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

Geothermal Waste to Value: Quantifying Availability at Hellisheidi Combined Heat and Power Station, Iceland

Taylor Alexandra Martin[1,2]*, Arna Palsdottír[1], Baldur Brynjarsson[1], and Juliet Ann Newson[2]
Reykjavik Energy[1]*, Reykjavik University Iceland School of Energy[2]
Taylor.Alexandra.Martin@orkuveitan.is

Keywords: Circular Economy, Cascade Utilization, Sustainable Resource Management

ABSTRACT

The main objective of the project is to evaluate waste streams from electricity and hot water production at the Hellisheidi Combined Heat and Power Geothermal Power Plant located in Iceland. Methods include defining waste, establishing boundary conditions specific to the plant, and identifying waste-to-value opportunities. Work investigates sources of waste, disposal methods, environmental impacts, and potential cascade utilization opportunities. Results indicate the portion of available excess that could be used in internal engineering processes and by the existing geothermal resource park. Ultimately, the tool developed through this research is evaluated alongside Reykjavik Energy's Research and Innovation department and ON Power's Geothermal Park to assess its utility in supporting future sustainability initiatives.

1 INTRODUCTION

Geothermal power plants generate a range of waste byproducts during production, many of which hold potential value as a secondary resource. Circular economy and cascade utilization principles provide structured approaches for repurposing these streams but translating these concepts into practice calls for a foundational understanding of what is realistically available.

This work aims to fill that gap by quantifying excess heat, water, gases, and minerals from Hellisheidi and evaluating their stability, constraints, and potential for secondary use. By establishing boundary conditions, characterizing disposal pathways, and incorporating operational, regulatory, and environmental constraints, the analysis distinguishes between total annual waste generated and waste reliably available for secondary use.

The broader goal is to bridge the space between innovation and what is operationally feasible. Understanding availability is essential for determining future utilization pathways, required infrastructure, pricing considerations, regulatory limitations, and the implications of new uses on electricity and hot water production. By establishing this foundation, the study enables informed planning for expanding ON Power's geothermal resource park and supports Reykjavík Energy's long-term sustainability objectives.

2 BACKGROUND

Background work defines a circular economy, cascade utilization, and eco-industrial parks, and applies them to the geothermal industry to highlight opportunities, methods, and challenges of using waste as a secondary resource stream.

2.1 Key Concepts

Traditional production systems often follow a linear "take-make-dispose" model, where resources are extracted, processed into products, and ultimately discarded as waste. This approach prioritizes production and profit over sustainability, leading to over-extraction, biodiversity loss, and resource depletion, Ghisellini et al., (2016). The circular economy provides a sustainable alternative, recognizing the finite nature of resources and aiming to retain materials and energy in use for as long as possible uses, Campbell Johnston et al (2020). In this system, waste becomes secondary raw material, promoting reuse, recycling, and recovery while maximizing the value of already extracted resources, Ghisellini et al., (2016).

Cascade utilization is a practical strategy within the circular economy, where energy or materials are used sequentially across multiple stages, typically moving from higher-value to lower-value uses. By extending the number applications a resource passes through, cascade use increases overall efficiency, reduces the need for new inputs, and minimizes waste along the value chain, Kalverkamp et al., (2017).

Eco-industrial parks represent a tangible implementation of these concepts. By connecting producers across industries through shared resource networks and byproduct exchange, they operationalize both the circular economy and cascade use. One producer's waste becomes another's secondary raw material, reducing disposal volumes and fostering collaboration, innovation, and sustainability, Van Berkel et al., (1997), Kalverkamp et al., (2017).

While the circular economy offers a strong alternative to linear systems, it is not without challenges. Definitions vary, ownership of secondary products can be unclear, and markets for these products offer variable returns on investment. Multidirectional resource flows and time-dependency add complexity, as secondary products may be produced sporadically or require years to reach high-value applications, Kalverkamp et al., (2017). Globally, only about 12% of secondary resources currently reenter the economy, Campbell Johnston et al., (2020), highlighting the gap between theory and practice. Although these barriers are significant, real-world examples, including lithium battery reuse in the automotive sector and cascading wood-products, demonstrate that circular models can succeed when appropriately designed, Campbell Johnston et al., (2020), Kalverkamp et al., (2017).

