Proceedings World Geothermal Congress 2026
Calgary, Canada, June 8 – 11, 2026.

The Þeistareykir Geothermal Power Station: Improved Efficiency for Electricity Generation with the Addition of a Topping Unit.

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Keywords: Geothermal Power Station, Theistareykir, Þeistareykir, Iceland, Topping Unit, Environment, High pressure, Energy Efficiency.

ABSTRACT

Landsvirkjun (the National Power Company of Iceland) owns and operates the Þeistareykir Geothermal Power Station (hereinafter referred to as Theistareykir Geothermal Power Station) (ThGPS), located on the north side of Iceland, which has two 45 MW_e condensing steam turbines and utilizes steam from over 10 wells in the area. Due to high silica concentrations in the geothermal fluid, many wells are operated at wellhead pressures significantly higher than those for which the existing steam-gathering system, separators, and turbines are designed. This excess pressure is today dissipated using orifice plates. The Topping Unit project was established to recover this unused energy and improve overall efficiency without increasing steam extraction, thereby making better use of the existing geothermal resources in the area.

The concept introduces a new high-pressure steam-gathering system, a large separator, and a back-pressure turbine in a dedicated powerhouse. The exhaust steam from the Topping Unit then feeds directly into the existing system, allowing seamless integration with the condensing units. In the initial design phase, it was estimated that the Topping Unit could increase generating capacity by up to 25 MW_e without impacting current turbine output. Since it utilizes existing steam, the project requires no additional wells and has minimal environmental impact. The unit is also being designed with black-start and island-mode capabilities, enhancing regional grid resilience. The project exemplifies Landsvirkjun's commitment to maximizing efficiency, reducing emissions, and optimizing the area already used for power production and other infrastructure. It is also an innovative way to better use natural resources at the site. It is part of a broader development strategy at Theistareykir, which aims to expand the power plant further. This approach is in line with Landsvirkjun's role which is to maximize the value of the renewable energy resources the company has been entrusted with, in a sustainable, efficient and economical manner.

1 INTRODUCTION

The Theistareykir Geothermal Power Station (ThGPS), located near Húsavík in the North-East of Iceland, is operated by Landsvirkjun (the National Power Company of Iceland). ThGPS currently generates 90 MW_e with two 45 MW_e condensing steam turbines commissioned in 2017–2018. Theistareykir was conceived as a multi-phase development project, designed for conservative expansion as the knowledge of the geothermal field increased. Plans for a third condensing turbine, which will increase capacity to 135 MW_e, are underway. Furthermore, it can be expanded further with the fourth condensing turbine, bringing the capacity to 180 MW_e.

Geothermal energy plays a crucial role in Iceland's 100% renewable power system, providing stable baseload generation alongside hydropower. The field's location on the tectonic boundary between the North American and Eurasian plates provides geothermal conditions for young volcanic formations.

Since commissioning, the operation of the Theistareykir Power Station has been highly successful, demonstrating both the stability and productivity of the geothermal reservoir. Continuous monitoring and operation over several years have provided valuable insight into the field's chemistry and thermodynamic behavior. The experience has shown that, due to the geochemical composition of the geothermal fluid, the

production wells must be operated at higher wellhead pressures than the existing steam-gathering system, separators and turbines were designed for. It is therefore necessary to operate wells at higher wellhead pressure to limit silica scaling inside the well and the formation, and thereby preserving well performance over longer periods.

Initially, as the design parameters for the Theistareykir Power Station were set, knowledge of the reservoir conditions was still evolving. The design pressure for the steam system and condensing turbines was selected based on the available test data from early wells, which suggested a lower average enthalpy and more moderate pressure regime. At that stage, not all production wells had been drilled or fully evaluated, and the steam supply was expected to include a broader range of well conditions. As additional wells were brought online, it became clear that the geothermal fluid had higher average enthalpy and required higher wellhead pressures to ensure chemical stability. This insight emerged through operational experience and long-term monitoring, once the field had reached steady production.

