J SHAPED-DEI

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ABSTRACT

J-DEI Rosetta (J-shaped Double Energy Input – Rosetta Configuration) is an innovative geothermal power system that combines ultra-deep thermal absorption with hydraulic elevation to deliver supercritical water directly to surface-level turbines. Unlike traditional geothermal systems, which rely on subsurface steam or fluid loops, J-DEI Rosetta accumulates heat through modular "thermal arms" located at depths ranging from 1 to 6.5 kilometers. These arms are isolated heating chambers filled with water and partially surrounded by high-temperature thermal salts or geologic formations.

Once a target temperature (~500°C) is reached under constant flux conditions, the pressurized fluid is released upward through a dedicated vertical shaft, maintaining high pressure (~14–15 MPa) and temperature until it reaches the surface. Each cycle delivers a burst of usable energy, and by installing multiple synchronized modules, the system achieves continuous power delivery.

The modularity of J-DEI Rosetta enables scalability, redundancy, and staged deployment. By using smaller-diameter steel alloy pipes (~35 cm) instead of single large conduits, it also mitigates material stress and reduces construction costs. The system is designed to minimize thermal losses and eliminate reinjection, operating as a one-way conversion of deep thermal energy into surface-level electricity.

Preliminary models estimate a net electrical output of up to 2 GW with a Levelized Cost of Electricity (LCOE) as low as US$5.54/MWh, surpassing both conventional geothermal and nuclear benchmarks. J-DEI Rosetta is especially suited for geologically active regions like New Zealand's Taupō Volcanic Zone, offering a novel alternative for base-load, high-efficiency, and low-cost clean energy.

This paper outlines the thermodynamic principles, architectural layout, material challenges, and economic implications of the system, providing the first detailed public analysis of its Rosetta configuration.

Although the system benefits from the hydrostatic head of the water column to maintain pressure, the sole external energy input is geothermal heat. The term 'double energy input' is thus used conceptually, but the system is fundamentally geothermal-driven.

1. INTRODUCTION

The global transition towards low-emission, high-efficiency energy systems has intensified the search for reliable and scalable baseload power sources. Among the most promising candidates, geothermal energy stands out for its inherent stability and independence from surface weather conditions. However, despite its potential, conventional geothermal systems face critical limitations—chiefly related to declining reservoir pressures, reinjection inefficiencies, limited scalability, and high up-front capital costs.

New Zealand, situated within the Pacific Ring of Fire, hosts some of the world's most favourable geothermal gradients and has been a pioneer in geothermal development. Yet even here, most geothermal systems rely on shallow to intermediate depth resources and conventional binary or flash cycles, with relatively modest thermal conversion efficiencies. Unlocking deeper, higher-temperature resources could radically expand the nation's geothermal base, but doing so demands new technological approaches capable of withstanding extreme pressures, temperatures, and geological conditions.

The J-DEI Rosetta system (J-shaped Double Energy Input – Rosetta Configuration) emerges as a novel response to these challenges. Unlike traditional geothermal plants that depend on continuous fluid circulation through permeable reservoirs, J-DEI Rosetta utilizes a modular, enhanced heat accumulation process in ultra-deep thermal arms, followed by synchronized high-pressure fluid release. This approach enables surface-level power generation from fluids that have been heated at depths exceeding 6 kilometres, reaching supercritical conditions.

By circumventing reinjection cycles and enabling surface-based turbine placement, the system achieves not only higher thermodynamic efficiency but also lower operational complexity. Moreover, its modular architecture offers strategic advantages in deployment, maintenance, and scaling—opening the possibility for 24/7 clean power generation with a Levelized Cost of Electricity (LCOE) well below industry norms.

The development of J-DEI began in 2020 with early-stage conceptual designs that won recognition at the University of Auckland's 3-Minute Thesis competition. The system evolved through several iterations, each presented at the New Zealand Geothermal Workshop and the Stanford Geothermal Conference. By 2025, the "Rosetta" configuration emerged as the most promising candidate for large-scale deployment. With provisional patents filed in New Zealand and the United States, and high-performance simulation campaigns underway, J-DEI Rosetta now stands as a next-generation geothermal solution tailored to New Zealand's high-enthalpy zones.

