Research and Development Projects on Climate and Environmental issues

Reykjavik Energy (RE) has been at the forefront of innovation and development on climate and environmental issues over the past decade.

Examples of projects developed in cooperation with the academia, business sector and municipalities 2023:

- **Carbon-neutral geothermal energy production**. In 2018, RE, along with partners, received a grant of over two billion ISK from the EU's Horizon 2020 Research and Innovation Programme for the GECO (Geothermal Energy and Climate Outlook) project, which is largely based on the Carbfix injection method. GECO, further developed the Carbfix method by injecting into four types of bedrock to test its effectiveness there as had been demonstrated in Icelandic basalt. The project included preparations for pilot carbon dioxide and hydrogen sulfide capture and storage at Nesjavellir Power Plant, which began in the spring of 2023. In addition, preparations are underway for a pilot operation of the second phase of carbon dioxide purification at Hellisheidi Power Plant to support its utilization in the ON Power's Geothermal Park. See more details below.

- **Carbon-neutral Hellisheidi and Nesjavellir Power Plants.** RE aims for carbon neutrality by 2030. To achieve this, nearly all carbon dioxide in the processing chain of ON Powers's power plants must be removed. The primary purpose of the first stages of the abatement unit at Hellisheidi Power Plant was to reduce H_2S emissions, which also allowed for a reduction in carbon dioxide emissions from the plant. Analyses based on the operation of the abatement unit since 2014 show that the same technology can be used to further reduce carbon dioxide emissions from the plant by up to 95%, sequester it in rock, and/or utilize it for value creation. Moreover, nearly all H_2S can be removed and sequestered in rock. In 2021, a grant of 600 million ISK was received for the Silverstone project from the Innovation Fund, the European Union's innovation fund, to build this abatement unit. It is expected to be operational by 2025. An experimental abatement unit at Nesjavellir Power Plant is already in operation, with plans for 95% carbon dioxide injection by 2030.

- **Carbon capture from the atmosphere at Hellisheidi**. Carbfix and ON Power continue their collaboration with the Swiss company Climeworks, which specializes in capturing carbon dioxide from the atmosphere. This is a large-scale project based on experience from a pilot project on integrating atmospheric carbon dioxide capture and mineralization that has been ongoing at Hellisheidi Power Plant since 2017. This project was part of the Carbfix2 project, supported by the EU's H2020 research and innovation program. In 2021, the first of its kind direct air capture plant (Orca) was launched in the ON Power's Geothermal Park. In 2022, construction began on the Mammoth direct air capture plant in the Geothermal Park, in collaboration with Carbfix and ON Power, which will increase the current capacity for capturing and storing atmospheric carbon dioxide tenfold in the area. The new facility is expected to be operational in 2024. The ongoing

development and expansion of the project will contribute to keeping global warming within the limits of the Paris Agreement.

- **Experiments to sequester CO_2 in geological formations with seawater in Helguvík**. Carbfix began experiments in Helguvík in 2023 using seawater to sequester CO_2 in geological formations. The project, named CO2SeaStone, is a collaborative effort between Carbfix and ETH Zurich, the University of Iceland, ÍSOR, the universities of Geneva and Lausanne, and University College London. The project is part of a larger development project, DemoUpCARMA, led by ETH Zurich, which aims to test and develop various technological solutions for capturing, utilizing, transporting, and disposing of CO_2 from Switzerland, either to achieve negative emissions or to reduce them by capturing from industries that struggle to reduce their emissions. Among the solutions DemoUpCARMA is exploring is capturing CO_2 from industry, transporting it to Rotterdam, and from there by ship to Iceland, where it will be dissolved in seawater for injection and mineralization using the Carbfix method. The first containers from Switzerland arrived to Iceland in 2022. The project is funded by Eurostars, Rannís, and the Swiss government's energy and environmental offices. Reykjanesbaer participates in the project by providing Carbfix with facilities in Helguvík. Samskip supports the project by transporting CO_2 in containers from Rotterdam to Iceland.

- **Coda Terminal in Straumsvík**. In 2022, Carbfix received a 16 billion grant from the European Union's innovation fund for the construction of the Coda Terminal (the Soda Station) in Straumsvík. The center will be the first of its kind in the world. Exploratory drilling began in the area in 2022, with the first phase of operations expected to start there in 2027 and reach full capacity by 2032. An environmental impact assessment for the construction began in 2022. In December 2022, a letter of intent for the development of the Coda Terminal was signed between Carbfix, Coda Terminal, the municipality of Hafnarfjördur, and Rio Tinto in Iceland.

- **Hydrogen production in the ON Power's Geothermal Park**. Since 2020, ON Power has been producing hydrogen at Hellisheidi Power Plant on an experimental basis. The hydrogen production was set up as part of a development project under the European Union's Hydrogen Mobility Europe. The power production at the plant is used for hydrogen production during times of lower electricity demand, and the hydrogen serves the public and industry for energy transitions in transport. ON Power is still the only hydrogen producer in the country. Skeljungur handles the distribution of the hydrogen. There are significant opportunities for hydrogen as an energy source, e.g., for heavy vehicles, construction machinery, ships, and aircraft, and in Iceland's energy sector.