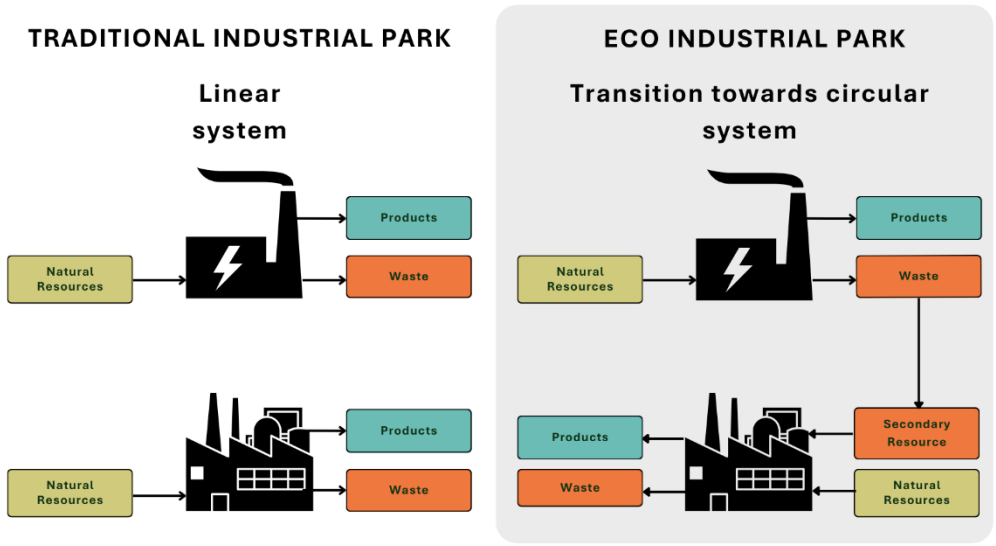


Figure 1: Comparison of Traditional Linear Systems and Circular Eco Industrial Parks, adapted from Van Berkel et al., (1997)

2.2 Applications to Geothermal

In geothermal systems, heat, water, gases, and minerals can be repurposed to create additional value while reducing environmental impacts. Many of the most mature examples of the circular economy in the energy sector appear in geothermal resource parks, where waste streams support new products and services ranging from district heating to mineral recovery.

A general Carnot expression illustrates the value of applying geothermal fluids across successively lower temperatures:

$$\eta = 1 - \frac{T_L}{T_H} \tag{1}$$

T_H is the reservoir temperature, or highest use temperature, and T_L is the reinjection temperature, or lowest use temperature. Cascading geothermal energy increases the value of extracted resources, allowing the same fluid to be applied at progressively lower temperatures. Lower use temperatures increase efficiency, allowing the same resource to deliver more value. In addition to more efficient use of resources, cascade use in geothermal can also enhance economic returns, Rubio-Maya, et al. (2015).

Global examples illustrate the diversity of geothermal cascade use. In the Americas, geothermal heat supports domestic hot water, mineral recovery, and agricultural production. Asia and Africa highlight community-focused heating and cooling systems, often integrated with solar technologies. The Middle East increasingly applies geothermal water to absorption chillers and food processing. Europe emphasizes district heating and emission-reducing solutions for community centers and industry, Rubio-Maya, et al. (2015).

Countries with higher-temperature reservoirs, such as Kenya, New Zealand, and Iceland demonstrate some of the most developed geothermal resource parks, using heat, separated water, gases, and minerals to support hydrogen production, carbon capture, and industrial application. However, high temperatures are not required for successful cascade use: moderate-temperature systems also supply greenhouses, aquaculture, drying facilities, spas, and mineral recovery using water down to 15–30°C, Rubio-Maya, et al. (2015), Lund et al. (2020). Together, these examples show that geothermal resource parks can convert waste into value across a broad temperature range, turning what would otherwise be discarded into additional value, supporting efficiency, new products, and environmental and economic benefits.

2.3 Hellisheidi Power Plant

The subsequent sections apply the background concepts directly to the Hellisheidi Combined Heat and Power Plant, which serves as the focus of this study. With a nameplate capacity of 303 MWe and planned expansion to 400 MWth for district heating, Hellisheidi is Iceland's largest geothermal plant and among the largest globally. Electricity production is driven by six high-pressure turbines and one low-pressure turbine, while the thermal plant currently supplies approximately 950 L/s, equivalent to 210 MWth, Karlsdottir er al. (2020).