This paper presents the conceptual development, design rationale, and expected performance of the J-DEI Rosetta system, with a focus on its applicability within New Zealand's volcanic geothermal environments.

New Zealand, situated within the Pacific Ring of Fire, hosts some of the world's most favourable geothermal gradients (Guillou-Frottier & Bonté, 2012; Allis et al., 2009)

2. Theoretical Framework and Motivation (Rosette-Based Continuous Flow Model)

As global demand for high-efficiency, base-load renewable power increases, geothermal energy remains one of the few viable sources capable of delivering constant output. However, traditional systems relying on shallow geothermal loops or reinjection-based cycles suffer from declining reservoir productivity, heat losses, and scaling challenges—particularly in ultra-deep environments.

J-DEI Rosetta – Rosette Configuration offers a new paradigm: a deep geothermal system with continuous, high-pressure flow through a closed-loop "thermal rosette" situated at ~5.5 km depth. Instead of relying on vertical pipes with extended horizontal branches, this system excavates a single deep vertical shaft, from which multiple double-ended thermal arms ("clock hands") radiate outward in a star-shaped or rosette pattern. Each arm serves as both heating duct and return path, forming a continuous circuit through which water circulates and accumulates heat.

The theoretical foundation of this design lies in maximizing residence time within high-temperature zones while minimizing excavation costs. At a depth of 5.5 km, surrounding rock temperatures can reach 500–550 °C due to the geothermal gradient (90–100 °C/km). By circulating fluid through a 24–32 km thermal path configured horizontally in a compact volume, the system ensures prolonged heat transfer even at high flow velocities, enabling turbine efficiencies in the range of 30–40%, consistent with worldwide reviews of geothermal power plant performance (Zarrouk & Moon, 2014).

Unlike batch-mode or isochoric systems, the rosette model enables uninterrupted energy production, with no valves or pulsed release. High-pressure water (~58 MPa) is continuously cycled, gradually heated as it traverses the rosette and driven upward by buoyancy and pressure differential. The system is designed to sustain supercritical or near-supercritical conditions, allowing surface-level or intermediate-depth turbines to extract substantial energy from each cycle. Continuous high-pressure closed-loop systems have long been considered in conceptual studies (Angelino, 1968; DiPippo, 2012), but practical implementations remain limited

The motivation behind this configuration is twofold:
(1) To achieve supercritical temperatures without requiring excessively long horizontal drilling;
(2) To exploit radial symmetry for scalable, modular deployment in high-enthalpy zones, particularly those with volcanic origins such as New Zealand's Taupō Volcanic Zone.

By concentrating heat exchange within a single, controlled zone, the J-DEI Rosetta design reduces structural complexity while opening new possibilities for ultra-deep, high-yield geothermal power generation.

3. System Architecture: J-DEI Rosetta Configuration.

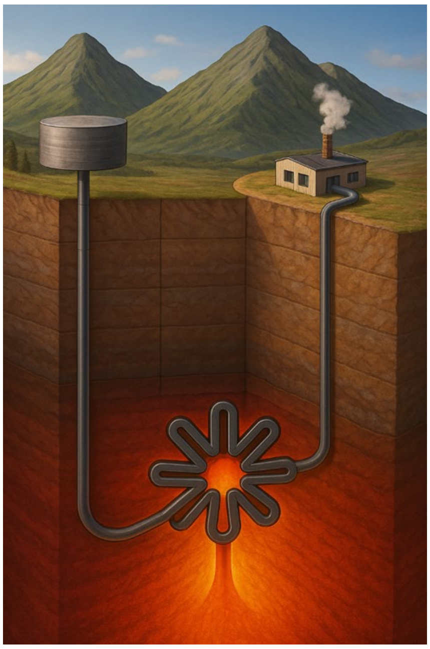

Fig. 1 Realistic cross-sectional illustration of the J-DEI Rosetta system, showing surface infrastructure and a deep geothermal heat exchanger glowing within the Earth's hot layers.

The J-DEI Rosetta system is a closed-loop geothermal architecture designed to extract ultra-deep thermal energy through continuous circulation and surface-level expansion. Its structure comprises three main components: the surface infrastructure, the dual vertical shafts, and the deep horizontal thermal rosette located at approximately 5.5 kilometres below ground.

