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The Integration of Organic Rankine Cycle (ORC) Technology with Enhanced Geothermal Systems (EGS) for Large-Scale Power Production: An Update on the Cape Station Project

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ABSTRACT

This paper delves into the integration of Organic Rankine Cycle (ORC) technology with Enhanced Geothermal Systems (EGS) for large-scale power production, highlighting the collaborative efforts of Turboden and Fervo Energy, and providing updates on the first large scale geothermal project at Cape Station. The synergy between these technologies aims to optimize resource utilization, enhance efficiency, and reduce levelized energy costs, making geothermal energy a more competitive and reliable sustainable baseload power solution.

EGS technology extends geothermal energy production beyond traditional hydrothermal regions, making it a scalable and viable renewable energy source, enabling competition with the other non-baseload mainstream renewables (sun and wind) and baseload sources such as gas or nuclear.

Large-scale geothermal projects, such as the Cape Station project (Fervo Cape Station Project Overview) with clusters exceeding 50 MW each, are showcasing the potential to optimize resource utilization, enhance efficiency, and reduce both time to market and levelized energy costs. The integration of EGS and ORC technologies, which harness high-temperature resources up to 392°F (200 °C) (and beyond for the future expansions), is revolutionizing the geothermal market, making this baseload renewable energy the most attractive option for the multi-GW demand currently under development in western America.

NOTE: AT THE TIME OF THE SUBMISSION OF THE FULL PAPER THIS IS THE INFORMATION AVAILABLE / THAT CAN BE SHARED ON THE PROJECT. BY THE TIME OF THE WGC CONGRESS HOPEFULLY THE PLANT WILL BE IN OPERATION, SO MORE INFORMATION WILL BE ADDED ON THIS FIRST OF THE KIND LARGE SCALE EGS COMMERCIAL PROJECT

1. INTRODUCTION

As the global energy landscape shifts toward decarbonization, geothermal energy is gaining renewed attention for its potential to provide reliable, renewable baseload power. This paper presents an update on the Cape Station project, a pioneering collaboration between Turboden and Fervo Energy that integrates proprietary Organic Rankine Cycle (ORC) technology with Enhanced Geothermal Systems (EGS). The project exemplifies how innovative engineering, and strategic partnerships can unlock geothermal potential in previously uneconomic regions, offering scalable solutions for multi-GW clean energy deployment.

Organic Rankine Cycle (ORC) systems convert thermal energy into electricity using organic fluids with low boiling points, making them ideal for geothermal applications with moderate temperatures (even beyond to 572 °F – 300 °C). The ORC process involves the use of an organic working fluid that is vaporized by heat from a geothermal source. The vaporized fluid then drives a turbine, which generates electricity. The fluid is then condensed and recirculated in a closed loop, making the process highly efficient and environmentally friendly. ORC systems are

particularly suited for low to medium temperature geothermal resources, which are abundant in many parts of the world (Bonafin J., Rossi di Schio C. 2015).

Founded in 1980 in Italy, Turboden is a global leader in ORC technology. The company designs, manufactures, and maintains systems that convert renewable heat sources into electric and thermal power. The company has delivered over 1 GW of ORC power in more than 50 countries worldwide.

