Hybrid Semi-Loop Single Well Closed EGS system for Highly Elevated Power Capacity

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ABSTRACT

Enhanced Geothermal Systems (EGS) were first introduced in the mid-1970s to augment natural hydrothermal production, which began its commercial use roughly a century ago. Yet, despite this long history of development and the vast global endowment of accessible geothermal energy, geothermal power has remained a minor contributor to global energy supply. The persistent underperformance of conventional EGS arises from two fundamental technical limitations.

First, effective access to subsurface heat is intrinsically limited by hydraulic and thermal short-circuiting. The conventional EGS design, which relies on intersecting perpendicular injection and production wells through an augmented fracture network via hydraulic fracturing, enables the circulating working fluid to flow preferentially along the pathways of lowest resistance. This channeling minimizes contact with large volumes of hot rock, reducing premature thermal breakthroughs that drastically shorten the system's useful life and output.

Second, the EGS system suffers from insufficient thermal replenishment within the fracture-stimulated rock volume. Closely spaced, congested fractures restrict the rate at which conductive heat from the surrounding formation can recharge the cooled fracture faces. As a result, EGS reservoirs experience rapid temperature decline and are forced into intermittent operational modes, effectively functioning as costly, low-efficiency thermal storage systems, rather than continuous power sources. Consequently, EGS and related Hot Dry Rock (HDR), 150-250°C, and Super-Hot Dry Rock (SHR), 374°C or above the water's critical point, approaches have struggled to deliver the sustained, high-capacity power output envisioned decades ago. Other EGS challenges, such as water loss and seismic risks, have reduced community support.

VegaGeo 3.0's Hybrid-Semi-Loop System (HSLS) technology, constructed in zero-permeability, plutonic rock, modifies the traditional EGS multiple-well deviated configuration by using a single vertical wellbore trajectory with induced, co-planar, bifurcated, propped hydraulic fractures. It maintains full hydraulic communication with the propagation plane of induced fractures. This integrated geometry enables continuous sweeping of the induced fracture surface area, eliminating flow bypass and maximizing hot rock contact. Numerical simulations indicate that VegaGeo 3.0 can sustain high, long-term baseload production exceeding 50 MW$_t$, demonstrating efficient heat extraction by fully utilizing flow paths in the propped fracture.

Long-length flow diverters are constructed in the propped fractures, bifurcating them, and causing lengthy heat-collecting fluid flow away from and back to the wellbore, superheating fluids over several hours of exposure to 350 – 750°F rock. Accessing deeper vertical depths within the earth's upper crust, with heat levels well beyond traditional practice, the reconfigured system fractures are separated laterally by more than 1000 ft, thus allowing high baseload level heat replenishment. Respecting all preferences and advantages for heat extraction from significant depth, the newer method is called the VegaGeo 3.0. This paper presents this novel approach and analysis of simulated performance in deep HDR and SHR.

The advanced VegaGeo 3.0 HSLS configuration was evaluated using Computational Fluid Dynamics (CFD) coupled with conjugate heat-transfer (CHT) analysis to predict production temperature and thermal power output under a range of geological, geothermal, and operational conditions. The modeling encompassed variations in rock thermal gradient, fracture geometry, vertical fracture separation, inlet temperature, and circulation rate, allowing a comprehensive assessment of system behavior from early-time transients to long-term steady-state operation.

Analytical optimization indicated that a configuration incorporating approximately 15 hydraulically connected co-planar fractures, vertically separated by up to 1,100 ft (~335 m), provides the most practical balance between drilling complexity, reservoir recharge, and sustained heat extraction.

Results from both transient and steady-state simulations demonstrate that the VegaGeo 3.0 architecture can achieve 10 to 30× increases in baseload geothermal energy output relative to conventional multi-well EGS systems. Modeled thermal production exceeds 110 MW$_t$ at initial startup, maintains an average of approximately 50 MW$_t$ over a 20-year operational period, and does not reach steady-state production of roughly 30 MW$_t$ until after 25 years of continuous operation. These findings confirm that the VegaGeo 3.0 framework enables unprecedented longevity and capacity in engineered geothermal systems, firmly establishing its potential as a true high-enthalpy baseload geothermal technology.