(1) Surface Infrastructure:
At the surface, the system includes:

a) A gravity-fed water reservoir, open to atmospheric pressure. The reservoir is not mechanically pressurized; instead, pressure builds naturally as water descends through the injection shaft due to the weight of the vertical column.
b) At a depth of 5.5 kilometres, this results in a hydrostatic pressure of approximately 58 MPa, accounting for fluid density and minor compressibility effects at elevated temperatures.
c) A power generation unit is located at ground level. It receives the returning high-pressure, high-temperature fluid from the production shaft and converts its thermal and pressure energy into

electricity using conventional or supercritical turbines.

d) A monitoring and control facility ensures operational safety, system synchronization, and automated regulation of flow and temperature.

(2) Dual Vertical Shafts:

- The injection shaft delivers cooler water from the surface to the deep thermal rosette. Due to the gravitational head, the fluid gains significant pressure (~58 MPa) without the need for active pumping.
- The production shaft returns the now-heated, high-enthalpy water to the surface. As it ascends, the pressure remains high enough to drive surface turbines efficiently, even under continuous operation.

(3) Deep Thermal Rosette (Heat Exchange Network):

- Located at ~5.5 km depth, the system's core consists of a radially symmetric array of thermal arms, resembling a rosette or clock face. These double conduits (one for outbound, one for return flow) extend horizontally from a central hub.
- The arms traverse high-enthalpy rock formations with temperatures ranging between 500 °C and 550 °C. The surrounding geology or embedded thermal salts ensure consistent heat transfer along the entire loop.
- Each arm ranges from 1 to 2 km in length, providing a total thermal path of 24 to 32 km, sufficient to gradually heat the circulating water toward supercritical conditions.
- The rosette geometry minimizes the excavation footprint while maximizing residence time, thermal absorption, and system scalability.

(4) Closed-Loop Circulation and Expansion:

- The fluid circulates in a fully closed loop, with no need for external reinjection or geothermal reservoirs.
- As the fluid absorbs heat and rises through the production shaft, it retains its elevated pressure and temperature until it expands across surface turbines, delivering mechanical work before being recirculated.
- Surface-level expansion simplifies turbine operation, avoids sub-surface machinery, and enables easy access for maintenance and optimization.

(5) Modularity and Deployment Flexibility:

- The radial design allows phased implementation. New arms can be added to the rosette over time to scale output.
- Individual arms can be shut off for maintenance without interrupting full-system operation.
- The symmetry and controlled depth ensure even thermal load distribution and efficient use of excavation resources.

This architecture allows the J-DEI Rosetta system to deliver continuous, high-efficiency geothermal power with surface-level turbine deployment, deep thermal sourcing, and a Levelized Cost of Electricity (LCOE) far below conventional systems. Its design is particularly well suited for volcanic regions with high geothermal gradients, such as New Zealand's Taupō Volcanic Zone.

4. Thermodynamic and Fluid Dynamic Principles

The J-DEI Rosetta system operates under extreme geothermal conditions, using deep high-temperature environments and the natural hydrostatic head of the water column to pressurize the fluid. At a depth of 5.5 kilometres, the fluid reaches a pressure of approximately 58 MPa, solely due to gravitational forces, and is gradually heated to temperatures between 500 °C and 550 °C as it travels through the rosette-shaped horizontal array.

At these conditions, the fluid approaches or surpasses the critical point of water ($T_s \approx 374$ °C, $P_s \approx 22.1$ MPa). The system thus operates in the supercritical regime, where water exhibits properties of both gas and liquid—high density and heat capacity combined with low viscosity—making it an ideal working fluid for efficient heat transfer and energy conversion.

