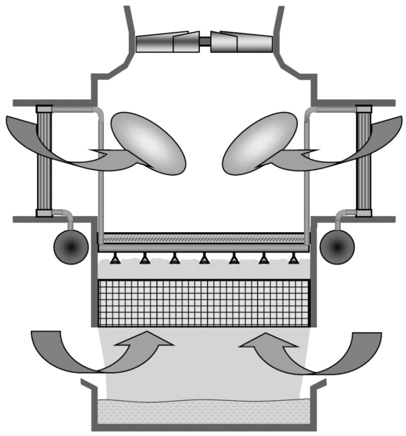

Figure 8: A schematic picture of a hybrid cooling tower.

The bottom unit is a traditional wet cooling tower. When the plume ascends it goes through an upper level. There, the plume is mixed with hotter air, which increases the saturation point of the gas. This allows the air to absorb more moisture and therefore reduce the plume. Plume visibility depends on the ambient air properties; temperature and relative humidity. The plume will be visible if the outside temperature falls below, or the humidity will rise above, a pre-defined constants: for example 5°C and above 80% humidity. However the plume will never be as prominent as when a traditional cooling tower is used.

6.2 H_2S cleaning station

Cleaning hydrogen sulphide (H_2S) was first examined at Nesjavellir power plant in 1989, VBL (1989). Since then no decision regarding the matter were made until 2008 when EIA for power plant at Hverahlíð and Bitra was in progress. The EIA cited environmental reasons for stating that the power plant could not be built without a successful H_2S abatement system.

There are known cleaning processes of H_2S and they can be categorized as biological, chemical and physical, Galeski (1978). The disadvantage of the biological and chemical processes is that they produce either elemental sulfur or sulfuric acid as a byproduct which has to be disposed of. Therefore, OR has focused on a physical process in which the H2S is separated from the geothermal emission, absorbed into spent geothermal brine from Hellisheiði Power Plant and re-injected into the geothermal field, Gunnarsson (2008).

OR is currently building an experimental H_2S cleaning station. This facility will experiment with a few simple methods of separating H_2S from the geothermal emission, all of which are followed by reinjection. First, the test facility will attempt to separate the emission into CO_2 and H_2S through column distillation. The presence of hydrogen (H_2) in the stream is a concern for this method. Therefore, two subsequent experiments for the removal of H_2 will be conducted. The first implements a membrane that can separate out H_2 and the second uses water to absorb CO_2 and H_2S, thereby removing H_2 as well. Once the H_2 is removed, CO_2 and H_2S will be separated in the distillation column. Fig. 9 shows a simple flow diagram of H_2S abatement using water as an absorbent. H_2S and CO_2 are absorbed and H_2 gas is liberated in the first column and the CO_2 and H_2S are removed from the water in the second column. Then the H_2S is separated from CO_2 in the third column and each gas is led to its respective reinjection site.

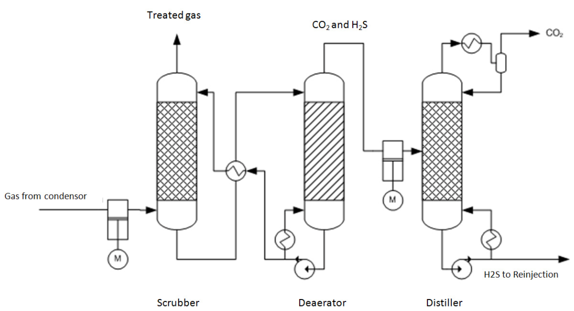

Figure 9: A simple flow diagram of an experimental H_2S cleaning station.

The experimental station will start in the fall 2009. The initial results from the experiment are expected 6 months later. If the results are positive OR plans to start a full scale design of a H_2S cleaning stations. If however, the results do not give positive answers then OR will focus on know cleaning processes. It is estimated that if the cleaning station works, the cleaning will result in 99% removal of H_2S from the power plant.

7. HVERAHLÍÐ AND BITRA

OR is planning two new geothermal power plants in the Hengill area, at Hverahlíð and Bitra. OR is also doing research in other places within the Hengill area such as Gráuhnúkar which is south of Hellisheiði power plant.

7.1 Power plant at Hverahlíð

The development area is located about 3 km southeast of Hellisheiði power plant. The development area of the power plant was reduced from its original planned size for environmental reason, see Fig. 10. Because of the reduction of the development area and OR's environmental policy the effect of power plant at Hverahlíð on its surroundings has been minimized, VSÓ (2008a).

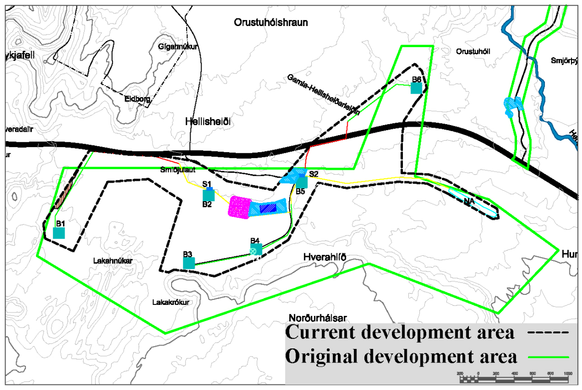

Figure 10: Development area at Hverahlíð.