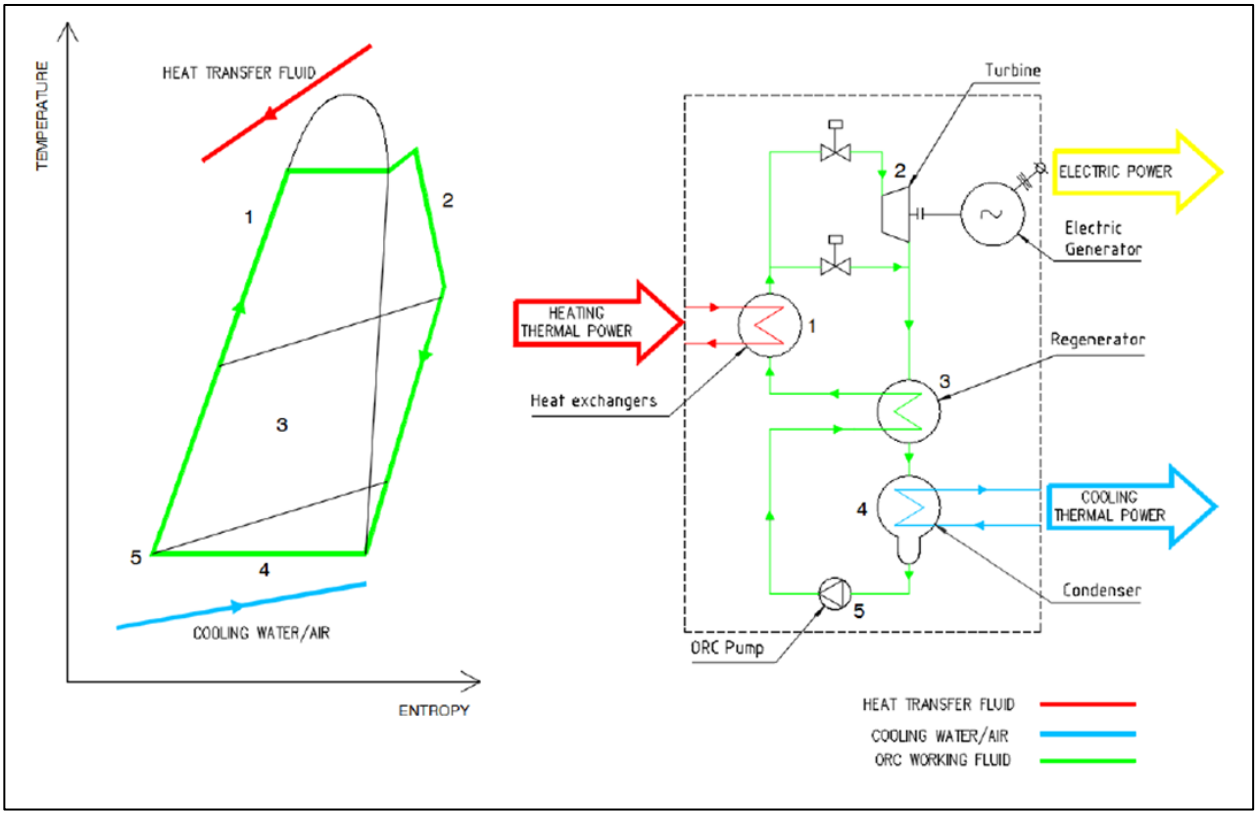


Figure 1: Organic Rankine Cycle T-s diagram and Process Flow Diagram

Enhanced Geothermal Systems (EGS) technology overcomes the limitations of conventional geothermal by creating artificial reservoirs in hot, impermeable rock. Through controlled fluid injection and fracturing, EGS enables heat extraction from regions lacking natural hydrothermal activity. This expands geothermal viability far beyond traditional zones and allows for scalable, dispatchable power generation. EGS technology involves drilling deep wells into hot rock formations and injecting fluid to create fractures. These fractures increase the permeability of the rock, allowing the injected fluid to circulate and absorb heat. The heated fluid is then pumped to the surface, where it is used to generate electricity in an ORC power plant. This process allows for the extraction of geothermal energy in areas that were previously unsuitable for conventional geothermal development.

Established in 2017, Fervo Energy is revolutionizing geothermal development by applying oil and gas techniques - such as horizontal drilling and fiber optic sensing - to enhance subsurface characterization and heat extraction. The company's mission is to provide cost-effective, reliable, and carbon-free geothermal energy, playing a crucial role in the clean energy transition.

2. CAPE STATION PROJECT OVERVIEW

Cape Station, located in southwest Utah, is the first large-scale geothermal project to integrate EGS and ORC technologies. Phase I targets 100 MW (Fervo Energy Press Release, April 2024) of dispatchable power, with Phase II bringing on an additional 400 MW (Fervo Energy, 2025). The project features clusters exceeding 50 MW each, showcasing the scalability of EGS and the modularity of ORC systems.

The Cape Station development spans multiple well pads, including the Frisco, Gold, and Bearskin Pads, supporting a mix of production, injection, and observation wells, and is located near the U.S. Department of

Energy's FORGE site. The geology of the Milford Basin is characterized by a granitic basement reservoir (Fercho et al., 2025), which lies at significant depth and exhibits remarkably consistent thermal and structural properties across the development area. The reservoir is underlain by high-temperature rock, with measured temperatures and stress conditions validating pre-drill 3D basin models (Fercho et al., 2024, 2025). These models have proven predictive, enabling efficient well placement and resource targeting.