ON Power operates an established geothermal resource park alongside the plant, utilizing electricity, separated geothermal water, hot and cold water, and geothermal gases as secondary resource streams, as shown in Figure 2. Current products include carbon capture and storage, silica and algae supplements, and hydrogen for transportation, Adalsdottir et al. (2021). These activities demonstrate the practical application of circular-economy principles and illustrate how geothermal operations can support diverse industrial and environmental solutions.

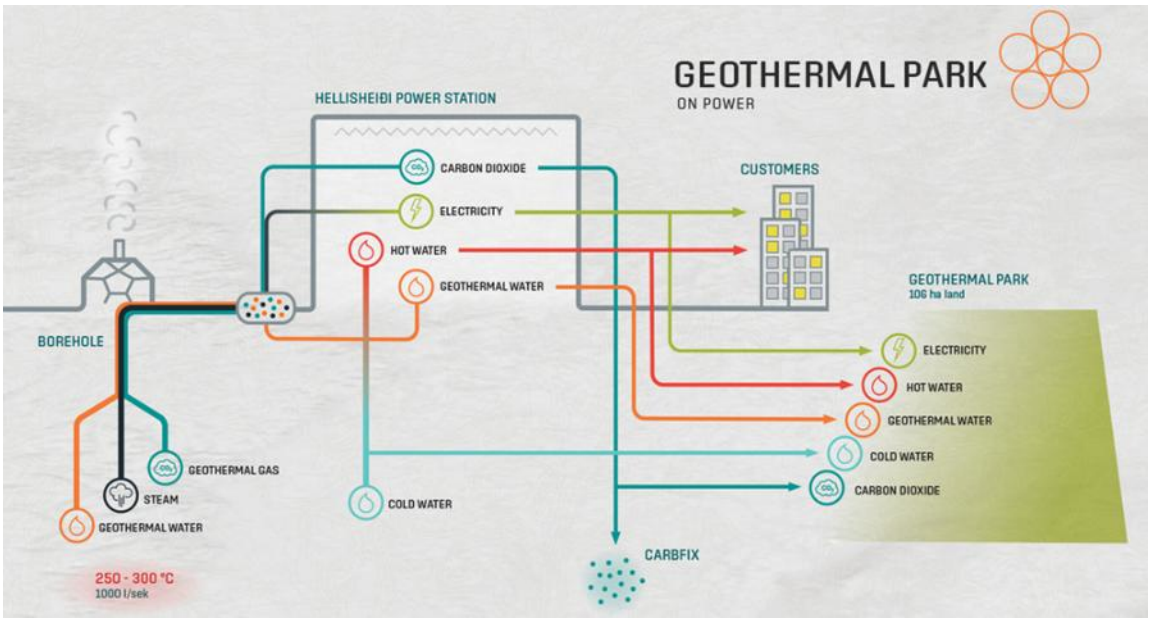


Figure 2: Flowchart of ON Power Geothermal Park, Hellisheidi, Iceland

3 METHODS

Background work first examines global waste-to-value concepts, highlighting practical examples and relevant opportunities for cascade utilization in the geothermal industry. Building on this foundation, the methodology integrates Hellisheidi's hot water and electricity production systems to identify waste streams, quantify excess availability, and evaluate the potential for expanded cascade use. The analysis focuses on secondary-resource opportunities that could support both plant performance and broader geothermal park operations while maintaining compliance with environmental and regulatory requirements, as illustrated in Figure 3.