While this requirement confirms the strength and sustainability of the reservoir, it also reveals an opportunity: the excess wellhead pressure, currently dissipated with orifice plates, represents untapped energy potential. The Topping Unit Project was therefore launched to recover this energy, transforming what was once a necessary operational constraint into a new source of clean, renewable electricity and a significant step forward in geothermal efficiency.

2 THE THEISTAREYKIR GEOTHERMAL POWER STATION

The geothermal area at Theistareykir has great potential for geothermal utilization and has been under development for decades. The geothermal field is a part of the north-east highlands of Iceland. The area is registered in the Icelandic Nature Conservation Register because the fumaroles there are very active. Stóravítishraun lava field covers approximately 525 km^2 and extends across the area. The Theistareykir geothermal field is part of the Theistareykir volcanic system, characterized by high-temperature geothermal reservoirs exceeding 300°C. Production wells, drilled to depths of 1.700–2.700 meters, tap a resource rich in silica and other minerals typical of young basaltic systems. The steam-gathering system collects steam from multiple well pads, currently distributed across a 1,3 km^2 field, and directs it to a central separator station. A good overview of the 90 MW_e Geothermal Power Plant in Theistareykir can be found in *Knútsson et al*. (2018). *Figure 1* shows the current Theistareykir Geothermal Power Station.



Figure 1. The figure above shows the current Theistareykir Geothermal Power Station. (Photo taken by Hreinn Hjartarson).

The Theistareykir geothermal field has been structured as a phased expansion, designed to evolve in step with operational experience and growing understanding of the geothermal resource. Each phase of development, from the initial test wells to the construction of the first two condensing turbines, has provided valuable information on reservoir performance, chemistry, and field dynamics.

This phased approach allows Landsvirkjun to make data-driven decisions for each subsequent stage. Before committing to new capacity, detailed production and reinjection data are analyzed to confirm reservoir stability, pressure response, and long-term sustainability. Lessons learned from daily operation directly inform engineering design choices, such as the layout of new well pads, the optimization of the steam-gathering system, and the configuration of future turbines.

By proceeding in measured steps, the Theistareykir project ensures that each expansion builds on proven performance rather than theoretical models alone. This minimizes technical and geological risk, allows for the fine-tuning of system parameters such as wellhead pressure and separator conditions, and ensures that energy extraction remains balanced with the natural renewal of the geothermal resource.

The planned Topping Unit is a continuation of this incremental and adaptive development strategy. It represents the next logical step in improving efficiency and maximizing energy recovery from the existing wells before larger capacity additions the third and fourth condensing turbines are implemented. In this way, Theistareykir continues to grow responsibly, guided by experience, operational data, and a deep respect for the sustainability of the geothermal field.

In geothermal operations, silica scaling poses a challenge for longevity. When the pressure in a well drops below the silica saturation point, solid silica precipitates, forming deposits that can reduce permeability and eventually block flow. To limit this, Theistareykir's production wells are operated above the silica scaling pressure. This keeps the wells productive and stable, but results in high wellhead pressures, often two to three times higher than the inlet pressure of the condensing turbines.

The excess wellhead pressure is managed through orifice plates at the wellheads before transporting the fluid to the steam-gathering system, dissipating significant potential energy. Meanwhile, silica scaling is relocated from the subsurface to surface infrastructure, where it can be managed through maintenance and mechanical or chemical cleaning. This approach preserves the well's integrity and has proven highly effective in ensuring long-term reservoir sustainability and stable production.

The field's design philosophy for managing surface scaling laid the foundation for the Topping Unit concept. By recovering the energy released during this pressure reduction, the new system will enhance power generation without altering reservoir management or extraction rates.