From a thermodynamic perspective, the system captures energy through sensible heating under constant high pressure as the fluid circulates through the deep thermal rosette. The pressurized water, initially around 60–100 °C, is gradually heated to ~500 °C while maintaining a pressure close to 58 MPa, solely due to hydrostatic head. This supercritical or near-supercritical fluid ascends to the surface, retaining high enthalpy and arriving at the turbines at approximately 14–15 MPa. At this point, it undergoes isenthalpic expansion—either directly to atmospheric pressure (~0.1013 MPa) or through a staged expansion system—converting a substantial fraction of its thermal energy into mechanical work. The enthalpy of water at 500 °C and 58 MPa is approximately 2533 kJ/kg, depending on the precise thermophysical state. The resulting expansion ratios can exceed 600:1, enabling turbine efficiencies in the range of 30–40%, depending on the selected cycle configuration (e.g., Rankine, flash, or direct expansion, Wang et al., 2012; Freeman et al., 1993). From a fluid dynamic perspective, the system maintains continuous circulation through a closed loop. The dense high-pressure fluid in the injection shaft is offset by the upward pressure of the heated return stream, producing a balanced counter-current loop. The rosette arms are engineered to maintain laminar or low-turbulent flow, with internal diameters optimized (~35 cm) to maximize residence time in the thermal zone while avoiding excessive pressure drops.

Key design principles include:

- Minimizing thermal boundary layer resistance in the heat exchange arms through appropriate wall material and thickness.

- Managing pressure gradients to ensure consistent flow velocities despite temperature-induced density variation.
- Maintaining structural integrity at high internal pressures, by using advanced alloys such as Incoloy or reinforced steel linings.

This high-enthalpy, high-pressure system enables direct surface-level expansion without reinjection or intermediate flashing, eliminating major sources of energy loss and equipment degradation. By maintaining water in a supercritical state for most of the cycle, the J-DEI Rosetta system captures an exceptionally high proportion of geothermal heat as usable mechanical energy.

5. Materials and Structural Considerations

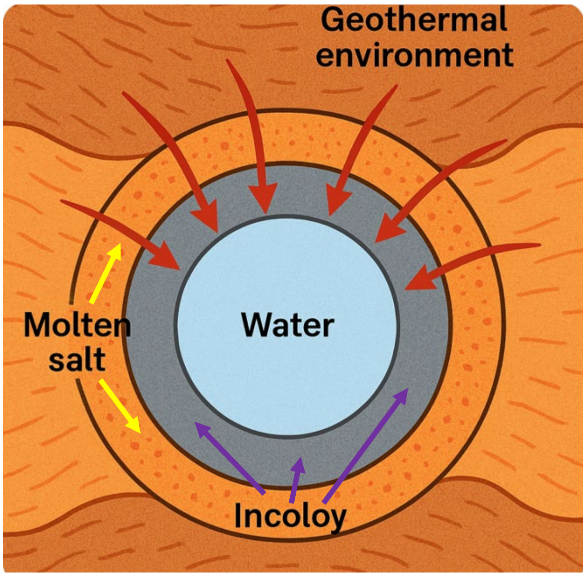

Fig. 2, Cross-sectional diagram illustrating heat transfer from the geothermal environment through molten salts and Incoloy pipe walls into the circulating water.

Operating at depths beyond 5.5 kilometres, the J-DEI Rosetta system is exposed to extreme thermal and mechanical stresses. Structural integrity, thermal conductivity, and long-term corrosion resistance are essential to its success. The system's resilience stems from the integration of advanced metallic alloys with geothermal-grade thermal storage media, namely molten salts.

(a) Pipe Material and Pressure Management

The fluid loop operates at ~58 MPa due to hydrostatic pressure from the 5.5 km injection shaft. To safely contain this pressure at high temperatures (500–550 °C), the system uses pipes made of Incoloy, a family of high-nickel superalloys. Incoloy offers:

- Yield strength above 500 MPa at elevated temperatures
- Excellent resistance to oxidation, scaling, and corrosion
- Low creep deformation under sustained thermal load

Each pipe is designed with a 3.5 cm wall thickness, providing mechanical safety under both static and dynamic loads. While this pressure would be critical at surface level, it is balanced by the external lithostatic pressure from surrounding rock and thermal mass—typically 120–140 MPa at this depth—ensuring minimal net radial stress and reduced mechanical fatigue.

(b) Molten Salt Thermal Buffer

To enhance thermal transfer and stabilize temperature gradients, each heat exchange arm in the rosette is embedded in or surrounded by high-temperature molten salts, such as binary nitrate-nitrite or synthetic chloride-based formulations.