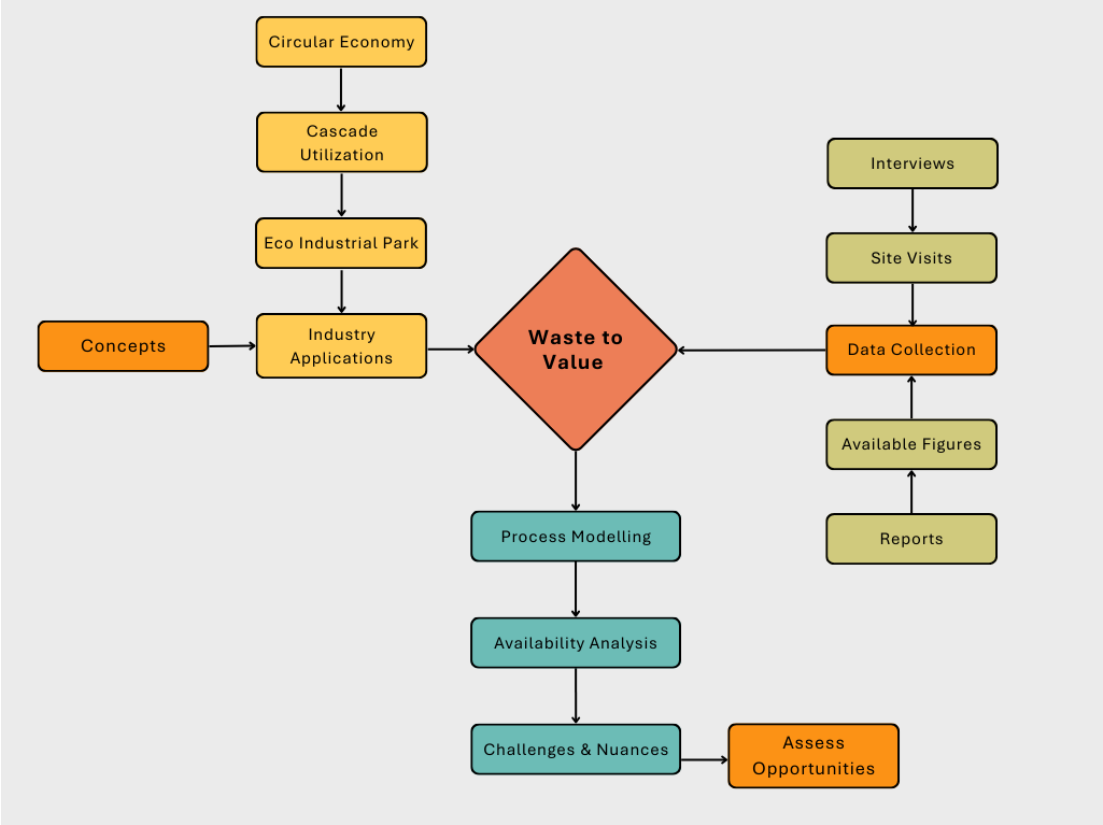


Figure 3: Waste to Value Analysis Flowchart

3.1 Process Modelling

A detailed process model of Hellisheidi was developed to characterize waste generation and management across electricity production, hot water production, and major maintenance events. The model traces the movement of streams through high- and low-pressure turbines, condensers, cooling towers, and the district-heating plant, identifying primary waste streams and peripheral flows to undergo an availability assessment.

Flows were mapped to their current uses within the resource park, their function in internal operations, and their existing disposal pathways. For example, steam condensate is used both within the resource park and to dilute geothermal separator water in the reinjection system, in compliance with regulatory limits. These interactions highlight the inherently multidirectional nature of flows through the power plant and the operational tradeoffs involved in reallocating any given stream, highlighted in Figure 4.

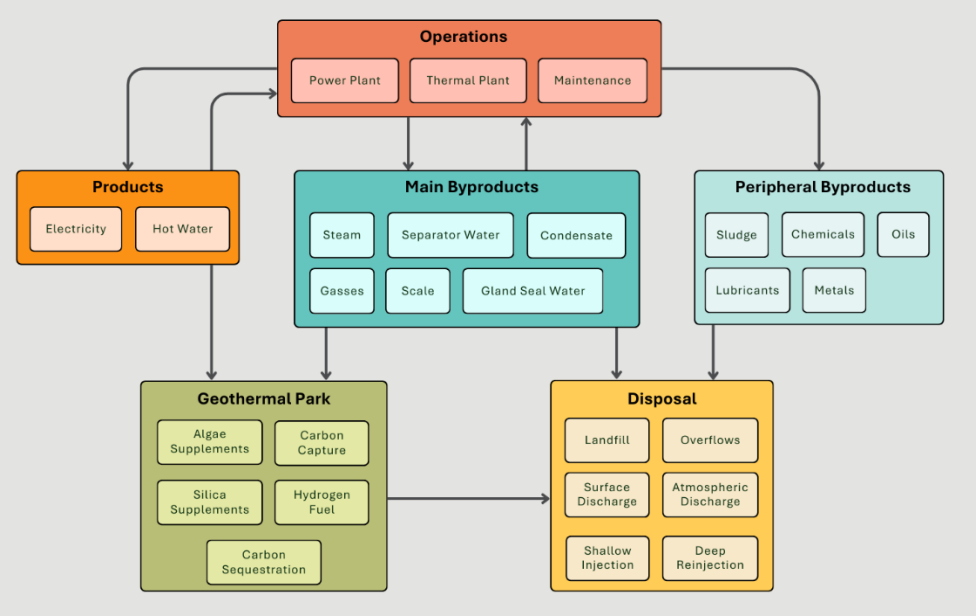


Figure 4: Process Modelling Flowchart

3.2 Availability Analysis

The process model was refined through site visits, interviews with operators, engineering drawings, existing models, and internal reports. This includes documenting how each stream is used within the plant, its interactions with other streams, disposal pathways, and the associated regulatory or environmental considerations.