3 HARNESSING THE PRESSURE DROP: THE TOPPING UNIT CONCEPT

The Topping Unit is designed as an integral extension of the ThGPS, not as a standalone power plant. It forms the next logical step in the plant's evolution utilizing the existing geothermal wells. The Topping Unit is an innovative approach to improving geothermal efficiency by capturing the energy potential within the steam-gathering system that is currently discarded. It introduces a separated high-pressure steam-gathering system connected to selected production wells, a new large-capacity separator, and a back-pressure turbine housed in a powerhouse near the main separator station. *Figure 2* shows simplified progress diagram of the Topping Unit. *figure 3* shows the powerhouse and steam separators and *figure 4* shows the layout of the Topping Unit in Theistareykir area.

High-pressure steam from the wells will pass through the new separator to ensure steam quality and protect the turbine. The steam will then expand through the turbine to the existing plant pressure, driving a generator before joining the mid-pressure system feeding the current two condensing units. The integration is seamless, and the topping unit acts as an additional expansion stage rather than a separate power block. The project also includes bypass loops to maintain continuous operation during maintenance periods of the Topping Unit.

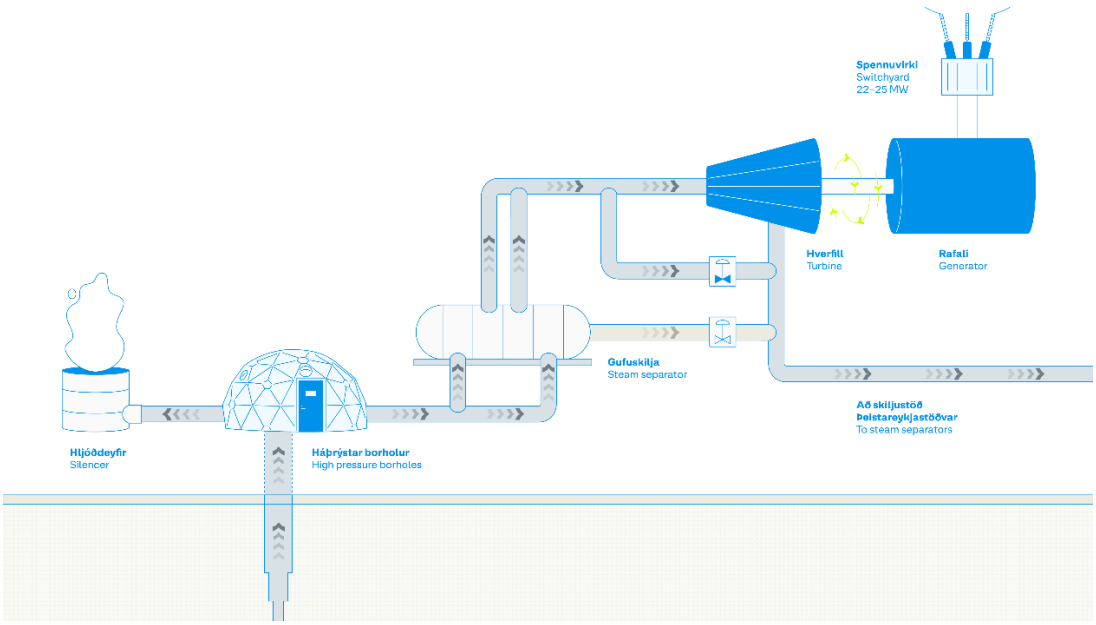


Figure 2 - Simplified progress diagram of the Topping unit.

Thermodynamic simulations predict a substantial efficiency increase, while maintaining steam conditions that safeguard existing turbine performance. Control integration with the main plant's distributed control system ensures synchronized start-up, load sharing, and real-time optimization.

In addition to energy recovery, the unit is being designed with advanced resilience features. The turbine will have black-start and island-mode capabilities, allowing it to supply critical loads or restart the grid during outages. This design supports energy security in the North-Eastern region and enhances the plant's role as a flexible, reliable contributor to Iceland's renewable grid.

The powerhouse design emphasizes efficiency and minimal impact. It will occupy a small area within the existing industrial footprint, with insulated steel framing and corrosion-resistant components. Emphasis has been placed on landscaping and ensuring that structures are in harmony with the environment.



Figure 3. A detailed design of the Topping Unit powerhouse and separator. (Drawings from Verkís Consulting Engineers, 2024).