The project began with the drilling of a deep vertical appraisal well, which reached a depth of 9,844 feet (3000 m) (Fercho et al., 2024) and confirmed a maximum temperature of 444°F (229 °C). This validated the presence of a high-quality geothermal resource in the Granitic Basement formation. From this foundation, Fervo launched an ambitious horizontal drilling campaign. As of September 2024, 15 horizontal wells have been successfully drilled (Norbeck et al., 2024), each meeting or exceeding temperature and depth targets. Notably, the drilling timeline improved dramatically over the course of the campaign, with well durations dropping from 35 days to under 20 days (Fervo Energy, Feb 2024), thanks to continuous optimization in drilling techniques and equipment. These improvements also translated into significant cost savings, with actual drilling costs consistently coming in under budget.

The completions phase of the project was equally successful. Fervo implemented a multistage, plug-and-perforate stimulation strategy across three horizontal wells, completing 80 stages with a 95% success rate in proppant placement and no screenouts (Norbeck et al., 2024). The use of composite stimulation plugs and the introduction of zipper stimulation operations - borrowed from unconventional oil and gas practices - enhanced operational efficiency and reduced non-productive time.

Following completions, a 30-day production test was conducted on the Frisco well pad. The results were impressive: the primary production well achieved a peak output of 12 MW and a sustained output of 8 to 10 MW (Norbeck et al., 2024). Importantly, the production temperature increased throughout the test, reaching a maximum of 383°F (195 °C), with no signs of thermal decline (Norbeck et al., 2024). This performance confirmed the technical viability of the EGS design and the robustness of the reservoir.

One of the most groundbreaking aspects of the Cape project is its multi-bench development strategy. By targeting multiple layers within the granitic basement formation, Fervo significantly increased the power density of the resource. The estimated power density reached 37.7 MW per cubic kilometer—five to ten times higher than previous EGS estimates (Fercho et el., 2025). This approach not only maximizes energy output but also minimizes surface disturbance, making it a more sustainable and scalable solution.

As of early 2025, Fervo has drilled over 200,000 feet of horizontal EGS wells, more than doubling its annual footage since 2021 (Fercho et al., 2025). Phase I project design temperature at the wellhead is 392 °F (200 °C). These wells are designed to stimulate and circulate geothermal fluids through engineered fractures in the hot rock, extracting heat to generate electricity. The fracture stimulation process has been highly successful, with image logs and seismic monitoring confirming consistent fracture growth and orientation. The use of Distributed Acoustic Sensing (DAS) and surface seismometers has enabled precise monitoring of microseismic events and thermal performance *(*Norbeck et al., 2024*)*.

Cape Station's geothermal potential is substantial. This level of productivity significantly surpasses earlier estimates for EGS systems and positions Cape Station as a model for scalable geothermal development. Phase II could ultimately support an additional 8 power plants (50 MW each) with potential for more in future phases. In summary, Cape Station exemplifies the future of geothermal energy—scalable, predictable, and deeply integrated with advanced drilling and monitoring technologies. It stands as a flagship project in the global push for clean, reliable baseload power.



Figure 2: Cape Station drilling well pad (Photo Credit: Fervo Energy)

3. PROJECT FEATURES AND EXPECTED OUTCOMES

The integration of ORC and EGS at Cape Station involves several key innovations, such as the High-Temperature resource utilization, with brine temperature reaching up to 392 °F (200°C) at the well-head to enable optimal ORC performance. Turboden has designed and procured the equipment for 3 complete ORC units.

The system will operate under a design ambient temperature of 56.5°F (13.6 °C), a condition that influences positively the performance of the air-cooled condensers (ACC) and overall cycle efficiency.

Phase I includes three ORC generator units, each paired with two turbines (proprietary design by Turboden), to optimize energy extraction across varying flow and pressure conditions. Each ORC unit is capable of producing 36 MW of net power at the design point, resulting in a total net ORC output of 108 MW for Phase I (excluding the parasitic power for the geothermal water circulation).

One of the main challenges is the design and optimization of heat exchangers that can efficiently transfer heat from the EGS fluid to the ORC working fluid. The working fluid selected for the ORC cycle is isopentane, chosen for its favorable thermodynamic properties at the given temperature and pressure ranges. The target Thermal Efficiency is expected to achieve 20%, which is the highest level so far achieved in an ORC geothermal plant. To support heat rejection, each ORC unit is equipped with 32 ACC bays, providing robust cooling capacity while minimizing water usage - a critical consideration in arid environments like Utah.

