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Pre-Feasibility Design of Hágöngur 100 MWe Power Plant in the Highland of Iceland

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ABSTRACT

Landsvirkjun is working on preliminary design of a geothermal power plant in the high temperature geothermal area at Köldukvíslarbotnar in the uninhabited wilderness west of the glacier Vatnajökull and Vatnajökull National Park. The name of the power plant is Hágöngur power station and is derived from two distinct mountains which are spectacular and characterize the landscape in the area. The geothermal area is estimated to be up to 41 km^2 in size according to resistivity measurements and is about 820 m a.s.l.

For decades, all proposed power projects in the highland of Iceland have been controversial. In an attempt to seek reconciliation, the government of Iceland decided in 1999 on a Master Plan for Nature Protection and Energy utilization, a tool to reconcile the often competing interests of nature conservation and energy utilization on a national scale and at the earliest planning stages. In the current Master Plan, a 150 MWe power plant assumed in the area is classified in the category “On hold” due to uncertainty about impact on the nearby Vatnajökull National Park. Landsvirkjun is designing in collaboration with the engineering firm EFLA, as a conservative approach, a conventual 100MWe power plant with two 45 MWe units and 10 MWe ORC unit by use of the separation fluid. However, the design approach is not conservative, aiming at meeting the concerns.

Landsvirkjun’s objective is to minimise negative impact of the power plant and rather support other use of the area, that is the tourism associated with the Vatnajökull National Park. The main goal is to incorporate all constructions into the landscape, avoid ascending steam flow and reinject the effluent fluid, to mitigate environmental impact, which is Landsvirkjun's policy for sustainable use of resources. Direct cooling by use of cold water from the river Kaldakvísl, will be implemented instead of cooling towers.

It is of great importance to be in good collaboration with the authorities concerning road crossing the highland and the board of the Vatnajökull National Park. One of the proposals is to combine staff housing with tourist mountain lodging as well as a base for highland rescue team and a gate to the National Park.

Within the research area, mapping, geological and geophysical research has been conducted, which was the basis for a decision to drill an exploration well in Svedjuhraun in 2003. In the preparation phase of drilling, the path to Hágöngur area was repaired, Kaldakvísl river was bridged, a new road track was built in Svedjuhraun. Now, two drill sites are in Svedjuhraun with a research hole on a northern one, and according to Landsvirkjun's plan, it is assumed to deviate the next exploration well on the current drilling site in Svedjuhraun to the west under the center of the geothermal area.

The first exploration well was drilled to a depth of 2360 m in 2003 and was flow-tested from 2003 to 2004. It confirmed a useful high temperature area and provided the main parameters for initial reservoir assessment. The well proved a 260-320°C geothermal reservoir from a depth of 700 m to the bottom. The main feed zone is at 930 m and the enthalpy of the flow is about 1100 kJ/kg. However, higher enthalpy fluid can be expected if permeable zones are encountered at greater depth.

1. INTRODUCTION

From the establishment of Landsvirkjun, the company emphasized to construct hydropower plants in the river Thjórsá and its watershed including adjoining rivers. In 1997-1999, the river Kaldakvísl was dammed, forming the 27 km^2 hydro reservoir Hágöngulón. Its purpose is to increase the efficiency of the catchment area of the rivers Kaldakvísl and Svedja. The main impact was the submergence of the active geothermal manifestations in the area named Köldukvíslarbotnar. Therefore, a geothermal research program was initiated as a part of the environmental impact assessment.

The research program commenced in the year 1994 with reconnaissance geological mapping (1996, 1997), sampling of geothermal fluid from fumaroles and continued with TEM-resistivity survey. The first exploration well was located and drilled in the year 2003 (Jonsson et.al. 2005), based on the investigation outcome. Figure 1 demonstrates the research with time. The roads and tracks were rebuilt or rehabilitated to transport the drill rig and necessary equipment as well was bridge construction needed to cross the river Kaldakvísl to access the drilling location in Svedjuhraun. Some delay in the operation activities in Hágöngur area occurred after the drilling completion and analysis of the drilling data caused by other geothermal project in NE-Iceland. The timeline illustrates how the time was used to add further research survey, like finish the geological mapping, TEM- and MT-measurements, micro-seismic activities and interpretation of the data.

Pre-feasibility project design report is in preparation in collaboration with the Engineering company EFLA. New approach is added to this project compared to previous one. The constructions in the concession will comply with the landscape of the area, emphasizing the uniqueness of the area and ensuring that the power plant is in harmony with its surroundings

2. GEOTHERMAL RESEARCH

The Hágöngur high temperature geothermal area in is located in central Iceland, at 800-860 m a.s.l. west of the great glacier Vatnajökull and the Vatnajökull National Park. It derives the name from two outstanding mountains, South- and North Mt. Háganga. A geothermal research program was initiated in the year 1995 with reconnaissance geology mapping (Fridleifsson et. al 1996 and Fridleifsson and Víkingsson 1997), surface formations, tectonic and distribution of geothermal manifestations. It was followed by TEM-resistivity survey, which indicated extensive resistivity anomaly, estimated 54 km^2, with a 13 km^2 low anomaly surrounding 41 km^2 high core (Karlsdóttir 2000). Gas thermometry was implemented to estimate the reservoir temperature which appeared to be 280-300°C. A hydro dam was constructed in depression in center of the geothermal area to form reservoir as a partial reserve for the several hydropower stations by flow from the rivers Kaldakvísl and Svedja. This operation submerged most of the active geothermal manifestations.

Sampling from the fumaroles, solfataras and run off water was carried out prior to the filling of the reservoir. The purpose was to estimate the geothermal reservoir temperature, concentration of the main soluble components and mark the conditions before any utilization (Fridleifsson et. al 1996). For future vision the water level of the dam was expected to drop during the spring time or late in the winter and selected geothermal manifestation might be accessible for sampling the fluid and act as monitoring sites.