1. INTRODUCTION

Today, less than 1% of the energy used for utility-scale electricity (1 MW) in the U.S. comes from geothermal resources.[1] As of 2023, approximately 15,000 geothermal wells, mostly natural hydrothermal, operate worldwide. A 2024 study estimated that about 3,700 production wells are currently in operation across around 198 geothermal fields worldwide.[2] These wells produce geothermal steam or hot water for power or heat.[3] With 3,900 MW of installed geothermal capacity as of 2023, the U.S. remains the global leader, accounting for about 25% of the total online capacity.[4] The total amount of geothermal energy available on Earth exceeds current global energy needs, but harnessing it efficiently for electricity production has been challenging. In 2022, worldwide installed geothermal energy capacity was 15 million MW.[5] Geothermal energy is widely available and differs from fossil fuels, such as coal, petroleum, and natural gas, which emit greenhouse gases and contribute to climate change. As a renewable energy source, geothermal energy has become increasingly attractive.

Hydrothermal resources are considered conventional geothermal resources because they can be developed using existing technologies and do not require the creation of human-made reservoirs, as is the case with enhanced geothermal systems (EGS). as needed with enhanced geothermal systems (EGS). The natural subsurface formation of a hydrothermal resource requires three principal elements: heat, water, and formation permeability. A natural hydrothermal resource ultimately depends on the coincidence of sufficient quantities of these three components. Current knowledge strongly suggests that this coincidence on Earth is infrequent. An alternative to dependence on naturally occurring hydrothermal reservoirs involves human involvement in developing hydrothermal reservoirs in hot rocks for commercial exploitation.[6]

The chronology of human contributions beyond hydrothermal in geothermal technology is shown in Figure 1. VegaGeo 3.0 Hybrid Semi-Loop Single Well Closed EGS (HSLS) currently stands alone as the only method that exploits the unlimited heat energy of deep hot dry rock (HDR) and super-hot dry rock (SHR), Earth's most abundant resource, producing utility-scale, zero-carbon baseload energy at the lowest levelized cost of electricity (LCOE) of all sources at US$21/MWh, one-half of the DOE target, Figure 2. The LCOE represents the average revenue per unit of electricity generated or discharged required to recover the costs of building and operating a generating plant during an assumed financial life and duty cycle.[7] The duty cycle refers to the typical utilization or dispatch of a plant to serve base, intermediate, or peak load. Wind, solar, or other intermittently available resources are not dispatched and do not necessarily follow a duty cycle based on load conditions.
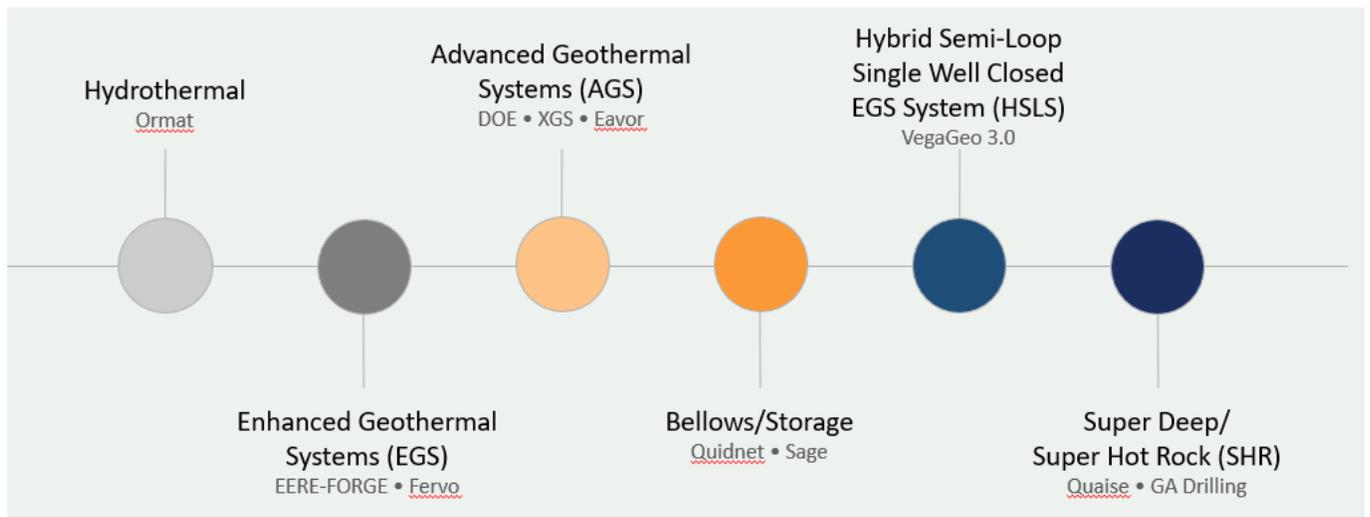