By introducing the HP steam line, the new system will relieve flow capacity on the MP steam network. This not only improves overall hydraulic performance and stability but also reduces loading and pressure losses in the existing pipelines. In turn, this optimization will lower the cost and complexity of future expansions, including the planned third and fourth condensing turbines as the new pipes create more room for steam from future wells.

The new High-Pressure (HP) steam-gathering system will be installed alongside the current system for the condensing turbines. This configuration minimizes surface disturbance for minimal environmental impact and maintains close integration with the existing mid-pressure (MP) steam network that currently feeds the condensing turbines.

As new production wells are drilled to supply steam for the third and fourth turbines, they can be connected directly to the HP steam-gathering system with minimal additional infrastructure. This forward-looking design ensures that the topping unit not only recovers currently wasted energy but also strengthens the foundation for future growth, improving both technical and economic efficiency across the Theistareykir development.

Currently, the project is in the tender design phase, and construction could start as early as 2026, with handover planned in early 2029.

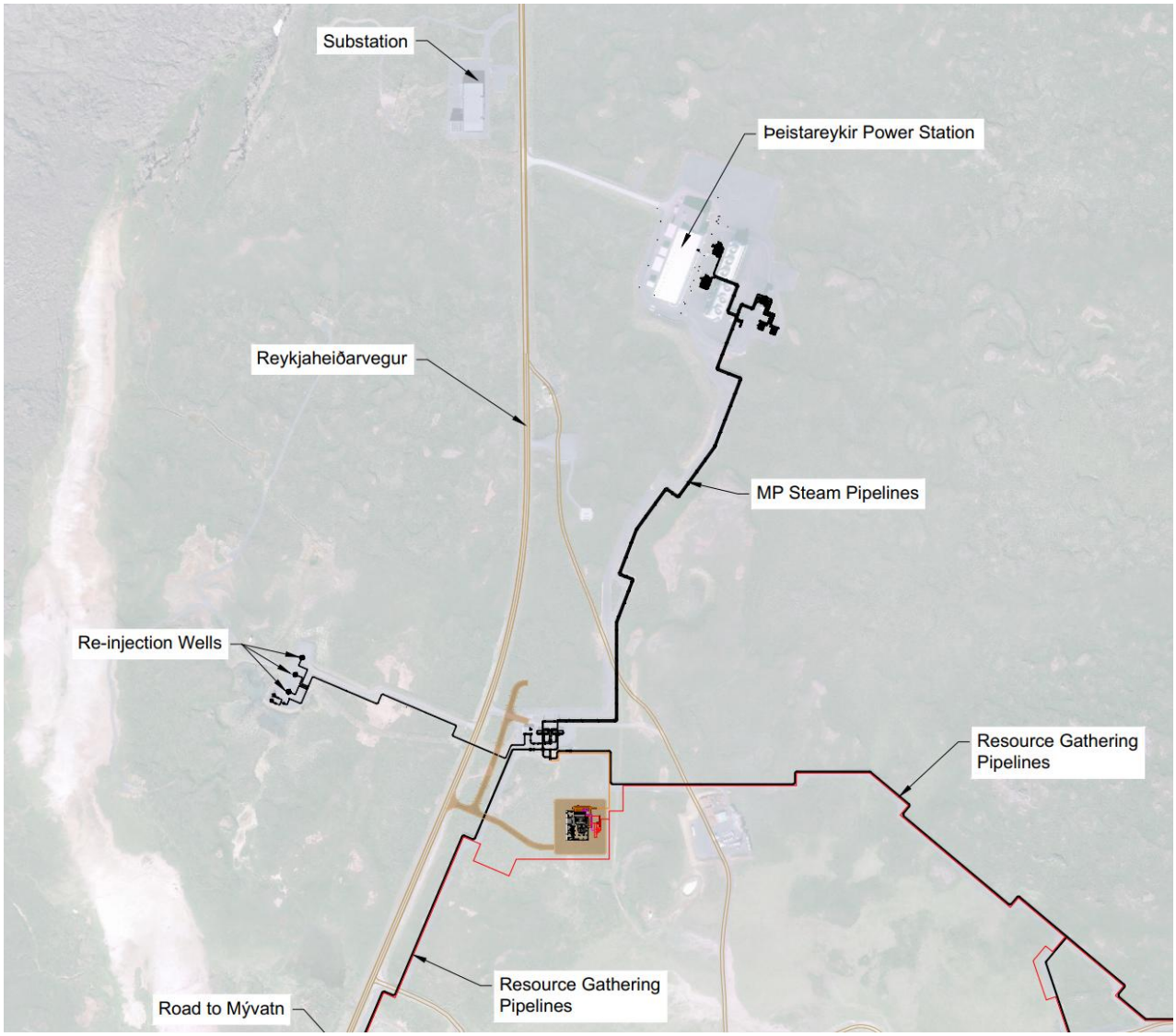


Figure 4. The figure above shows the layout of the Topping Unit in the Theistareykir area. (Drawings from Verkís Consulting Engineers, 2024).

4 STRATEGIC CONTEXT AND SUSTAINABLE DEVELOPMENT

The Topping Unit Project embodies Landsvirkjun's broader strategy to maximize efficiency, reduce emissions, and make better use of areas already dedicated to energy production. Instead of expanding into new land or drilling additional wells, Landsvirkjun is improving the productivity of existing assets. This approach demonstrates how technological innovation can drive sustainable growth within existing environmental and social boundaries. This is in line with Landsvirkjun's role which is to maximize the value of the renewable energy resources the company has been entrusted with, in a sustainable and efficient manner.

By integrating the new turbine into the existing system, each unit of steam will generate more electricity, directly lowering the plant's carbon footprint. This aligns with Landsvirkjun's environmental strategy and supports national climate goals. Theistareykir will continue to serve as a model of responsible development, demonstrating that growth, efficiency, and environmental protection can advance together.