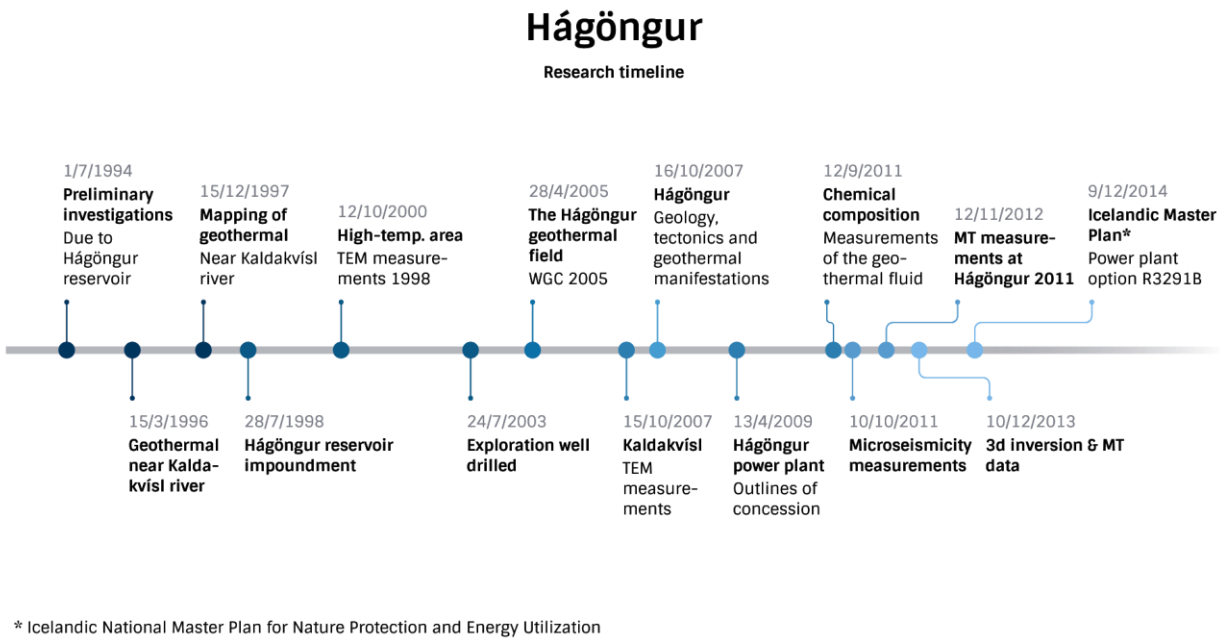

Figure 1. The research timeline in Hágöngur high temperature geothermal area.

Two well pads were prepared on the lava Svedjuhraun at the lakeside, for deep exploration drilling, based on the research outcome. In the year 2003 was the first and only well, HG-1, so far located and drilled down to 2360 m depth with production casing down to 803 m (Jónsson et. al. 2005). At the edge of the drilling pad, a 15 m deep well was drilled to provide circulation water for the deep drilling. Well HG-1 provided valuable information about temperature, pressure, permeability, chemistry of the fluid and geological formations. During the drilling cuttings were sampled every two meters and analyzed at drill site. Lithological log was prepared as well as the alteration minerals distribution, which indicated the formation temperature. All drilling parameters were recorded in the rig's system. Occasionally some downhole loggings were performed like pressure- and temperature logs. In the end of each section and in the completion of the well, lithological logs were performed to improve the lithology by adding some physical parameters. It was in fair contest to the assumption based on the surface investigations. Figure 3 shows temperature logs and formation temperature. The main permeability zone was connected to hyaloclastite formation just below the casing shoe at ~800-900 m depth, which is in a good agreement with flow test. The enthalpy of the discharge fluid is 1170 kJ/kg and the total flow 27 kg/s at 11 bar-g (Bjarnason 2011). According to these numbers the inflow temperature at the aquifer is estimated 260 °C. Higher enthalpy will be anticipated in permeable zones below 1000 m depth were the formation temperature is closer to 300°C.

The timeline of the research at Hágöngur reveal further geological mapping as well as resistivity measurements. The mapping of the surface geology was continued and published in a report 2006 (Jóhannesson and Fridleifsson 2006)). Comparison of the surface formations to the log of the well HG-1 inspired the ideas of the first conceptual model. Rhyolite formation in the Hágöngur mountains indicate relation to 400 m thick formation of rhyolitic composition, which is identified at 350 m depth in well HG-1. These observations compared to the tectonic lineaments on the surface brought up the concept of caldera formation as a part of a central volcano (Figure 4). Furthermore, the geothermal sites line up on the main tectonic structure, NE-SW. According to the conceptual model the future drilling strategy was focused on alleged fractures in the middle of the dam and the wells will be deviated from Svedjuhraun to western direction.

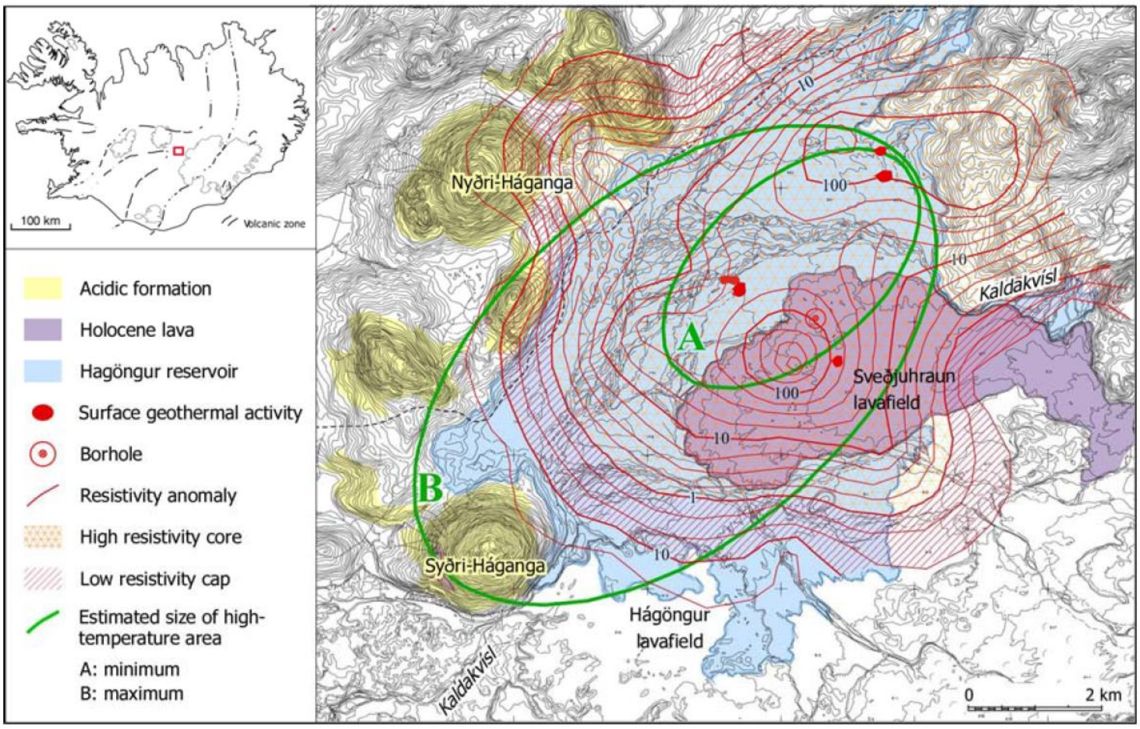

Figure 2: Location of the Hágöngur high-temperature geothermal area and simplified geological map. Resistivity anomaly (from Karlsdóttir, 2000) in the Hágöngur area at sea level. Isopaths in Ωm.

It is important to assess where the effluent fluid will be disposed. In the prefeasibility study of the power plant it must be on the sites of the river Kaldakvísl. No research wells have been drilled so far but according to the evidence from the drilling of HG-1, the option on the site of Svedjuhraun is more likely to be decided. The permeability and temperature distribution is not known in that specific part but it will be investigated thoroughly.