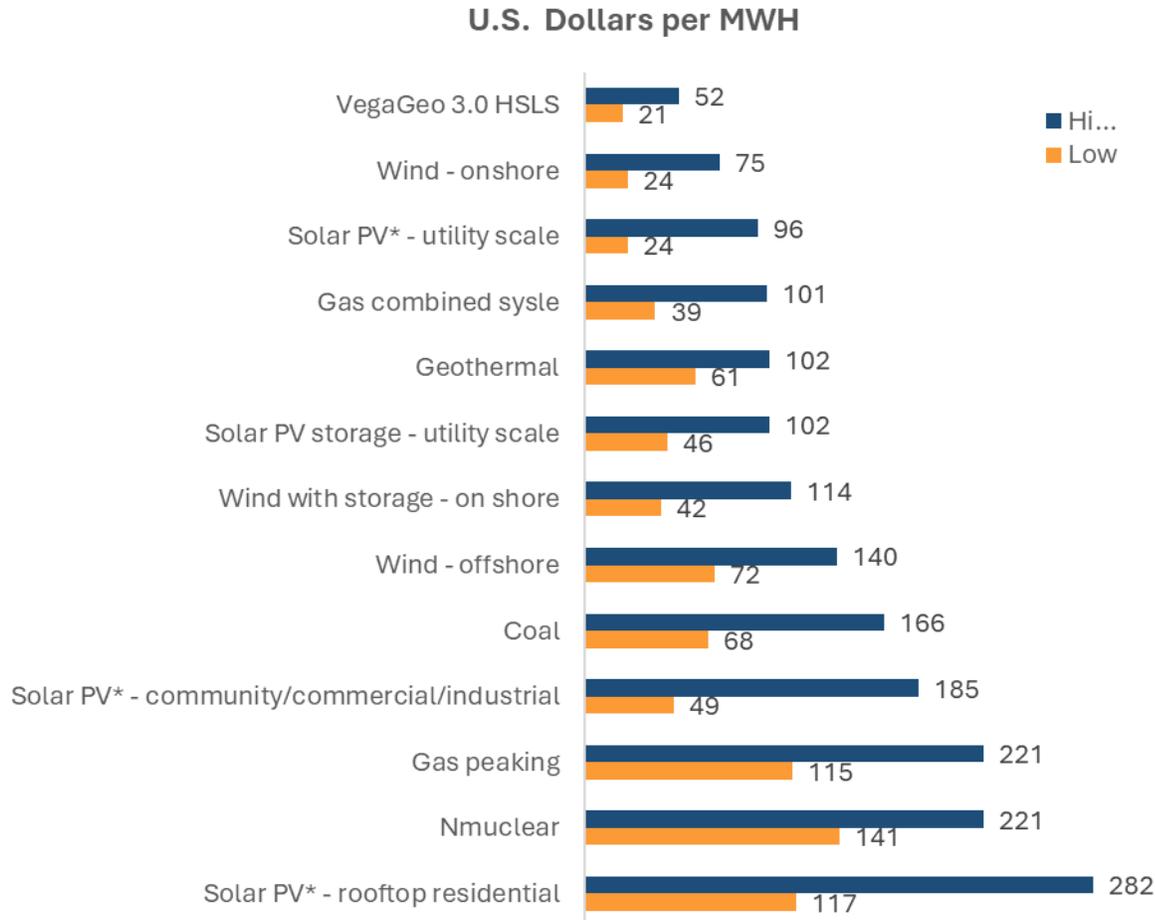**Figure 1: Development History of Geothermal Methods**

U.S. Dollars per MWH

Technology	High	Low
VegaGeo 3.0 HSLS	52	21
Wind - onshore	75	24
Solar PV* - utility scale	96	24
Gas combined sysle	101	39
Geothermal	102	61
Solar PV storage - utility scale	102	46
Wind with storage - on shore	114	42
Wind - offshore	140	72
Coal	166	68
Solar PV* - community/commercial/industrial	185	49
Gas peaking	221	115
Nmuclear	221	141
Solar PV* - rooftop residential	282	117

Figure 2: Unsubsidized LCOE

The reasons why other current geothermal power systems cannot significantly impact climate issues and struggle with profitability are outlined

Hydrothermal–naturally occurring hot water and steam
- Comes from the Earth's internal heat (magma bodies or high geothermal gradients)
    - Water-dominated systems in permeable rock formations
- High reliability mature technology with a high-capacity factor
- Exceedingly scarce, baseload renewable resource in tectonically active regions (volcanic zones and rift systems)
    - Only ~5% of the Earth's land area contains even partial criteria: sufficient subsurface heat (>150°C), water, and rock permeability for suitable electricity generation.
    - 10% success rates on that 0.5% with ≈3-5 MW average well production.
    - Easiest discoveries already made, commenced in the early 1910s with the first geothermal power station in Larderello, Italy.