Sensor data from more than one hundred Supervisory Control and Data Acquisition (SCADA) inputs are analyzed using daily and 10-minute averages to establish a mass balance for each stream and determine excess quantities. The approach relies directly on measured data rather than constructing a thermodynamic model to estimate mass flows, allowing for algebraic calculation of excess without evaluating enthalpy, entropy, heat, or work terms. Because production and demand vary daily and seasonally, each time interval is treated as its own steady state, as shown in equation (1).

$$\sum \dot{m}_{In} = \sum \dot{m}_{Out} \tag{2}$$

Stream-specific mass balances are defined using the process model. For example, condensate exiting the condenser , $\dot{C}_{Out}$, is distributed to reinjection $\dot{C}_R$, non-condensable gas collection $\dot{C}_{NCG}$, cooling towers, $\dot{C}_{CT}$, boiler pumps, $\dot{C}_P$, the thermal plant, $\dot{C}_{HW}$, and the gas capture plant, $\dot{C}_{HEX}$. The remaining portion represents the excess, $\dot{C}_E$. Available sensor data for all input terms allows the excess term to be directly calculated, as shown in equation (2).

$$\dot{C}_{Out} = \dot{C}_R + \dot{C}_{NCG} + \dot{C}_{CT} + \dot{C}_P + \dot{C}_{HW} + \dot{C}_{HEX} + \dot{C}_E \tag{3}$$

Outliers were checked against maintenance and emergency events, which often produce short-term peaks or drops. Both instantaneous excess and annual totals were quantified, along with the fraction realistically available for secondary use, which accounts for fluctuations in demand and production.

Results are presented for current and projected operations after the implementation of planned projects by 2030, providing insight into both existing and future opportunities for cascade utilization within the geothermal park.

4 RESULTS

Due to confidentiality agreements between ON Power and its partners in the resource park, detailed results and specific quantitative figures from this work cannot be disclosed. Instead, Table 1 provides a high-level overview of the findings, accompanied by representative examples that do not breach confidentiality. Results address key elements of the analysis, including each major byproduct, its current handling or disposal pathway, and the technical, regulatory, or operational considerations associated with potential secondary use.

Table 1. Overview of Results

Focus Area	Flow	Comments
Available Products	Groundwater	Figures are provided in tons/yr, m/s, and l/s for total flow through the power station, flow used for internal operations and the existing resource park, maintenance and emergency events, and excess for 2023. The portion of excess available for use as a secondary resource is provided in l/s and tons/yr for current operations and operations post 2030, after accounting for estimated flows utilized by projects currently in development.
	Steam	
	Condensate	
	Separated Geothermal Water	
	Gasses	
	Scale	
Regulated Disposal Methods	Reinjection	This section outlines regulatory requirements, addresses whether discharge was within bounds, and any challenges or successes. Figures are presented along with major markers from Reykjavik Energy's Annual Report
	Surface Release	
	Emissions	
	Hazardous Waste	

Figure 6 illustrates current and potential cascade use at Hellisheidi. In the current system, geothermal resources are utilized from approximately 250°C at the wellhead down to around 60°C at reinjection. Along this temperature path, existing processes already produce hydrogen fuel, hot water, carbon capture and mineralization, and algae and silica supplements through integrated use of waste streams.

Future opportunities, including proposed thermal lagoons, greenhouses, or aquaculture, extend potential utilization down to approximately 30°C, illustrating the range of possible applications identified through the availability analysis.

Overall, while Hellisheidi already hosts a mature geothermal resource park with several established circular-economy applications, results indicate significant remaining opportunities for growth. The availability analysis highlights which streams have reliable excess, how availability varies through operational cycles, and which flows have the strongest potential for new secondary uses.