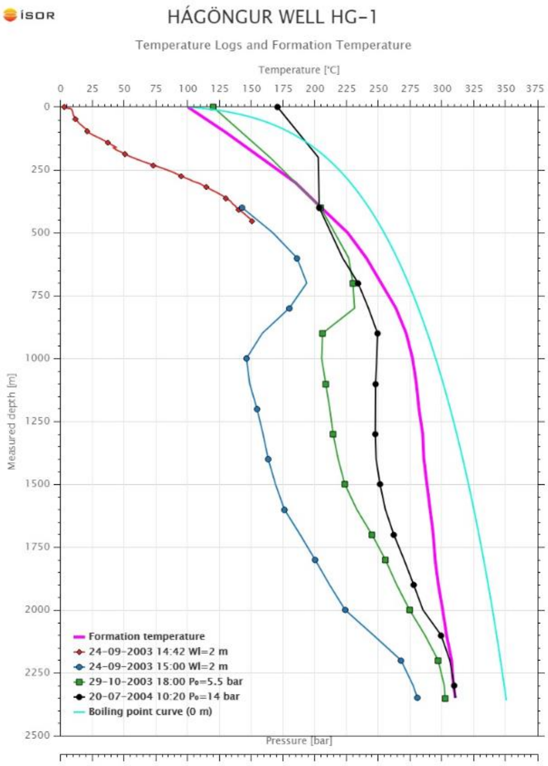

Figure 3: Temperature loggings in the warming up period after drilling completion and estimated formation temperature, compared to the boiling point curve.

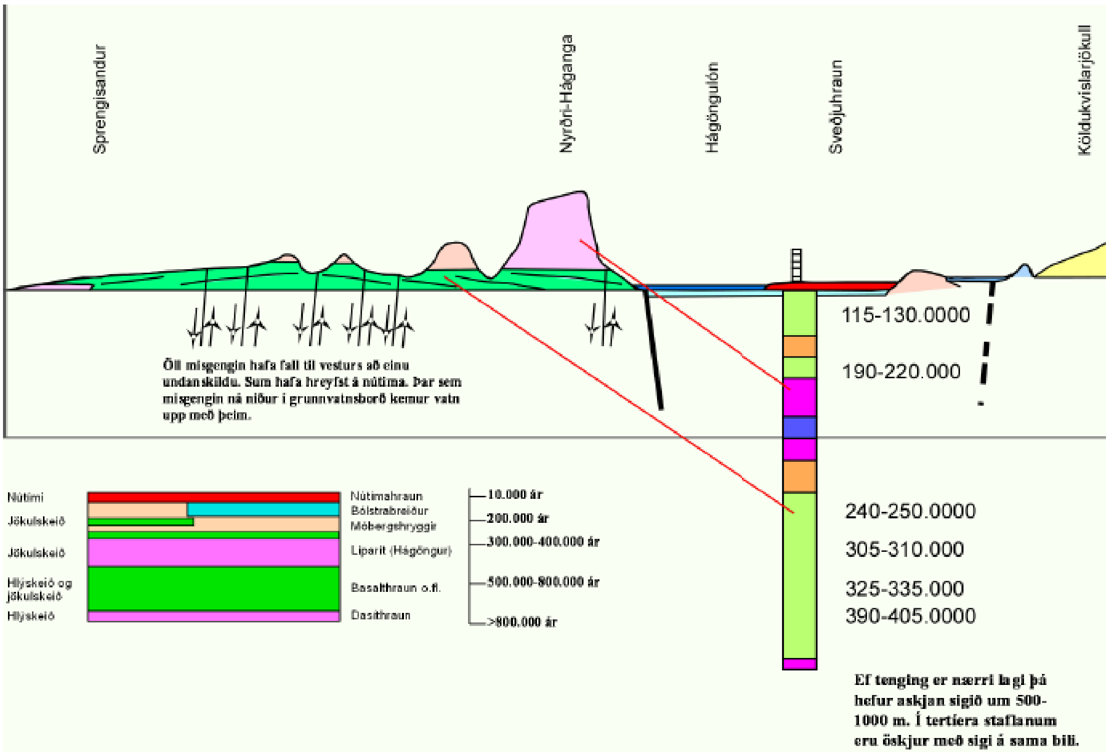

Figure 4. The first hypothetical model of the Hágöngur high temperature geothermal area (from Jóhannesson and Fridleifsson 2006).

3. ENVIRONMENTAL ISSUES

Sustainable development has three main pillars: Economic prosperity, social progress and environmental balance. These three components must be viewed in context and an effort made to maximize economic prosperity and social progress without harming the environment.

Landsvirkjun's operations are controlled by the company's management system, including Environmental Management system certified according to the latest release of the international standard ISO 14001. Landsvirkjun environmental policy is to be at the forefront of environmental issues and supports sustainable development within society. The Company is committed to acquiring knowledge on the environmental impact of its operations and to reducing any impact. Landsvirkjun Environmental policy has five main components; Using natural resources more efficiently, carbon neutral operations, operate in harmony with nature and the appearance of land, stakeholder engagement and operations without environmental incident.

Landsvirkjun places great importance on sustainability and responsible utilization of energy resources, with careful consideration for any potential impact on the economy, society and the environment. Sensitive geothermal areas must be built up in stages and given time to respond to utilization. Power projects make every effort to maximize the utilization of the resource, considering all environmental perspectives and with the goal of minimizing any negative environmental impact.

To ensure early compliance with the environmental criteria's set by the company the project group for Hágönguvirkjun preliminary report involved staff from the environmental department. The preliminary design was viewed and refined in context with the significant environmental aspects identified by Landsvirkjun. This process revealed potential environmental impacts of the project, that could either be avoided by adjusting the preliminary design or that will need further research in the next steps of the project design process. Opportunities for further prevention of potential environmental impacts and mitigation measures were identified as well and it will be explored further in the next stages of the project development.

The early emphasis on the environment in the development of Hágönguvirkjun have resulted in a set of environmental targets that will follow the power project through various stages of the development.

- Planning and design of the power plant will comply with the new company´s landscape policy which landscape of the area, emphasizing the uniqueness of the area and ensuring that the power plant is in harmony with its surroundings.
- The cooling system will be a direct system to prevent steam strokes and minimize the visual impacts of the power plant
- A binary plant will be used to further utilize the energy extracted and maximize the utilization of the resource.
- The eluent from the power plant will be reinjected to prevent environmental impacts associated with surface release of eluent.
- The transmission lines will be laid underground to the next possible substations or transformer stations.