The project reflects the evolution of Icelandic geothermal expertise. From early exploratory developments to highly optimized systems like Theistareykir, Icelandic engineers have refined the art of efficiently harnessing geothermal energy.

5 ENVIRONMENTAL AND OPERATIONAL BENEFITS

The Theistareykir Topping Unit Project delivers environmental benefits that extend well beyond the immediate gain in efficiency. Because it requires no additional wells or additional extraction, the project's physical and ecological footprint remains minimal. The entire installation is confined to the existing industrial zone, avoiding new land disturbance or visual impact.

The project also contributes to Landsvirkjun's objective of reducing power plant emissions per kilowatt-hour. By generating more electricity from the same amount of geothermal fluids, specific CO_2 emissions per kilowatt-hour will decrease. The topping unit reinforces Landsvirkjun's goal to continually reduce its carbon footprint.

The black-start and island-mode capability provides added security for Iceland's northeastern grid. In the event of a grid fault, Theistareykir will be able to operate independently, restoring supply locally and contributing to grid recovery.

6 FUTURE OUTLOOK AND STRATEGIC VISION

The Theistareykir Topping Unit Project represents a forward-looking approach to geothermal energy, one that blends innovation, sustainability, and strategic growth. Its successful implementation will set the stage for future expansions of the Theistareykir Power Station, including the planned third and fourth turbines, while serving as a model for similar projects across Landsvirkjun's geothermal portfolio.

By demonstrating that additional capacity can be achieved through optimization rather than solely through expansion, the project strengthens Landsvirkjun's long-term geothermal strategy. It demonstrates that the path to greater energy production does not always require new infrastructure, but rather smarter use of what already exists. This philosophy of maximizing the output of each natural resource while minimizing its impact lies at the heart of Landsvirkjun's role and strategy which can be seen in Figure 5 below.

At its foundation, the company's role emphasizes responsible utilization of Iceland's renewable resources. The Topping Unit directly embodies this principle. It increases electricity generation without requiring new wells or additional land use, thereby enhancing output while protecting the geothermal reservoir and minimizing surface disturbance. The project demonstrates that resource stewardship and energy expansion can coexist with a message that resonates strongly across Landsvirkjun's entire operation.