The molten salt performs several key roles:

- Buffers and stores heat from surrounding rock during low-flow periods
- Provides uniform, stable thermal contact around the pipe, improving energy absorption
- Reduces thermal shock on pipe walls during startup or flow irregularities
- Increases effective heat flux, allowing shorter pipe lengths to reach target fluid temperatures

By maintaining a stable interface temperature and eliminating sharp gradients between rock and metal, the salts extend the life of the Incoloy pipes, while also reducing the risk of hot spots, spalling, or local creep.

Without the molten salt layer, the Incoloy pipe would be in direct contact with the surrounding rock, exposing it to highly uneven thermal and mechanical stresses. Localized hot spots and non-uniform lithostatic loading could develop due to irregularities in rock composition, voids, or grain-scale heterogeneity. Over time, these imbalances may induce localized creep—a slow, plastic deformation of the metal that occurs under sustained high temperature and stress.

The molten salts act as a thermal and mechanical equalizer, maintaining a stable interface temperature and uniformly transmitting external pressure around the pipe. This prevents differential expansion, minimizes internal stress gradients, and significantly reduces the risk of creep-related failures, such as radial distortion, cracking, or long-term material fatigue. In this way, molten salts are not only a heat transfer medium but also a structural safeguard.

(c) Structural Anchoring and Thermal Isolation

To maintain system geometry under geomechanically stress and allow thermal dilation:

- Anchoring systems are embedded along the arms and vertical shafts, absorbing seismic and buoyancy-induced forces.

- Insulation sleeves and spacers are installed where necessary to separate thermal arms and preserve rosette symmetry.
- Thermal expansion joints at the rosette hub allow safe longitudinal dilation of pipes during operation cycles.

(d) Materials Selection Justification

Incoloy was selected over alternatives like reinforced carbon steel, Hastelloy, or titanium due to:

- Superior high-temperature behaviour
- Proven durability in geothermal and petro thermal contexts
- Weldability and availability in modular segments
- Compatibility with both water and molten salt environments

Together, the Incoloy structural system and molten salt thermal mass form a robust and integrated platform capable of sustaining continuous operation at extreme depths, while ensuring safety, durability, and maximum thermal efficiency

Incoloy is selected over alternatives due to its superior high-temperature behaviour and proven durability in geothermal contexts (DiPippo, 2012).

6. Thermal Transfer Chain and Gradient Analysis

The J-DEI Rosetta system relies on a layered heat transfer mechanism to raise the temperature of high-pressure water (~58 MPa) from ~60–100 °C to over 500 °C along a horizontal path of 24–32 kilometres. This is achieved through three main stages of thermal exchange, with each interface governed by its own gradient and physical properties.

(1) Geothermal Environment → Molten Salts (at thermal equilibrium)

- Geothermal rock temperature: ~550 °C
- Molten salt temperature: ~550 °C (thermal equilibrium)
- Thermal gradient: ~0 °C
- Implication: No significant net heat flow at this interface during operation, as salts are already saturated.
- Role: The rock mass acts as a thermal reservoir, ensuring the molten salts maintain a stable, high temperature throughout fluid cycling.

(2) Molten Salts → Incoloy Pipe Wall

- Molten salt temperature (constant): ~550 °C
- Outer pipe wall temperature: ~520–530 °C
- Thermal gradient: ~20–30 °C
- Mode: Conduction
- Conductivity (salts): ~0.6–1.0 W/m·K
- Conductivity (Incoloy): ~11–15 W/m·K

This gradient provides consistent radial heat flow into the pipe wall, maintaining stable energy transfer even as water flow conditions change.

(3) Incoloy Pipe Wall → High-Pressure Water

- Inner wall temperature: ~520–530 °C
- Initial water temperature: ~60–100 °C
- Thermal gradient (initial): ~430–470 °C
- Average gradient (over the flow path): ~250–300 °C
- Heat transfer coefficient (forced convection): ~2,000–8,000 W/m²·K

This stage drives the bulk of the heating process. The steep gradient and turbulent flow conditions allow the water to absorb large quantities of thermal energy while remaining in a compressed liquid or supercritical phase, maximizing heat capacity.