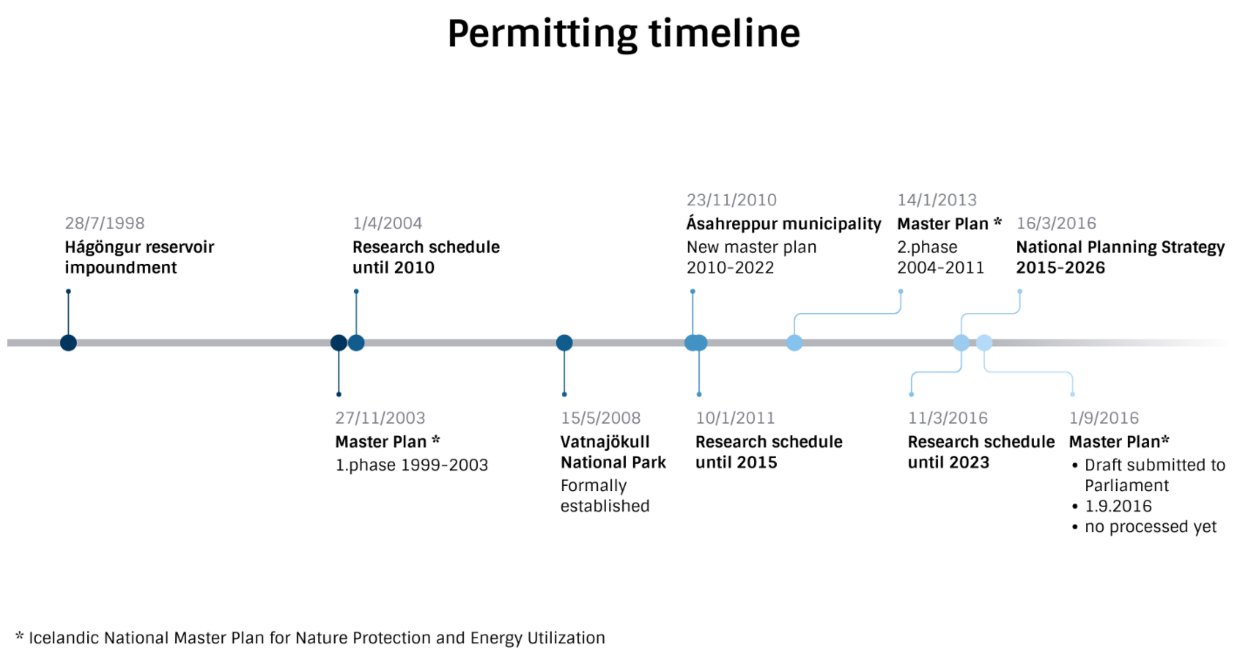

Figure 5: The planning and licencing in a timeline.

3.1 Landscape and visual amenities

Landsvirkjun Environmental policy has highlighted landscape and visual impact as one of the major components in environmental effects of renewable power projects. In 2016, Landsvirkjun put forward a new policy on landscape and design of an energy projects and the policy states working procedures in accordance with the five milestones in the development of power projects.

The new landscape policy states two kinds of working process to be carried out in the preliminary project phases; Pre-feasibility study & reconnaissance phase and the Feasibility study & Pre-design phase. It describes working methods used for Landscape Inventory, landscape analysis & assessment and results. It will describe the planning status, landscape in the Highlands of Iceland, major elements, challenges, constraints and opportunities. It discusses method to evaluate the landscape and visual impact and how potential developments may affect it. Landscape assessment is used to enhance landscape design concepts in project planning of a geothermal power station. It talks about landscape character, compatibility, sensitivity of landscape and recommendation for next steps in project layout and design.

The prospective project Hágönguvirkjun is the first power project that is developed in early phases according to the new policy pertaining landscape. It is an example of how a landscape analyst and assessment can be used to enhance landscape-led design of a power station and how it can be taken a step further than in traditional geothermal power project design.

3.2.1. Environmental Inventory

During Pre-feasibility study & reconnaissance phase the working procedure for Environmental Inventory was carried out. The purpose of this working procedure is to compile basic information on planning and land use concurrent near the proposed power plant, and to make a rough assessment of what needs to be particularly considered in the next design steps of the power plant. The final document was a report with maps, tables and photos (Árnason, 2017A). The report is intended as a basis for further design, in accordance with Landsvirkjun' s policy on landscaping and appearance of structures.

3.2.2 Landscape analysis and assessment

During Feasibility study & Pre-design phase the working procedure for Landscape planning, analysis and assessment was carried out. The purpose of this working procedure is to analyse further the basic information that was collected in primary phase and to assess it. In addition, it discuses actions that need to be considered in the design of the power plant at the next design stage to seek sustainable design. The final document was a report with maps, tables and photomontage. The report is based on the base of a preliminary environmental study of the proposed power plant. It is about analysing, sorting and evaluating information collected in the first phase. It deals with the characteristics of the landscape and theoretical visual effects. It describes the landscape characteristics, visual amenities and visibility of man-made structures, possible constraints and opportunities, proposals to strategic design guidelines and mitigations actions (Árnason, 2017B).

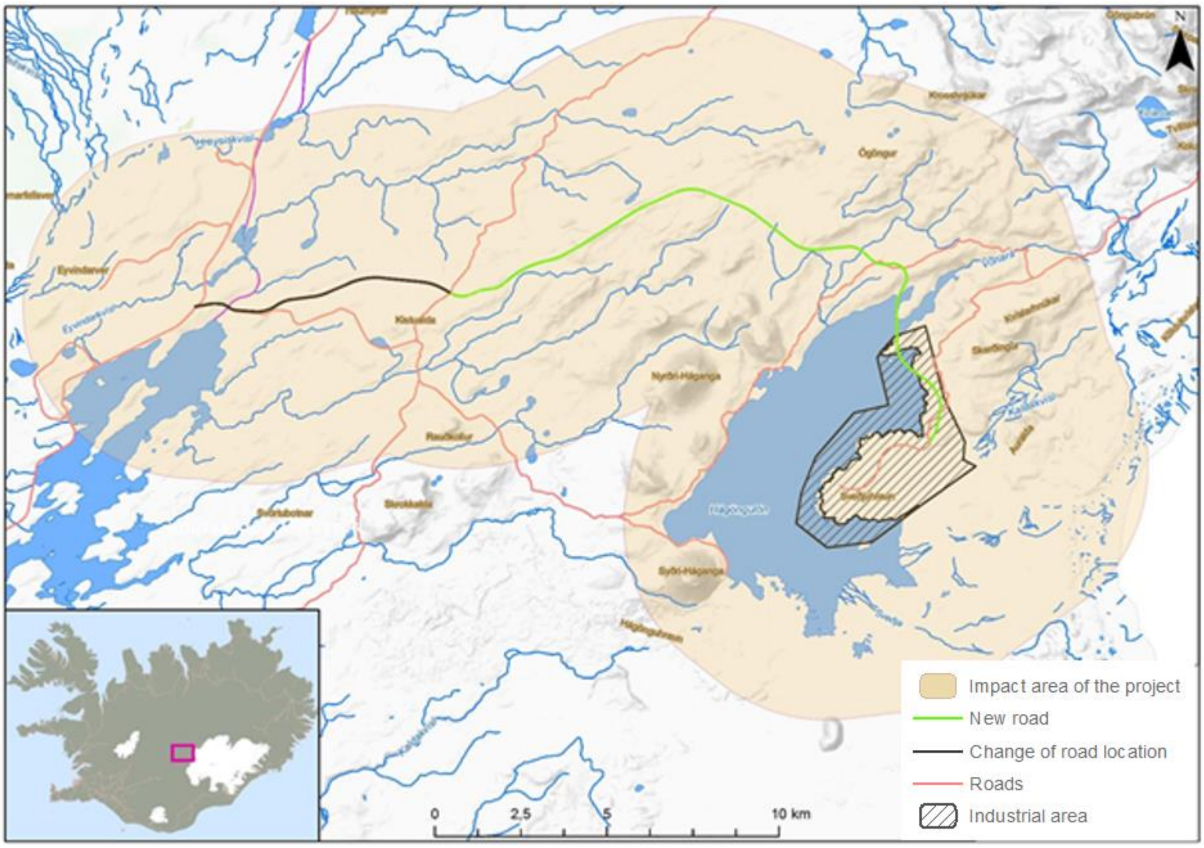

Figure 6: The figure above shows proposed power plant near the reservoir Hágöngulón in the Municipality Ásahreppur. The coloured zone is the theoretical impact zone according to 5 km distance stated in the Nature Conservation Act.