Enhanced Geothermal Systems (EGS)–technology designed to produce energy where hydrothermal resources do not exist
- Does not require natural hot water or natural rock permeability and greatly expands the geographic feasibility with major developments in the U.S. and Europe.
- Requires two wells, typically today highly deviated or lateral, an injector, and a producer, in 150 to 200°C rock, that are connected by a fracture network.
- The first EGS experiment was done at Fenton Hill, New Mexico, by Los Alamos National Laboratory in 1974, and experimental closed-loop circulation tests were performed in the 1980s-1990s.
- Inconsequential output, frac spacing congestion, unsustainable baseload, typically <2 MW levels, lower than high-quality hydrothermal wells.
- Output is currently being repackaged as intermittent/backup energy.
- Problematic double-well cost, excessive water use, and induced earthquake issues.

Loops/Advanced Geothermal (AGS)–a newer class of technology designed to recover heat with no fluid loss from the subsurface without creating or stimulating fractures

- Extracts reservoir heat purely by conduction in 120-200°C rock by circulating a working fluid (water or CO2) in fully sealed piping.
- First demonstrated in Alberta, Canada, in 2019.
- Several methods of closed wellbore circulation generate an initial output of approximately 0.4 MWt per mile for a sealed borehole with piping at 175°C.
- Substantially longer wellbores are needed to increase the surface area for heat transfer, which results in higher drilling costs.
- Production temperatures can be halved within approximately 24 hours of operation.

Bellows/Storage–A closed-loop geothermal energy storage and recovery concept
- Not a classical geothermal resource type as described above, but rather a hybrid of geothermal + thermal energy storage generally targeting shale or shale/tight sedimentary intervals.
- A bellows/storage, which acts as a pressure or volume-buffering element, helps control thermal expansion during both charging and discharging and is often used together with AGS.
- Generally inconsequential kW-level generation or storage.
- It can repurpose existing abandoned wells.

Hybrid Semi-Loop Seigle Well Closed EGS System (HSLS)-Defined in Section 6

Superdeep/Superhot
- Costs and risks rise faster than the value of the extra heat that is recoverable.
- Simply drilling deeper to hotter rock cannot alone harvest sufficient heat without heat exchange by circulating fluid contacting adequate surface areas.

2. HOTTER AND DEEPER WELLS IN MORE STABLE ROCK

Hot Dry Rock (HDR) and Super-Hot Rock (SHR) geothermal production is a high-volume mass-energy concept. It is obtainable only from much hotter, deeper, and more stable rock than is traditionally exploited by EGS, AGS, and Bellows/Storage.

Power recovery of any significance from HDR and SHR is difficult, and there is no shortcut. This is a significant challenge for manmade methods. Only large-scale, detailed, high-efficiency extraction flows from properly separated, extensive heat transfer surfaces can deliver the world-class performance necessary for climate and economic impact. Developers have thus far followed traditional extractive industry practices, emphasizing the easiest, shallowest, or most obvious courses, leading to greater limitations and higher costs than the energy abundance would suggest.

Examples of these failed approaches include shallow drilling and stimulation, which mostly lead to instability, high water losses, and possible seismic activity. Horizontal drilling modestly increases total heat but fails to improve baseload capability, especially because non-replenishing fracture congestion from insufficient spacing between fractures limits the recoverable energy potential. Additionally, piercing thin fractures perpendicularly with a small-borehole connection between the well and fractures results in very low efficacy, with potential for short-circuited heat recovery. Multiple wells can improve reliability and capacity in some contexts, but are usually ineffective overall in hotter and deeper formations

Geothermal energy, as implemented through the VegaGeo 3.0 Hybrid Semi-Loop Seigle Well Closed EGS System (HSLS), offers an alternative to previous inconsistent approaches that have contributed to its minimal market presence as an energy source.

Achieving solutions to geothermal exploitation requires doing many things opposite to the last 100 years' practices, and includes:

Hydrothermal Resource Scarcity	→HDR and SHR Ubiquity, 15% of Earth's Landmass
Shallowest Resource Investment	→Deeper, Higher Temperature, Less Problematic Geology
Unstable Drilling, Water Loss, Seismicity	→Solid, Uniform, Impermeable Rock
Limited Heat, Shallower Horizontal Drilling	→Vertical, Directly Additive Heat-Energy
Two Well Cost, Injection & Recovery	→Single Well Expense Performing Both
6% - 10% Energy Extraction Efficiency	→90%+ Heat-Energy Recovery
Highest CAPEX, Lowest Efficiency, ORC at 10%	→Lowest CAPEX, 3X Flash Output Efficiency Gains
Intermittent Energy, Negligible Impact	→Around-the-Clock Energy
Non-economic or Unrealistic Business Model	→Lowest Unsubsidized Cost Power of Any Source