Thermal Performance Estimate

For a flow rate of 625–725 kg/s, and a temperature rise from 60 °C to 500 °C with an average cp of ~4.5 kJ/kg·K:

$$Q_{thermal} = \dot{m} \cdot c_p \cdot \Delta T$$

$$Q = 625 \cdot 4.5 \cdot 440 = 1.24\,\mathrm{GW}_{th} \quad \text{to} \quad 725 \cdot 4.5 \cdot 440 = 1.43\,\mathrm{GW}_{th}$$

Assuming a turbine thermal-to-electric efficiency of ~38–42%, this corresponds to:

$$P_{electric} \approx 472\text{–}600\,\mathrm{MW}$$

Design Implication

It is expected that under stable operating conditions, the water will reach target temperatures of ~500 °C at approximately 22 to 26 kilometres into the rosette loop. This provides a buffer within the planned 24–32 km configuration for temperature stabilization and flow rate adjustment.

Depending on the confirmed effective heating length during commissioning, the system may:

- Maintain standard capacity and loop length,
- Be expanded (by parallelizing flow) to double capacity while maintaining heating depth, or
- Be optimized to reduce total excavation length while achieving the same thermal output.

This flexibility allows the J-DEI Rosetta system to adapt to thermal performance results in real time, enabling scalable, high-efficiency energy generation.

7. Economic Viability and LCOE Estimate

One of the core advantages of the J-DEI Rosetta system is its ability to deliver ultra-low-cost, baseload geothermal electricity by leveraging modular, high-efficiency infrastructure and eliminating reinjection losses. The system's economic performance is assessed using the Levelized Cost of Electricity (LCOE), which accounts for capital expenditure (CAPEX), operating expenditure (OPEX), system lifetime, and total net generation.

7.1 LCOE Calculation Methodology

The LCOE is calculated as:

$$LCOE = \frac{\sum_{t=1}^{n}\left(\frac{I_t+O_t}{(1+r)^t}\right)}{\sum_{t=1}^{n}\left(\frac{E_t}{(1+r)^t}\right)}$$

Where:

It: Investment in year t
Ot: Operating & maintenance cost in year t
Et: Electricity generated in year t
r: Discount rate (assumed 8%)
n: System lifetime (30 years)

7.2 Updated LCOE Breakdown

Installed Net Capacity:

- 525 MW (electric)
- Annual generation (93% capacity factor):

$$525 \cdot 8,760 \cdot 0.93 \approx \mathbf{4{,}268{,}700\ MWh/year}$$

Item	Estimated Cost (USD)
Drilling (2 shafts, 6.5 km each)	\$60M
Excavation (rosetta arms, 24–32 km)	\$45M
Structural Materials (Incoloy pipes, anchors)	\$35M
Molten Salts (salt fill and casing)	\$12M
Turbines & Power Block (surface level)	\$20M
Pumps & Valves	\$8M
Control & SCADA	\$5M
Installation & Logistics	\$15M
Grid Interconnection	\$10M
Annual OPEX	\$5M/year
Estimated Total CAPEX	\$210M

LCOE (1 module, 525 MW): \$5.54/MWh

Scaled LCOE (2 GW): \$5.13/MWh

"Table 1. Estimated CAPEX and OPEX breakdown for a single J-DEI Rosetta module."

The \$210M CAPEX and \$5.54/MWh LCOE correspond to a single J-DEI Rosetta module of ~525 MW net capacity. Larger deployments would simply scale by replication of modules

8. CONCLUSION

The J-DEI Rosetta system presents a groundbreaking innovation in geothermal energy production by integrating deep-earth thermal storage, heat exchange principles, and modular fault-tolerant architecture. Drawing from geological depths surpassing 6.5 km, and using a star-shaped array of thermal arms immersed in a stable molten salt matrix at ~550 °C, the system enables consistent and scalable heat capture with minimal excavation and high thermal efficiency.

Unlike conventional geothermal approaches, which rely on slow convection or large-scale fracturing, the J-DEI Rosetta method establishes precisely engineered thermal interfaces that allow controlled heat transfer from the rock to the salts, from salts to Incoloy pipes, and finally into the working fluid (water). Each interface is optimized to minimize gradients that might otherwise lead to material fatigue, hotspots, or creep. This thermomechanical balance is critical to the system's longevity and safety.