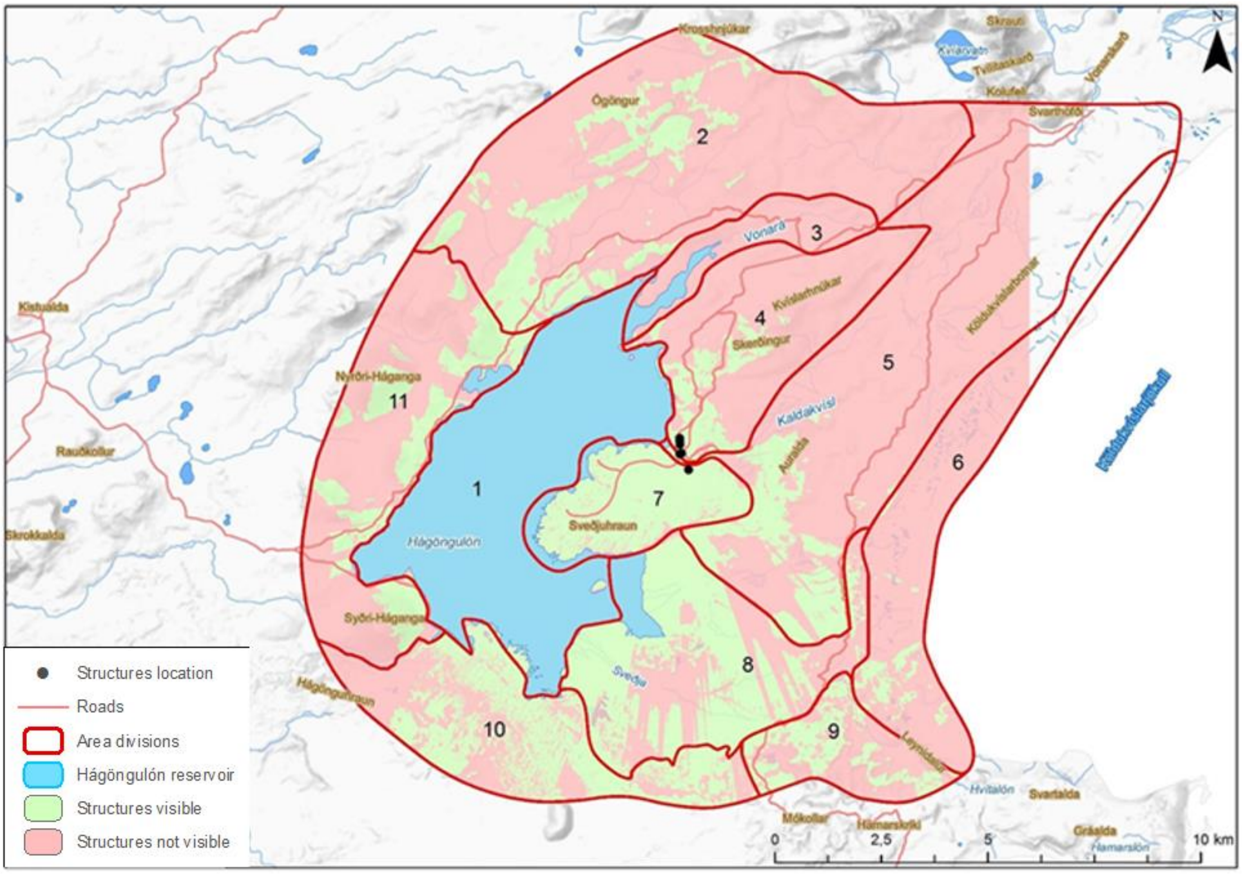

Figure 7: Rough analysis of the visibility of man-made structures. Numbers refer to landscape characters types.