The size of the power plant was estimated from information gathered from two research boreholes drilled in 2007 and results from a model of the geothermal area, Björnsson (2007). Estimated capacity of the power plant in that area is 90 MW_{el}.

Six research boreholes have been drilled in Hverahlíð. If results from testing and monitoring the research boreholes are positive drilling will continue in 2010 and civil works will start in middle of that year. It is estimated that the power plant will start production in the middle of 2012.

7.2 Power plant at Bitra

The development area is located about 8 km northeast of Hellisheiði power plant. The development area of the power plant was reduced from its original size because of environmental consideration, see Fig. 11. Like at Hverahlíð the reduction of the development area and OR's environmental policy will result in minimal effect of the power plant on its surroundings, VSÓ (2008b).

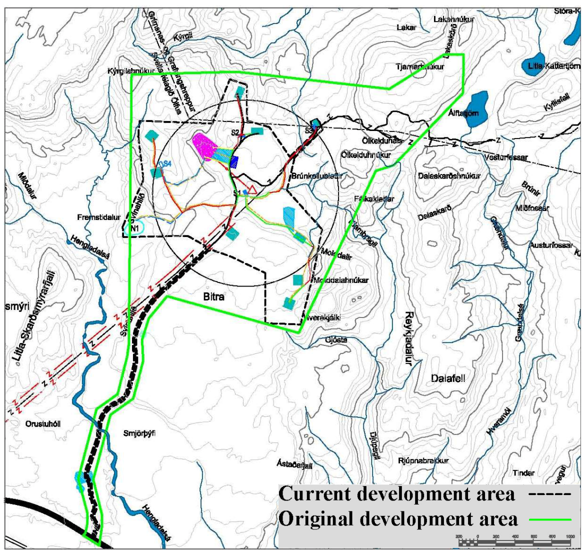

Figure 11: Development area at Bitra.

Three research boreholes have been drilled in the Bitra area. Size of the power plant was estimated from information gathered from those boreholes and results from a model of the geothermal area, Björnsson (2007). Estimated capacity of power plant in Bitra is 135 MW_{el}.

Time schedule for power plant in Bitra has yet to be defined.

8. ENVIRONMENTAL IMPACT ASSESMENT

New geothermal power plants projects are subject to EIA according to Article 5 and item 2 of Annex 1 of the Icelandic EIA Act no. 106/2000. Preliminary EIA proposals for the project at Bitra and Hverahlíð were presented in August 2007, the EIA were published in March 2008 and the Planning Agency issued their conclusion in May 2008.

In the EIA for both Hverahlíð and Bitra different locations, arrangements and structural types were investigated with the goal of reducing environmental impact. Aside from describing the execution, which has been covered in previous chapters, the main emphasis was laid on the geothermal system and reservoir engineering, landscape, recreation, the tourism industry and land use. Geological formations, archaeological remains, hydrology, vegetation, birds, gas emissions into the environment and the biosphere of hot springs were also dealt with. The conclusion of the project owner is based on information obtained from specialists' research on the relevant environmental factors. The effect on each environmental factor was valued as insubstantial, considerable or substantial. Table 1 shows the estimated impact on each environmental factor by power plant at Hverahlíð and Bitra followed by their combined effect.

Table 1: Summary of the environmental impact of power plants at Hverahlíð and Bitra

Environmental factors	Hverahlíð	Bitra	Combined
Geothermal heat	Uncertain/ Insub.	Uncertain/ Insub.	Uncertain/ Insub.
Hydrology	Insub.	Insub.	Insub.
Geology	Insub./ Consid.	Consid.	Consid./ Subst.*
Landscape	Insub./ Subst.	Consid.	Consid./ Subst.
Air quality	Insub.	Insub.	Insub.
Vegetation	Insub.	Insub.	Insub.
Biosphere of hot springs	Uncertain/ Insub.	Uncertain/ Insub.	Uncertain/ Insub.
Birds	Insub.	Insub	Insub
Archaeological remains	Insub	Insub	Consid.
Sound level profile	Insub.	Insub./ Consid.	Insub.
Tourism and recreation	Insub.	Consid.	Consid./ Subst.*

(Insub.: Insubstantial effect, Consid.: Considerable effect, Subst.: Substantial effect)
* Combined for all power plants in the Hengill area; Hverahlíð, Bitra, Hellisheiði power plant, Nesjavellir power plant and related high-voltage lines.