Another important aspect of the integration is the modularity of the ORC units. Turboden's ORC systems, are designed to be scalable and modular, allowing for phased deployment and rapid commissioning. This modular approach not only reduces the time to market but also allows for greater flexibility in the design and lower cost of operation of the power plant. As of September 2025, the powerplant is in advanced phase of construction at site.

The capacity-factor of the power plant is expected to exceed 90%, providing consistent and reliable baseload power. This high capacity-factor is a key advantage of geothermal energy, as it allows for continuous power generation regardless of weather conditions or time of day. This makes geothermal energy a valuable complement to other renewable energy sources, such as solar and wind, which are intermittent in nature.

As a result, the levelized cost of energy (LCOE) is expected to be significantly reduced through the optimized utilization of the geothermal resource and the modular deployment of the ORC units. This makes the Cape Station project a cost-effective solution for large-scale renewable energy production.



Figure 3: One of the three ORC Units currently under construction at Cape Station site (September 2025) (Photo Credit: Turboden)

4. MARKET IMPACT AND FUTURE DEVELOPMENTS

According to ThinkGeoEnergy, currently there are about 17 GW of geothermal powerplants installed worldwide (including ORC and conventional steam turbines). As of today, about 2 GWs are made by ORC technology, while in the last decade (2015 – 2025) 60% of new powerplants additions have been done with ORC technology. The average weighted capacity of new projects addition is about 20 MW each. Phase II of Cape Station is approximately 500 MW, developed with modular clusters of 50 MW each (incrementing by 250% the average capacity of the last 10 years).

Cape Station is therefore redefining the geothermal market by demonstrating the viability of large-scale EGS-ORC integration, making geothermal energy a more attractive option for investors and developers. No other projects with ORC powerplants have been implemented in such a short term. The success of the Cape Station project is expected to have a significant impact on the geothermal market, opening up new geographic markets and reducing development risk. This is expected to drive further investment and development in the geothermal sector, leading to the deployment of additional large-scale projects.

The explosive growth of artificial intelligence and cloud computing in North America is driving an unprecedented surge in electricity demand, particularly from hyperscale data centers that power AI model training and inference. This demand is reshaping the energy landscape and accelerating the deployment of large-scale Enhanced Geothermal Systems (EGS). With data centers projected to consume up to 12% of U.S. electricity by 2028 (U.S. DOE, Data Center Energy Use Report, Dec 2024), the need for clean, reliable, and around-the-clock power has never been greater. EGS projects are uniquely suited to meet this challenge, offering high-capacity, dispatchable baseload power with minimal environmental impact. As tech giants pursue aggressive carbon neutrality goals, geothermal's zero-emission profile and high-capacity factor make it a strategic fit.

5. CONCLUSIONS

The Cape Station project is a testament to the potential of combining ORC and EGS technologies to create a more efficient and sustainable energy solution. By leveraging the strengths of both technologies, the project aims to optimize resource utilization, enhance efficiency, and reduce levelized energy costs. This integration not

only makes geothermal energy more competitive but also provides a reliable and sustainable baseload power solution.

This project represents a transformative milestone in the evolution of geothermal energy, at an unprecedented scale. With Phase I delivering 108 MW of net power with Phase II delivering an additional 400 MW of power (Fervo Energy, 2025)., Cape Station sets a new benchmark for modular, scalable, and dispatchable renewable energy. The project's success is underpinned by advanced drilling techniques, precise reservoir modeling, and innovative thermal energy conversion systems, all of which contribute to exceptional thermal recovery and power density.

By achieving a capacity factor exceeding 90% and targeting a thermal efficiency of 20% - the highest ever for an ORC geothermal plant - Cape Station demonstrates the economic and technical viability of large-scale geothermal deployment. Its modular design, rapid construction timeline, and minimal environmental footprint make it a compelling model for future developments worldwide.

As the global energy sector seeks reliable, low-carbon baseload solutions, Cape Station stands as a flagship project that redefines the potential of geothermal energy. It not only paves the way for future expansions within Fervo Energy's portfolio but also catalyzes broader market adoption, investment, and innovation in the geothermal space. In doing so, Cape Station plays a pivotal role in accelerating the clean energy transition and securing a sustainable energy future.

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