3.2.3 Innovative design and architecture

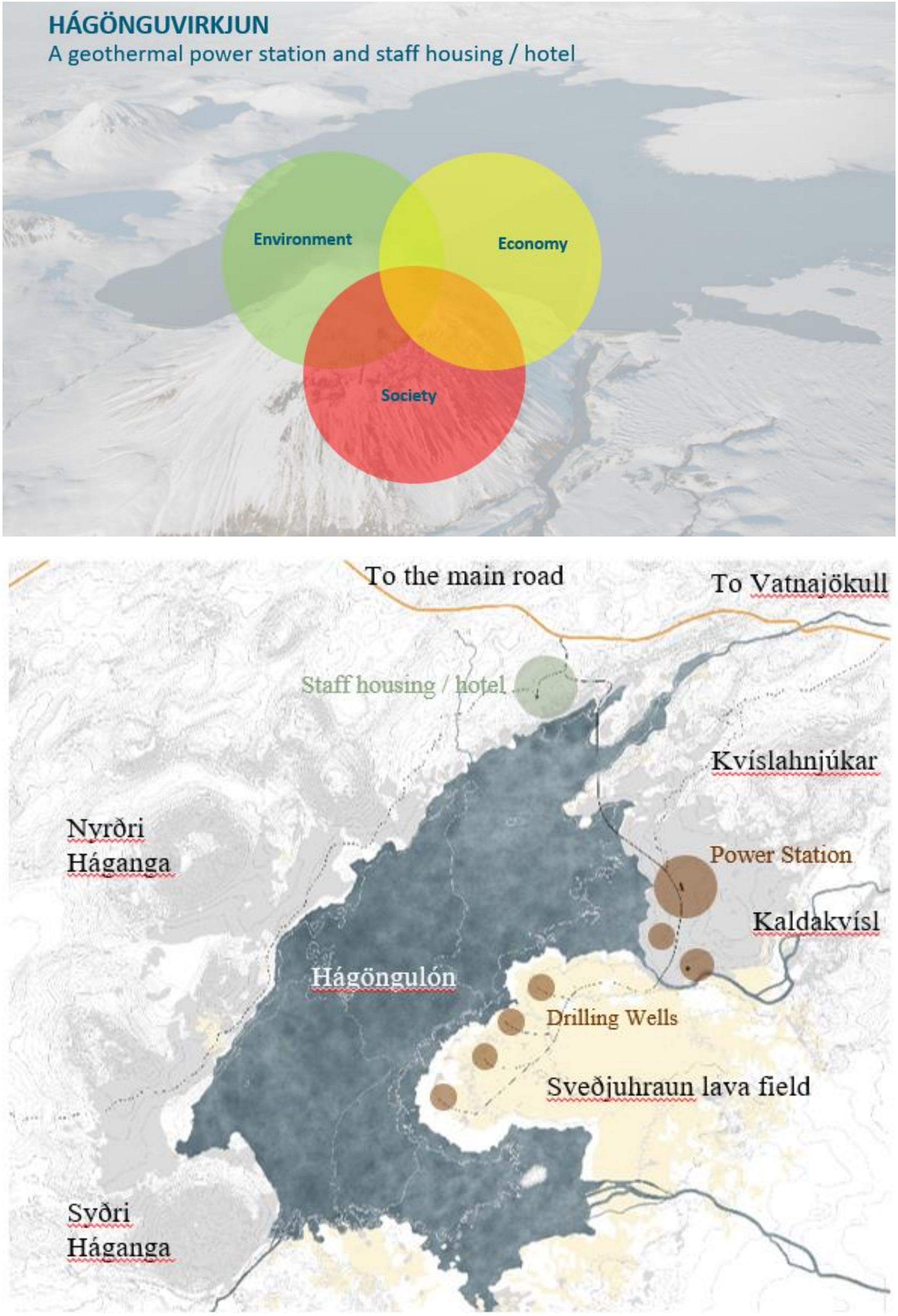

Figure 8: Shows proposed site layout by A2F architects over the industrial area for Hágöngur power station.

Landsvirkjun' s new landscape policy is to create an overall balance between the appearance of structures and landscaping within the landscape and the natural environment. Ways to meet the new policy objectives is to have landscape & architectural design enhance the natural landscape and sense of place. The proposed project design should respect and reflect the environment and landscape character, thus there is an emphasis on design and architecture. Another reason to why so much emphasis on design and architecture is due to the fact that the proposed project is located in the highlands of Iceland approx. 800 m a.s.l., and there are no forest or vegetation that can be used to hide the power plant or mitigate for visual effects. Therefore, it is necessary to have careful design and landscaping of the development and to have high quality architecture that reinforces the buildings horizontal forms in order to visually anchor the building to landscape. To achieve these objectives and gain new ideas to a traditional energy power projects, it was decided to involve two architect offices A2F and Arkís. The design memorandum for the architectural work was to create:

- Embrace Landsvirkjun' s new landscape policy
- Layout, scale and façade of buildings should be in harmony with the existing landscape.
- Architectural style of buildings should create the ambience of "mountain hut" feeling.
- Design layout should integrate multi-use for tourists and recreational activities.
- Sustainable and creative design.

Figure 9: Proposed solutions for architecture for the new power station in Hágöngur by A2F architects

This approach can offer an innovated design and it shows an example of integrated, collaborative and adaptive solutions. It provides an opportunity to engage with the community and it seeks to marry infrastructure with place-making. Working together on a common path with informed choice of structures and designs, can improve the project that is located and a controversial and sensitive site in the Highlands of Iceland. The aim is that by exploring new and more sustainable design ideas the proposed project will gain better consensus, social responsibility and meet the future vision in new era of environmental awareness in the community. The two architects offices came up with two very different proposals, but with great potentials.

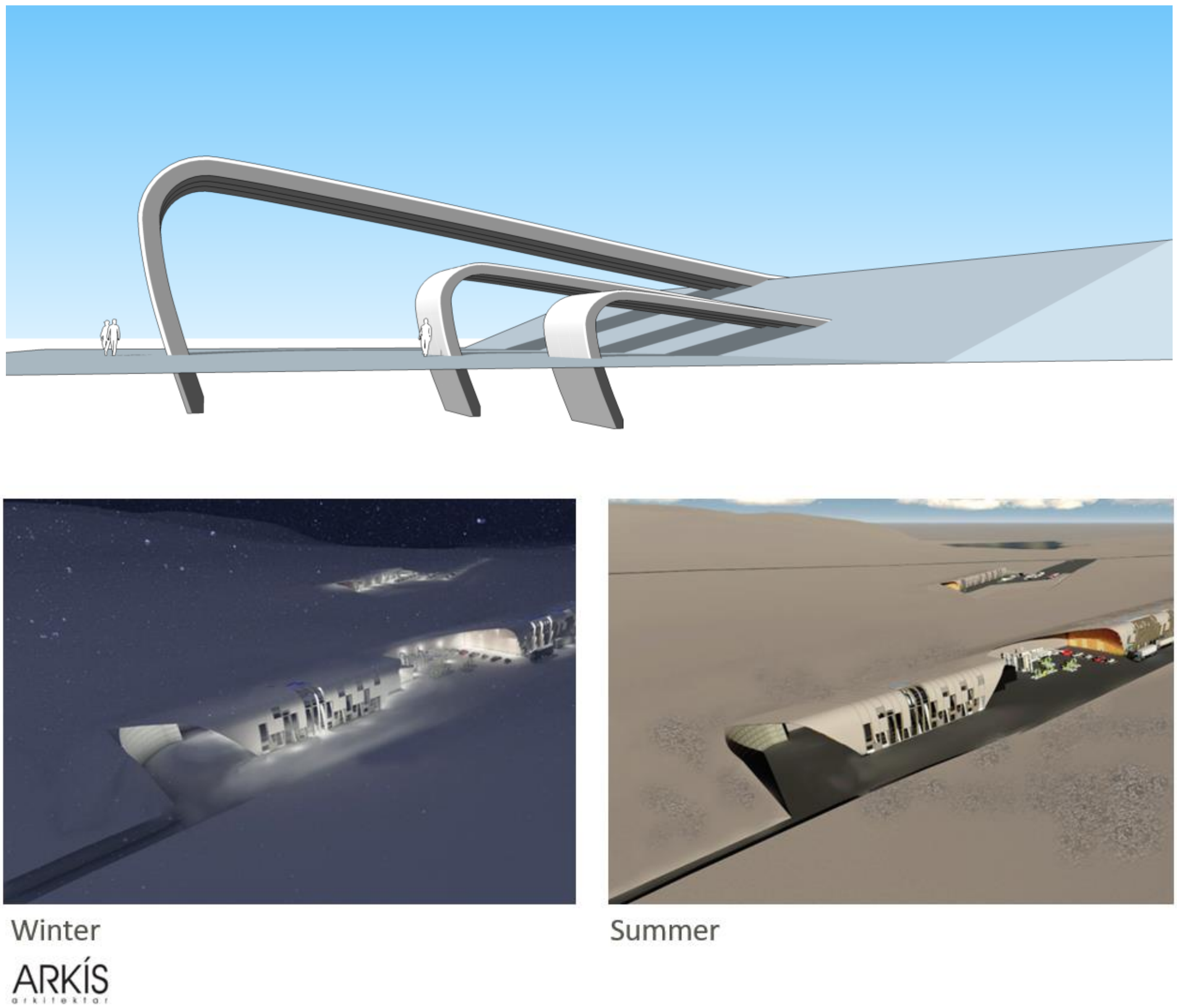

Figure 10: Proposed ideas and solutions for architecture for the new power station in Hágöngur by Arkís architects.