- **Energy transition in transportation in Iceland**. The "Better Charging" project is part of a larger European research project, SPARCS, in which Reykjavík Energy, along with ON Power, Veitur Utilities, and the City of Reykjavík, are participants. It is supported by the European Union's innovation fund, Horizon 2020, and the "Better Charging" project is partially funded by the grant. The research in Iceland will provide valuable insights into how electric vehicle owners charge and use their cars and provide important information for large-scale load management.

Better Charging will test different methods for load management with electric vehicle owners over a two-year period, which can be divided into two main categories: methods based on changes to the tariff and methods based on direct control of charging power. See more: https://www.or.is/um-or/nyskopunfraedsla/hlodum-betur

- **Deep drilling** is a project aimed at drilling deeper into the geothermal systems on high-temperature fields – into their roots, that is. The goal is to develop methods to extract geothermal energy from these deep hot strata and thereby expand the exploitable geothermal system downwards. Technical challenges still need to be resolved to make this feasible. Reykjavík Energy and ON Power are participants in several grant projects funded by the European Union (GeoPRO, HotCase, GeConnect, COMPASS) and the Geothermica fund (HEATSTORE, DEEPEN) aimed at addressing these challenges. As part of the DEEPEN project, 500 seismometers along with three fiber optic cables were used for measurements in the summer of 2021 – the largest number of seismometers ever used for measurements in Iceland. The third deep drilling hole in Iceland, IDDP-3, is planned to be drilled in the Hengill area over the next five years in collaboration with other energy companies, and preparations for this project have begun.

- **Improved resource utilization in low-temperature areas for the future**. In the RESULT project, funded by the Geothermica fund, better resource utilization in geothermal fields in urban areas has been explored with partners in Iceland (ÍSOR), the Netherlands, and Ireland. In Iceland, the focus was on the Elliðaárdalur field, which has been used for hot water production since 1968. All information about the wells in the system, their drilling and stimulation, geology, and aquifers was compiled and used to build a three-dimensional geological model of the area. All temperature measurements were compiled and analyzed, and a thermal model of the system was created. Data on the chemistry, temperature, abstraction, and water levels of the wells in the area were compiled, analyzed, and interpreted, as the oxygen content in the water from the system has long been a challenge. Additional chemical, temperature, and flow measurements were made during the period to shed light on the cooling in the area and the origin of oxygen in the system. Based on the work and measurements within the RESULT project, suggestions for improved utilization in the Elliðaárdalur valley were made. These include tracer tests in the system, exploring the use of sodium sulfite chemical injection into the wells to eliminate oxygen before it starts to corrode pipes and equipment, and the potential drilling of new wells in the area in the future.

- **Improved resource utilization in high-temperature areas for the future with water mixing in the district heating of the capital area**. In 2018, a research project started with the aime at merging the district heating systems of the capital area. The system is divided into two parts; one with heated groundwater from ON Power‘s's geothermal power plants and the other with low-temperature water from Veitur Utilities. These two types of water cannot be mixed due to the formation of precipitations. The goal is to modify the hot water processing at ON Power's plants so that water can be produced that can be mixed with the low-temperature water in the

distribution system of the Capital's district heating without forming precipitations. Additionally, the project will increase the maximum power from the current exploited resources, increase the efficiency of the plants' thermal production, which results in less resource waste along with reducing environmental impacts. Research looks promising and has already been useful for water exchanges and summer rest of low-temperature fields in the Capital region. Work is underway on developing a system at the scale of 10 l/s to prove the functionality of a comparable system at full scale these days. The pilot system is expected to be operational in the summer of 2024 and the trials in the system to be completed by the summer of 2025.

- **Drinking water quality.** The implementation of real-time microbial measurements is ongoing. The goal is to create a real-time view to i) increase understanding of the interplay between microbial contamination and weather and environmental factors, ii) always manage water intake according to the best quality and thus maximize consumption handling, especially when weather events threaten water quality at water intake areas, and iii) ensure the best consumption quality all the way to the consumer. Veitur Utilities now has five cell-flow cytometers. In 2023, one cell-flow cytometer was installed at Veitur Utilitie's water intake area in Grábrók for the purpose of monitoring the effects of weather events on the microbial quality of the water source.

- **Future vision for drinking water reserves**. A future vision for reserve matters has been developed for i) City og Reykjavik and Akranes Township, based on forecasts of drinking water needs until 2060, and ii) Borgarnes Municipality, Bifröst, and nearby rural areas, and iii) Hvanneyri and Reykholt based on forecasts of drinking water needs until 2070. Future forecasts also assess potential maximum demand that can occur on dry and sunny summer days. Climate models indicate that the frequency of extreme weather events will increase in the coming years, so conditions leading to peak load are expected to become more frequent in the coming decades. However, more time is needed to assess how these effects materialize.