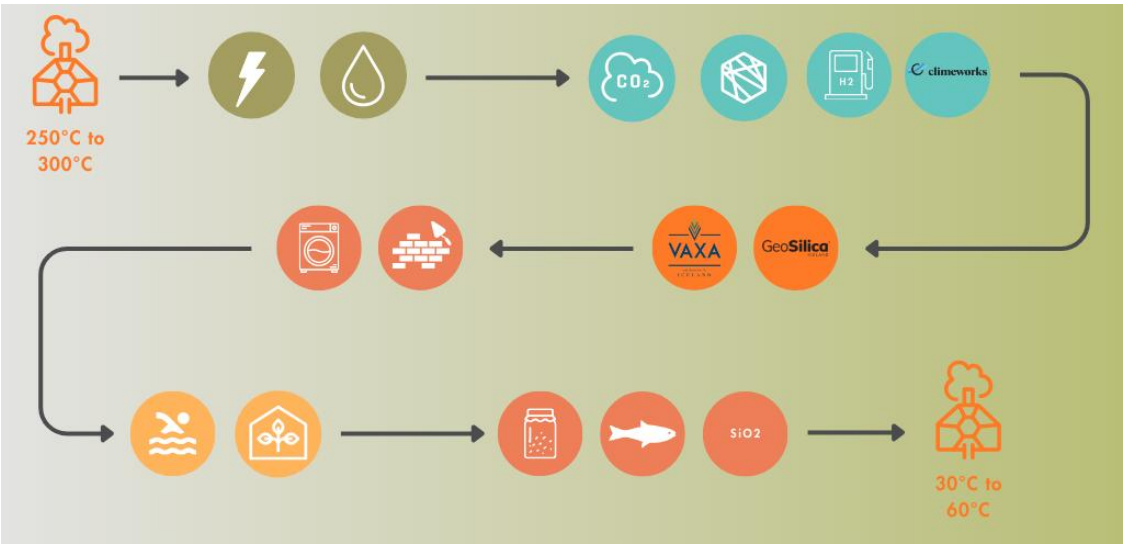


Figure 6: Geothermal Park Opportunities at Hellisheidi

5 DISCUSSION

Electricity and hot water production, environmental management, and the resource park at Hellisheidi form an interconnected system where changes in one area often influence others. Understanding these interactions is central to identifying realistic waste-to-value opportunities.

The analysis shows that many waste streams already support internal operations and the geothermal park. For example, using steam condensate as a secondary resource stream and dilution of separator water supports additional products, reinjection performance, and reservoir health. Shared flows between ON Power, Carbfix, and Climeworks have enabled near-zero CO_2 and H_2S emissions from the power plant, demonstrating the benefit of leveraging byproducts rather than disposing of them.

At the same time, several interdependent constraints shape the feasibility of additional cascade uses.

- *Operational variability:* Electricity and hot water demand change seasonally, during maintenance, and during emergency events, influencing how much waste can be reliably committed as a secondary resource.
- *Fluid properties:* Variations by well, turbine, and processes determine scaling risk, treatment needs, allowable sourcing points, and viability of downstream users.
- *Shared ownership and pricing:* Multidirectional flows and overlapping process boundaries create uncertainty around responsibility, rights to secondary products, and long-term contract structures.
- *Market and regulatory context:* Electricity, hot water, and secondary markets, such as hydrogen, differ in profitability and regulatory stability. Public mandates, such as prioritizing cold water for district heating over hydrogen production, can outweigh purely economic considerations.

Taken together, these findings emphasize that cascade opportunities cannot be evaluated in isolation. They require a system-wide perspective that accounts for technical interdependencies and evolving priorities. Modifying one stream's management can create ripple effects across multiple processes. Successful expansion of cascade utilization requires navigating these technical, regulatory, and economic interactions holistically to identify opportunities that are both feasible and resilient over time.

6 NEXT STEPS

Goals of this work are to quantify available supply of waste as a secondary resource and clarify operational complexity surrounding their use. Results establish a baseline understanding of what ON Power could make available to potential partners, supporting targeted development moving forward. Recommendations target three priority areas:

1. *Opportunities using existing infrastructure***:** Several streams present viable, low barrier options for immediate or near-term utilization without major capital investment
2. *Streams with significant future availability:* Following planned developments, these flows may support new industries or expansions of existing partners. Identifying these early enables long-term planning that aligns with expected operational changes.
3. *Strengthening circular flows between ON Power and resource-park partners:* Enhancing exchanges, both from the plant to the park, from park users back to the plant, and between park users, can improve efficiency, reduce disposal needs, and support innovation within Reykjavik Energy's sustainability goals.