A2f proposed to have the appearance of the buildings warm and appealing and to create human scale. However, the power station building is big in scale, so to transform is done to alter the scale of the roof in different angels and brake it up to a smaller units to create a human scale. A stone wall grows out of the ground, a and acts as a foundation for the building. The upper part is covered with lighter material larch, which will gray over time. The direction of the larch follows the slope of the roof rack and functions like streaks in the glacier. A2F suggested a new solution to the original site layout, to move the staff buildings (working camps) away from the power station and ORC. The main entrance of power station is for staff and guests. On the second floor there is a space for exhibition and education with view into to the engine room. A2F locates the staff building 3 km away from the power station to the north, overlooking to the south over the reservoir (lake like feeling). The staff building which will initially be used for staff accommodation during the construction of the power station, can later be used as a hotel and spa for tourists or maintenance. Hot water from the power plant can be reused to for the spa and a greenhouse built along the corridor. It will be possible to grow plants and vegetables and fruits for guests. All buildings are planned to be harmony in form, material and shape to create an overall feeling of coherence (Atladottir, 2017).

Arkís proposed the idea of repetition of modules for miscellaneous usage, from the small to big. It refers to nature, where reproduction forms a solid image and many small units form a larger unit. The form and shape of the structures seeks it inspiration from the surrounding natural folding in the landscape by the mountain waives. The power station is to be sunken into the ground and half way into the hilly landscape. The power station is proposed to be linear in structure and modules can easily be added for expansion. The appearance of the buildings are coherent in shape, material and colour and are built to be sunken into the ground and merge with the landscape. Proposed material is laminated wood, rubble from the surroundings for texture on the wood covering and steal (Jonsson, 2017).

3.2 Summary of Landscape led Design

During the early design phases design principles were create, but it was also necessary to research new solutions. However, it is necessary to emphasize that this ideology needs to be reviewed regularly as more information becomes available and it may be appropriate to update it. The analysis of the terrain is used as part of the basic state information about the area and used in support of decisions on the structure of the project. It sharpens the fact that landscape analysis is an important benefit in obtaining baseline information on an area and opening the term from activation to implementation. The purpose of a project was to fulfil the steps in Landsvirkjun' s new landscape policy regarding landscape and the appearance of structures.

Understanding the baseline will contribute to all stages of the power project from early feasibility work through detail design to assessment and implementation. At each stage, it is important to revisit the landscape baseline to address any changes or new insights into character. The design and assessment processes are linked and iterative: design solutions should be tested against the landscape baseline and refined until an optimized scheme is developed which successfully balances the needs of the project with the demands of the landscape.

This approach does not mean that bold design statements must be avoided only that they must arise from the project context rather than being imposed from outside. The approach can be applied to all elements of project design from siting, form and positioning to detailed use of materials and colours. By creating schemes that are sympathetic with their surroundings, projects can provide multiple benefits for biodiversity, recreation, heritage and landscape, resulting in genuinely sustainable solutions.

4. POWER PLANT DESIGN

Among the special features of the Hágöngur power plant is the location of the geothermal field itself, which is located 820-850 m. above sea level and mostly under water, in the highlands of Iceland and placed on the westside of Vatnajökull National Park. One of the main goals for the project design team was to reduce the visual impact of all structures as much as possible as well as utilizing the energy resource efficiently and ensure its sustainability. Another special feature of the Hágöngur site is the abundant availability of cold water which can be used as cooling water for direct cooling, to eliminate the traditional steam plumes stepping from the power plant in this remote area.

The geothermal fluid is expected to range from 1400-1700 kJ/kg. and for the ongoing predesign, a 1.550 kJ/kg and 5-6 MW per well was used as basis for the evaluation of the number of production wells and drilling sites. It is estimated that the Hágöngur project needs at least 20 production wells and 4-6 drilling platforms. Four of them will be built in the lava field Svedjuhraun south of the Kaldakvísl river and one or two platforms will be built north of Kaldakvísl. Emphasis is placed on reducing the number of drilling platforms at Svedjuhraun by drilling 4-5 production wells on each drilling pad. Resulting in each drilling pad needs to be somewhat larger in size, than a traditional one, however it will have a positive impact on infrastructure such as roadwork and gathering pipes. The total size of area needed for drill pads is also significantly reduced by grouping wells together on pads.

The early stages of the pre-design of the power plant was to establish a solid ground for the location and implementation of all structures and buildings for the power plant in the Hágöngur area. Initially, the project team looked at the traditional flash steam flash construction located near the planed drilling platforms. Further investigation of the local conditions, environmental considerations, possible natural disasters and weather conditions, the location of the power plant has shifted from being located at the Svedjuhraun lava field and moved to a safer area north of Kaldakvísl.

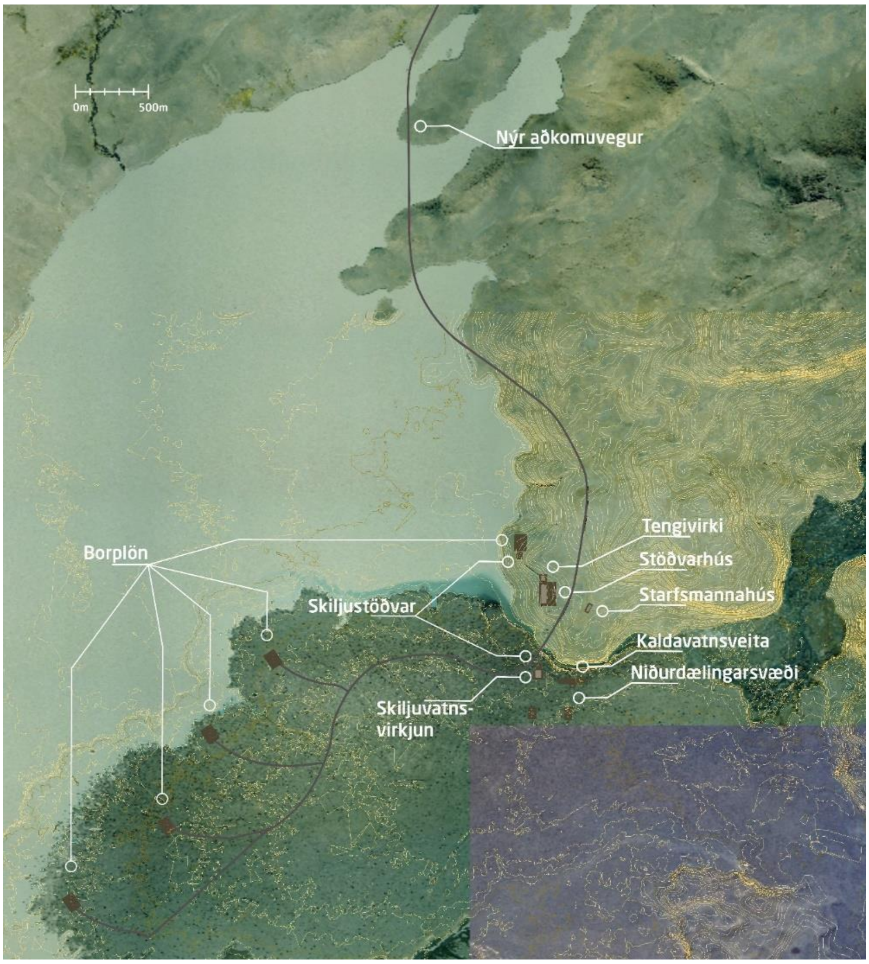

Figure 11: A layout diagram for the main installations for the Hágöngur Geothermal Power Project.