- **Reserve acquisition for district heating**. Veitur Utilities is working on a strategy project with Reykjavík Energy to create a Guide for all district heating systems where reserves are mapped and future demand forecasts are made. Work for Rangárveita was completed this year. In the coming years, the work will continue, with the utility in Stykkishólmur next in line.

- **Better overview of the collection and distribution system**. Several projects aimed at better overview of the condition, usage, and failures in Veitur Utilities systems with digital meters, automatic data analysis methods, and system models are underway. The electricity utility, along with Reykjavík Energy and ON Power, started the two-year project "Charge Better" in the autumn of 2022, which aims to explore possibilities for controlling/shaping electric vehicle load with the goal of reducing power losses and thus better utilizing the infrastructure already in place. Initial results suggest that the load due to electric vehicles is significantly higher than previous indications suggested. See also the discussion on Energy Transition in Transportation in Iceland above. An initiative is underway regarding control and oversight in the flow of energy through the electricity distribution system. With better information, the system can operate closer to its

limits and delay or avoid certain investments, but also build up the system where data shows that there is a need.

The district heating Utility is working on projects aimed at better overview of the condition, usage, and failures in the systems with digital meters, automatic data analysis methods, and system models.

- **Utilization of wastewater**. A significant amount of waste is generated by Veitur Utilities from the sewage that the wastewater treatment receives from customers. Part of this waste is energy-rich and can be rich in nutrients etc. It has been landfilled, resulting in the emissions of greenhouse gases and the waste of valuable resources. Veitur Utilities aims to reduce this landfilling, especially the part that is biodegradable. The wastewater utility is preparing for the reuse of wastewater waste such as sand, sludge, fat, and screen waste, as landfilling . Wasting these values is outdated and not in the spirit of implementing a circular economy.

  A contract was concluded with the sludge reception at Flúdir for the reception of sludge from Veitur Utilitie's biological treatment plants in Borgarbyggd Municipality.

  Work on assessing the feasibility of reusing sand from sewage treatment plants began at the beginning of 2022 and was completed in 2023. The results of this work are available in a report on Veitur Utilities website and will be used in decision-making in these matters.

  Veitur, in collaboration with the engineering firm EFLA, has been working hard to prepare for a tender on the reception of fat from wastewater treatment plants. Such a service was not available on the market, and Veitur Utilities therefore resorted to an innovation-driven tendering process, as described in the project status report (IS) published in 2023 and available on Veitur Utilitie's website. Veitur Utility sincerely hopes that the intensive dialogue they have cultivated with the market and stakeholders in waste matters will result in bids for the service, despite the need for development by the bidders with the associated capital costs.

- **Development and construction of wastewater simulation models**. Work is underway on the construction and scaling of simulation models in the wastewater system. The models will provide better insights into the operation of the system as they can be used, for example, to assess the volume of untreated sewage, identify bottlenecks in the systems, evaluate the benefits of investment projects, perform alternative analyses, and more.

- **Development of methods to avoid discharges of untreated wastewater in conjunction with construction work in pump stations and the wastewater transport system**. Last year's annual report mentioned a trial of using a portable pump station for bypass pumping while maintenance work was ongoing at wastewater pump station at Faxaskjól. In 2023 and into 2024, work was done on decommissioning pump station at Gelgjutangi by Ellidaárós alongside the commissioning of a new wastewater pump station at Naustavogur. With careful preparation and coordinated efforts of all involved in the project, this challenging task was completed without the

need to discharge untreated wastewater into the sea at Ellidaárós. The new Naustavogur pump station is also the first station of the wastewater system designed innovatively so that it is expected that maintenance and construction work can be carried out without having to fully shut down the station in most cases.

- **Innovation and development projects related to more efficient and improved utilization of geothermal energy.** ON Power participates in three H2020 European grant projects focused on improving operation, efficiency, and utilization; GeoHex, GeoSmart, and OptiDrill:

    - **GeoHex:** The project started in 2019 and concluded in October 2023. The objective was to develop a new metal coating for heat exchangers to increase their efficiency through enhanced thermal conductivity and reduced fouling adherence. For example, seamless coatings were used to reduce corrosion and fouling on heat exchangers. Tests within the project were conducted on corrosion-resistant and anti-scaling coatings, along with thermal expansion tests on the coatings in an Organic Rankine Cycle (ORC) in a real environment at Hellisheiði Power Plant.

    - **GeoSmart:** The project began in 2019 and is expected to conclude in 2024. Its goal is to design methods to increase the profitability of geothermal energy utilization, considering energy storage, energy fluctuations, and energy efficiency. Technology will be developed to store excess thermal energy produced during low-demand periods (at night) and use it during peak demand periods (during the day). With this technology, it will be possible to distribute and balance the load on the geothermal plant throughout the day, thus increasing the flexibility in production. Efficiency in such a system will be enhanced with a "hybrid" cooling system and designed to reduce scaling.

    - **OptiDrill**: The project started in 2021 and aims to conclude in 2024. The objective is to optimize drilling techniques to reduce drilling costs by up to 30% of the total cost. A part of the drilling operation will be automated with artificial intelligence, where appropriate trajectories from different geological areas/layers will be input into simulation software.