Advancing any specific opportunity requires follow-up analyses, including conceptual and feasibility studies, infrastructure design, pricing and market assessments, partner engagement, and, where relevant, research experimentation. Aligning these efforts with the availability results ensures that future developments are grounded in realistic operational constraints while supporting innovation across the Hellisheidi resource park.

7 CONCLUSION

The waste-to-value tool developed in this work provides a structured approach for identifying realistic cascade-use opportunities at the Hellisheidi geothermal power plant. By integrating detailed operational analysis,

environmental and regulatory awareness, and nuanced understanding from interviews and field visits, the framework translates circular-economy theory into practical application.

A key contribution of the tool is distinguishing between total waste generated and the portion that is feasibly available as a secondary product. Variability in electricity and hot-water production, maintenance schedules, seasonal demand, and emergency events directly influence how consistently streams can be supplied to additional users. Understanding these dynamics is essential for evaluating supply stability and ensuring that new utilization pathways support long-term operational resilience.

The analysis also highlights the broader benefits of waste-to-value practices already implemented at Hellisheidi. Waste streams currently support carbon capture and mineralization, silica and algae production, hydrogen generation, and internal operations, demonstrating how circular practices can improve efficiency, reduce environmental impacts, and create value across multiple sectors. Expanding this approach provides additional pathways to advance Reykjavik Energy and ON Power's sustainability and innovation goals.

Ultimately, maximizing the use of already extracted geothermal resources represents a direct and innovative strategy for advancing sustainable geothermal development. As geothermal systems worldwide face increasing pressure to improve efficiency, reduce emissions, and diversify value streams, the waste-to-value framework presented here provides a replicable model for identifying opportunities that are technically sound, operationally feasible, and aligned with long-term resource management.

Acknowledgements

This work was submitted as a master's thesis at the Iceland School of Energy, in partnership with Reykjavik Energy, and ON Power. Special thanks to supervisors Dr. Arna Pálsdottír, Dr, Juliet Ann Newson, and Baldur Brynjarsson. Appreciation is also extended to ON Power and the Geothermal Park for site visits and access to internal data. Work was funded by the Leifur Eiriksson Foundation Fellowship, Geothermal Rising Marcello Lippmann Graduate Award, and Reykjavik Energy Science Fund.

REFERENCES

Adalsteinsdottir, H., Karlsdottir, M., Magnusdottir M., Sveinsson, G.: Testing the New Geothermal Sustainability Assessment Protocol on Hellisheidi Geothermal Heat and Power Plant. *Proceedings*, World Geothermal Congress, Reykjavik, Iceland (2021).

Campbell-Johnston, K., Vermeulen, W., Reike, D., and Brullot, S.: The Circular Economy and Cascading: Towards a Framework, *Resources, Conservation & Recycling*, **7**, (2020).

Ghisellini, P., Cialani, C., and Ulgiati, S.: A Review on Circular Economy: The Expected Transition to a Balanced Interplay of Environmental and Economic Systems, *Journal of Cleaner Production*: *Towards Post Fossil Carbon Societies: Regenerative and Preventative Eco-Industrial Development,* **114**, (2016), pp. 11–32.

Kalverkamp, M., Pehlken, A, and Wuest, T.: Cascade Use and the Management of Product Lifecycles, *Sustainability: Economic and Business Aspects,* **9**, (2017), p. 1540.

Karlsdóttir, M., Pálsson, Ó, Pálsson, H., and Maya-Drysdale, L.: Life Cycle Assessment of a Geothermal Combined Heat and Power Plant Based on High Temperature Utilization, *Geothermics*, **84**, (2020), Article 503–519.

Lund, J., Toth, A.: Direct Utilization of Geothermal Energy 2020 Worldwide Review, *Geothermics*, **90**, (2021), Article 101 915.

Rubio-Maya, C., Ambríz Díaz, V., Pastor Martínez, E., and Belman Flores, J.: Cascade Utilization of Low and Medium Enthalpy Geothermal Resources − a review, *Renewable and Sustainable Energy Reviews*, **52**, (2015), pp. 689–716.

Van Berkel, R., Willems, E., and Lafleur M.: The Relationship between Cleaner Production and Industrial Ecology, *Journal of Industrial Ecology*, **1**, (1997), pp. 51–66