The initial design has therefor changed and now the powerhouse, mist separators, steam gathering system and substation are all located north of Kaldakvísl. The selected location has considerable slopes, which places some constraints on the building area and design of a pipeline system north of Kaldakvísl. The area south of Kaldakvísl is relatively flat and therefore it is technically advantageous to locate the separation station and the Binary plant on the north outskirts of Svedjuhraun near Kaldakvísl. When nature conservation and environmental considerations are considered the preferable location for most of the structures be located north of Kaldakvísl away from the lava field.

The preliminary energy model shows the energy process for the utilisation of the high enthalpy fluid at Hágöngur for a 100MW electricity production.

An exploration well was drilled to a depth of 2360m and temperature measured in the range of 260 to 300°C at 700 to 2000m depth, with the highest temperature measurement of 320°C at the bottom of the well. The pre-design of the geothermal power plant is therefore based on a 1550 kJ/kg and extraction of at least 430 kg/s of geothermal water at well head pressure in the range of 10-15 bar and the separation pressure is 8bar(a).

The two-phase flow from the geothermal field will be separated into a steam phase for the 2 x 45MW turbines at 8 bar(a) pressure and the separation system will also deliver over 250 kg/s of 170°C fluid. The project group decided is to explore the possibility of using the separation fluid for further utilizing in an Organic Ranking Cycle plant (ORC) for electrical production.

The ORC plant contributes to improved utilization of the geothermal fluid by using the 170°C thermal content of the separation fluid down to 90°C for 10-15MW electrical production. After cooling of the separation fluid in the ORC system it will be cooled even further down by adding the condensate at 45° C from the steam system. To preserve sustainability, it was decided that all extracted geothermal fluid will be reinjected back into the geothermal field at Hágöngur. The ORC system increases the efficiency of the power plant by additional electrical production from the same flow from the geothermal field. Another advantage of lowering temperature of reinjected fluid has been explored at Hellisheiði Geothermal Power Plant where the reinjection wells have higher permeability if the temperature of the separation fluid is lower (Gunnar Gunnarsson, 2011). The chemical composition of the extracted geothermal fluid needs to be evaluated to confirm the lower value for the ORC cooling.

The final decision regarding the location of the power plant was taken after a sight visit and evaluation of the slope that has influence on the civil structure, gathering and separation system. Due to the slope, considerable earthworks is required for the main building that is planned to have a façade facing the Hágöngur reservoir. It is therefore feasible to reduce visibility of mist separators, steam gathering pipes, rock mufflers and other mechanical equipment and place them behind the main building as shown above.

It is estimated that at least 20 production wells will need to be drilled for the 100MW power plant at Hágöngur and to reduce foot print of the well pads it was decided to enlarge each platform for at least 4 production wells. The above picture shows the layout of one of the planned drilling sites at Hágöngur with the option of having a separation system for every 4 wells that will be further evaluated in the final design of the project.

The above picture shows the layout of the ORC system, steam separation system for the 90MW plant and reinjection pump station and main piping system. The ORC system will be installed close to the steam separation system to limit piping for the utilization of the 170°C geothermal fluid for electrical production. The cooled geothermal fluid from the ORC will be mixed with condensate from the 90MW power plant before it is reinjected in the lava area south in Sveðjuhraun lavafield.

5. OTHER ACTIVITY IN THE HÁGÖNGUR AREA

As previously mentioned, Landsvirkjun's objective is to minimise the negative impact of Hágöngvirkjun on the environment and nearby society and rather support other use of the area. The Hágöngur geothermal field is in an area that is already identified in plans as energy utilisation area, as most of the reservoir is under the Hágöngulón hydro reservoir and the planned infrastructure for the geothermal power plant is on the banks of the reservoir. However, Landsvirkjun must consider the close vicinity of the nearby Vatnajökulsþjóðgarður National Park which has both preservation value as well as value as a future tourist destination. With that in mind, Landsvirkjun has consulted with stakeholders the possibilities for joint utilization of access road of personnel buildings and accommodation for visitors for the National Park. Such a co-used accommodation would require building designed in the spirit of a mountain hut to support the wilderness experience. It is quite clear that the year-round access road will benefit the visitors of the National Park and at the same time allow the staff of the park to provide better service. The access to the Hágöngur geothermal power plant could therefore open up an entrance in to the Vatnajökull National Park in the west.

The trained staff, working and staying all year-round in the power plant and the powerful equipment that is required would highly increase the safety of the all people in the area, therefore the plant staff could serve as an ad-hoc rescue team in the area.

It is also the objective of Landsvirkjun maximise the utilisation of all value streams from its geothermal resources, meaning not only to generate electricity from the steam phase. The rural location of Hágöngur minimises the options for industrial applications. However, the warm geothermal effluent water could provide bathing water for the hikers staying in the co-used accommodation and electricity, warm water and CO2 from the power plant could be used to grow vegetable for staff and visitor in a greenhouse, to mention a few options that could apply in this location.

It is clear that by innovative thinking and design, the Hágöngur Geothermal Project could become a unique geothermal power plant for such a unique environment.

CONCLUSIONS

Currently, all new power projects in the central highland of Iceland will be controversial and a conventional approach towards a geothermal power plant in Hágöngur is likely to meet an opposition. Landsvirkjun appreciates that, however, most of the resources to utilize are hosted in the highland. To meet the concerns, Landsvirkjun has proposed an innovative approach towards a pre-feasibility design for the Hágöngur geothermal power project. A special effort has been made to analyse landscape and design the project with minimum negative impact on the landscape and wilderness feeling of the area. Various innovative architectural approaches have been studied and technical solutions such as replacing conventional cooling tower with a water cooling from the nearby river. Finally, a totally new approach has been made towards employee facilities, designing it in a way that it can also serve as a center for the Western Vatnajökull National Park and as accommodation for visitors to the park where it must fit into the landscape and the "wilderness atmosphere" of the area.

The Hágöngur pre-feasibility study is an approach to convey the common opinion to new direction., where sustainability is in the front. Cascade utilizing is the concept which is emphasised and collaboration with other stakeholders is important.

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