The conclusion of the EIA for Hverahlíð was that the effect of a power plant at Hverahlíð on the environment would be insubstantial. The factor of the environment that would be most affected is the landscape. The conclusion of the EIA for Bitra was that the effect of a power plant in Bitra on the environment would be insubstantial to considerable. The factors of the environment most affected in the project area are landscape, the tourism industry, outdoor recreation and sound level profile. Other effects on the environment, both at Hverahlíð and Bitra, have been minimized because of the measures described in OR's environmental policy and design basis.

9. RESEARCH PROJECTS

With more knowledge of the Hengill geothermal area accumulated through running the Nesjavellir and Hellisheiði power plants and research drilling new opportunities arises which can be utilized both in future power plants in the area and in other projects. Two of the most important research projects that OR participates in at the moment are Carb-Fix and IDDP.

9.1 Carb-Fix. Nature Imitated in Permanent CO_2 Storage Project

In fall 2007 a project was launched with the aim at storing CO_2 in Iceland's lavas by injecting the green-house gas into basaltic bedrock where it literally turns to stone. Carbon dioxide turning into calcite is a well known natural process in volcanic areas and now the scientists of the University of Iceland, Columbia University N.Y. and the CNRS in Toulouse, France are developing methods to imitate and speed up this transformation of the gas that is the prevalent contributor to global warming.

Injecting CO_2 at carefully selected geological sites with large potential storage capacity can be a long lasting and environmentally benign storage solution. The uniqueness of the Icelandic project is that whereas other projects store CO_2 mainly in a gas form, where it could potentially leak back into the atmosphere, the current project seeks to store CO_2 by creating calcite in the subsurface. Calcite, a major component of limestone, is a common and stable mineral in the Earth and is known to persist for tens of millions of years.

In the project at Hengill area a mixture of water and steam is harnessed from 2.000 m deep wells at Hellisheidi power plant. The steam contains geothermal gases, i.e. CO_2. It is planned to dissolve the CO_2 from the plant in water at elevated pressure and then inject it through wells down to 400-800 m, just outside the boundary of the geothermal system

It is estimated that the project will take three to five years and its scheduled to start CO_2 injecting late 2009. For further information see http://www.carbfix.is.

9.2 IDDP, The Icelandic Deep Drilling Project

The Icelandic Deep Drilling Project (IDDP) is a consortium of three, Icelandic energy companies preparing to drill a 4-5 km deep borehole into a high-temperature hydrothermal system. The goal is to reach 400-600°C supercritical hydrous fluid.

The main purpose of the IDDP is to find out if it´s economically feasible to extract energy and chemicals out of hydrothermal systems at supercritical conditions. Potential benefits of the IDDP include increased power output per well, perhaps by an order of magnitude, and production of higher-level, high-pressure, high-temperature steam. Other potential benefits are access of a energy source below current producing energy fields and extended lifetime of the exploited geothermal reservoirs. The IDDP consortium is composed of OR, Hitaveita Suðurnesja, Landsvirkjun and the National Energy Authority of Iceland. For further information see http://www.iddp.is.

10. COST ANALYSIS

With additional works to minimize the effect of a power plant on the environment it is inevitable that the cost of the power plant will increase. Preliminary cost analysis has been done for a conventional geothermal power plant at Hverahlíð and a "green" geothermal power plant at Hverahlíð. For the "green" geothermal power plant additional cost regarding the techniques which have been described previously has been estimated.

If it is assumed that the total cost for a conventional geothermal power plant at Hverahlíð is 100 units, then the cost partition between parts of the conventional plant can be estimated and compared to an estimated price increase for each part if the power plant were "green". Table 2 shows the cost partition between part of a conventional power plant and comparison with "green" power plant.

Table 2: Cost comparison for conventional power plant and "green" power plant at Hverahlíð.

	Conv.	"Green"	Increase
Drilling	29 units	29 units	0%
Steam collection and Re-injection	20 units	22 units	10%
Plant Buildings	10 units	13 units	30%
Piping, equipment and control system	41 units	47 units	15%
Total	**100 units**	**111 units**	**11%**

No cost increase is estimated for drilling. Some changes might be in the finalized wellhead and adjusting the drill site to its surroundings but those changes are minimal compared to the fluctuation of the drilling cost from well to well. The cost of steam collection and re-injection is estimated to increase by 10% due to semi hidden and hidden pipelines. A 30% cost increase is estimated for adjusting plant buildings to their surroundings. Finally, there is an estimated 15% increase in cost of equipment due to more complicated hybrid cooling towers and the H_2S cleaning station. In total, it is estimated that the cost increase of minimizing the environmental effects of Hverahlíð power plant is around 11 %.

11. CONCLUSION

Due to OR's commitment to the community and the environment, a great emphasis has been focused on finding ways to reduce the environmental impact of future power plants. To ensure OR's environmental policy a design basis has been defined for power plant construction.

OR places its main emphasis on the quality of its goods and services. The company focuses on quality, reliability and profitability to ensure successful operations. OR realizes the importance of protecting the country's resources and ensuring their sustainable utilization as much as possible.

10. ACKNOWLEDGMENT

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