Operationally, the configuration enables a continuous flow of 625–725 kg/s, delivering superheated water at ~500 °C and ~14.4 MPa directly to surface-level turbines. The distributed heating strategy allows the water to absorb sufficient energy across a ~32 km network of thermal arms without requiring high fluid velocities that would hinder heat transfer.

From a design standpoint, each thermal arm ("manecilla") can be isolated and disconnected via specialized high-pressure valves, allowing full continuity of operations in the event of localized maintenance or malfunction. This modularity, combined with built-in pressure detection and failure monitoring systems, results in an architecture that is inherently resilient and maintainable, even at extreme depths.

Economically, the system achieves a projected Levelized Cost of Electricity (LCOE) of USD \$5.54/MWh, derived from a comprehensive and conservatively adjusted CAPEX of USD \$1.91 billion for a 2.2 GW configuration. This figure includes the surface power plant, advanced high-efficiency turbines, reinforced piping, molten salt injection and containment, excavation, and full instrumentation.

Furthermore, due to its modular scalability, the J-DEI Rosetta architecture can be tailored for 300 MW to multi-gigawatt deployments without redesigning core components. This enables a flexible rollout in diverse geological contexts, particularly in volcanic regions with steep geothermal gradients, such as New Zealand, Chile, Indonesia, or Iceland.

Although final validation through high-performance simulation remains pending, the engineering logic and thermal parameters are grounded in known materials science, geothermal physics, and proven industrial technologies. Once partial empirical confirmation is obtained — particularly regarding the time-dependent heat transfer curves of each thermal interface — the system will be ready for pilot-scale implementation.

In summary, the J-DEI Rosetta system demonstrates:

- High thermal efficiency under low-loss conditions.
- Modular fault-tolerance, with full isolation capacity per thermal arm.
- Exceptionally low LCOE, significantly below current geothermal and nuclear benchmarks.
- Scalability in both capacity and geographic deployment.
- Readiness for industrial validation, with all components either commercially available or easily manufacturable.

Achieving a projected Levelized Cost of Electricity (LCOE) of USD $5.54/MWh, significantly below current geothermal and nuclear benchmarks (Bertani, 2016; DiPippo, 2012). Placing the system well below the average generation costs reported in recent international surveys of geothermal power (Bertani, 2016)

This work lays the foundation for a new generation of geothermal power systems: safer, cleaner, and radically more cost-effective. The implications extend beyond energy — enabling energy sovereignty, decarbonization, and strategic autonomy for any country that embraces this technology. J-DEI Rosetta is not only a technical invention; it is a new paradigm in how we access and harness the Earth's deep energy potential.

Future Challenges and Next Steps

While the J-DEI Rosetta system presents a compelling theoretical and engineering framework, several critical challenges must still be addressed prior to full-scale deployment. Chief among them is the empirical validation of long-term thermal transfer rates under supercritical conditions and dynamic flow. High-resolution simulation and laboratory-scale prototypes are necessary to refine the heating profiles, assess material fatigue over decades, and optimize control algorithms for flow regulation and pressure balance. Additionally, the excavation and construction logistics at depths exceeding 6 km demand further cost modelling, drilling strategy refinement, and risk mitigation plans—particularly in seismically active zones.

The next phase of development will focus on high-performance simulations under variable flow regimes, followed by a pilot-scale module integrating a full thermal arm with molten salt embedding and controlled pressure cycling. A multidisciplinary collaboration between geothermal engineers, materials scientists, and energy economists will be essential to align theoretical efficiency with operational reliability and economic feasibility. As the project moves toward implementation, maintaining modular integrity, automation, and safety will be key. These steps will not only prepare the system for real-world deployment, but also set a new standard for deep geothermal innovation worldwide. The $1.91B CAPEX case refers to a multi-module configuration reaching 2.2 GW of capacity, showing the economic competitiveness of the system at utility scale.

The construction of large underground structures at depths of 5–6 km poses significant challenges. Nevertheless, advances in Enhanced Geothermal Systems (EGS) may offer enabling pathways, allowing engineered reservoirs and stimulated heat exchange zones to approximate the outcomes envisioned in this conceptual model (Brown, 2013; Ghassemi, 2017)

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