The second layer of the strategy pyramid focuses on value creation for Icelandic society. By increasing the efficiency of existing assets, the Topping Unit delivers measurable economic and environmental value. More clean energy will be available to support regional development, power new industries, and strengthen Iceland's renewable grid, all without compromising the long-term health of the resource. This represents the type of responsible growth that Landsvirkjun strives to achieve: one that benefits both people and nature.

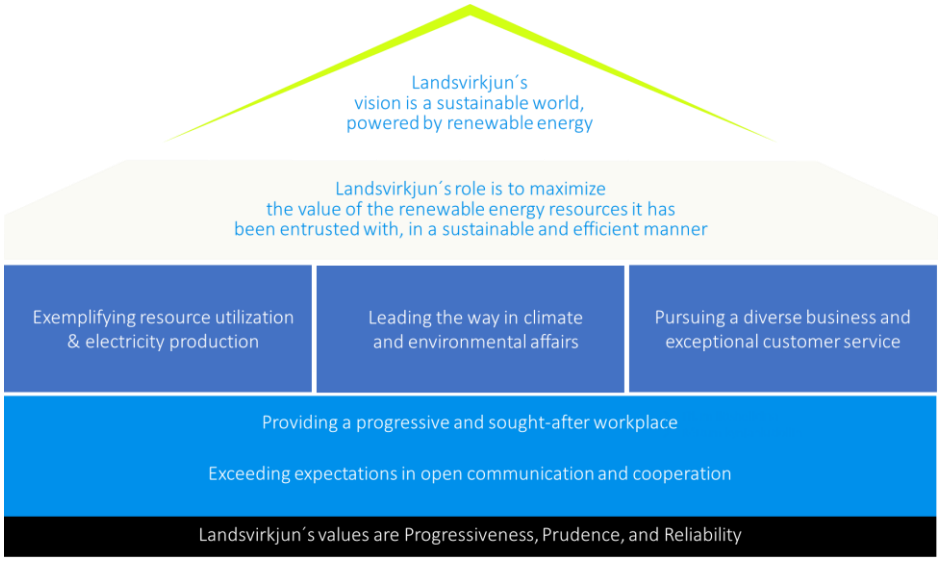


Figure 5. The vision and role of Landsvirkjun.

At the top of Landsvirkjun's strategic hierarchy is sustainability — the unifying goal that connects environmental, economic, and social responsibility. The Topping Unit contributes to this objective on multiple levels. Environmentally, it lowers the plant's specific CO_2 emissions and improves the efficiency of the geothermal cycle. Operationally, it adds resilience through black-start and island-mode capabilities, enhancing the reliability of the North-East Icelandic grid. Socially, it sets a precedent for projects that combine technical excellence with environmental care, strengthening public trust in geothermal development.

7 SUMMARY

The Theistareykir Topping Unit Project is an efficiency-focused expansion of the Theistareykir Geothermal Power Plant, operated by Landsvirkjun. Because the geothermal fluid contains high silica concentrations, many production wells must run at higher wellhead pressures than the existing steam system was designed for. This excess steam pressure is currently reduced through orifice plates.

The Topping Unit will recover this unused energy by adding a new high-pressure steam-gathering system, a new separator, and a back-pressure turbine whose exhaust feeds into the existing mid-pressure steam-gathering system. The concept is expected to add up to 25 MWe, resulting in minimal environmental impact and improved overall efficiency.

The project builds on operational experience gained since the plant was commissioned. Long-term monitoring has shown that the reservoir has higher average enthalpy and requires more elevated pressures than early design data indicated. The new system not only recovers energy but also supports future expansion toward the third and fourth turbines.

Aligned with Landsvirkjun's strategy, the Topping Unit maximizes the value of existing renewable resources, reduces emissions per kilowatt-hour, strengthens grid resilience, and demonstrates responsible, data-driven geothermal development.

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