3. DEVELOPMENTAL CHALLENGES FOR EGS[8]

A. Scarcity of connected natural fracture networks, particularly in deeper, hotter intervals where occurrences of natural fractures decline or there is insufficient reservoir volume

B. Doubled problematic drilling and doubled drilling costs of a two+ well system
   a. Per MW drilling cost is 3X to 6X over other approaches
   b. Doubled well integrity issues
   c. Increased risk of lost circulation

C. Lost or stuck downhole equipment. Induced seismic tremors or earthquakes – according to Joern Ole Kaven, Research Geophysicist with the U.S. Geological Survey, there is no "one-size-fits-all" approach to earthquake risk with EGS.

Earthquakes happen regardless of industrial activity. And no one can confidently indicate how much EGS might be accelerating the timeline of a major earthquake … or how severe that earthquake could be.[9]

    D.   Difficulty with the stimulation effectiveness of connecting natural existing fractures between the production and injection wells. Injectivity issues.
        a.   Poor connectivity between injection and recovery causes production losses, wasted energy, and water loss.
        b.   Commercially insufficient injectivity potential due to the cooling of the hot rock
        c.   Parasitic injection loads or electric power consumed to inject fluids
        d.   Concentrated flow path, or hydraulic/thermal "short-circuiting," leading to an early thermal breakthrough

    E.   Low energy output due to limited non-vertical heat access, inadequate reservoir-stage volumes, and the need to operate for non-intermittent longer periods.

    F.   Long-term reliability of well completion and production equipment.

4. DEVELOPMENT CHALLENGES FOR AGS

The main downside of these deep artificial closed-loop circuits and radiator styles is that they cannot benefit from the large surface area in reservoirs without extended boreholes. Rock does not conduct energy quickly, thus requiring a large amount of surface area in reservoirs is important for conventional hydrothermal systems and EGS. There are hard constraints based on the laws of heat conduction that limit the amount of heat energy that the system can acquire. Broadly speaking, AGS is inherently limited because the contact of heat-harvesting fluids with sufficient surface areas reduces energy production and turns AGS into more of an energy storage system than a utility-grade power source.[10,11,12]

5. DEVELOPMENTAL CHALLENGES FOR BELLOWS/STORAGE

It is a Pressure Geothermal System, which uses a deep engineered "lung" fracture—a subsurface reservoir created in low-permeability rock—to store and release energy using, in this case, a supercritical carbon dioxide (sCO_2) power system poised to deliver long-duration, dispatchable storage.[13]

"The flow conductivity of a single fracture will be insufficient to sustain the high flow rates needed for economic viability, nor will it access sufficient surface area to achieve long-term sustainability. An economically viable project would require 100s or 1000s of fractures, and firms are experimenting with proppant to improve the flow rate achievable through those fractures…"

As hot water rises from the underlying part of the fracture (or as cool water sinks downward from the heat exchanger), it will equilibrate in temperature with the surrounding rock. This will prevent the high temperatures at the bottom of the fracture from reaching the top of the fracture, and vice versa.[14]

6. GEOTHERMAL'S BREAKTHROUGH: VEGAGEO 3.0, GLOBAL SCALE BASELOAD – DEPLOYABLE NOW

VegaGeo 3.0's Hybrid Semi-Loop Single Well Closed EGS System (HSLS) has five to 30X more output than any other geothermal method and the lowest unsubsidized LCOE of US$24/MWh. HSLS is a closed, vertically stacked series of propped fractured reservoirs capable of 110 MWt peak baseload well flows with full hydraulic thermal sweep/energy recovery. It is constructed in a single vertical well with deeper, hotter, more stable hot rock, Earth's most abundant resource, Figure 3.

VegaGeo 3.0's HSLS application merges established oilfield technologies with the strengths of legacy geothermal systems—high hydrothermal output and minimal closed-loop risk—while eliminating issues such as unsustainable water loss and increased seismic risk found in other approaches.

HSLS offers deeper, high-heat, highly conductive hydraulically fractured reservoirs with 335 m stage spacing, enabling reliable baseload performance. Propped reservoirs are bifurcated by an impermeable barrier that causes circulating heat-carrying fluids to flow great distances from the wellbore, thereby picking up substantial heat. The liquid then turns 180° around the end of the diverting barrier. It collects additional heat while flowing on the lower side of the engineered barrier and as it re-enters the well annulus.
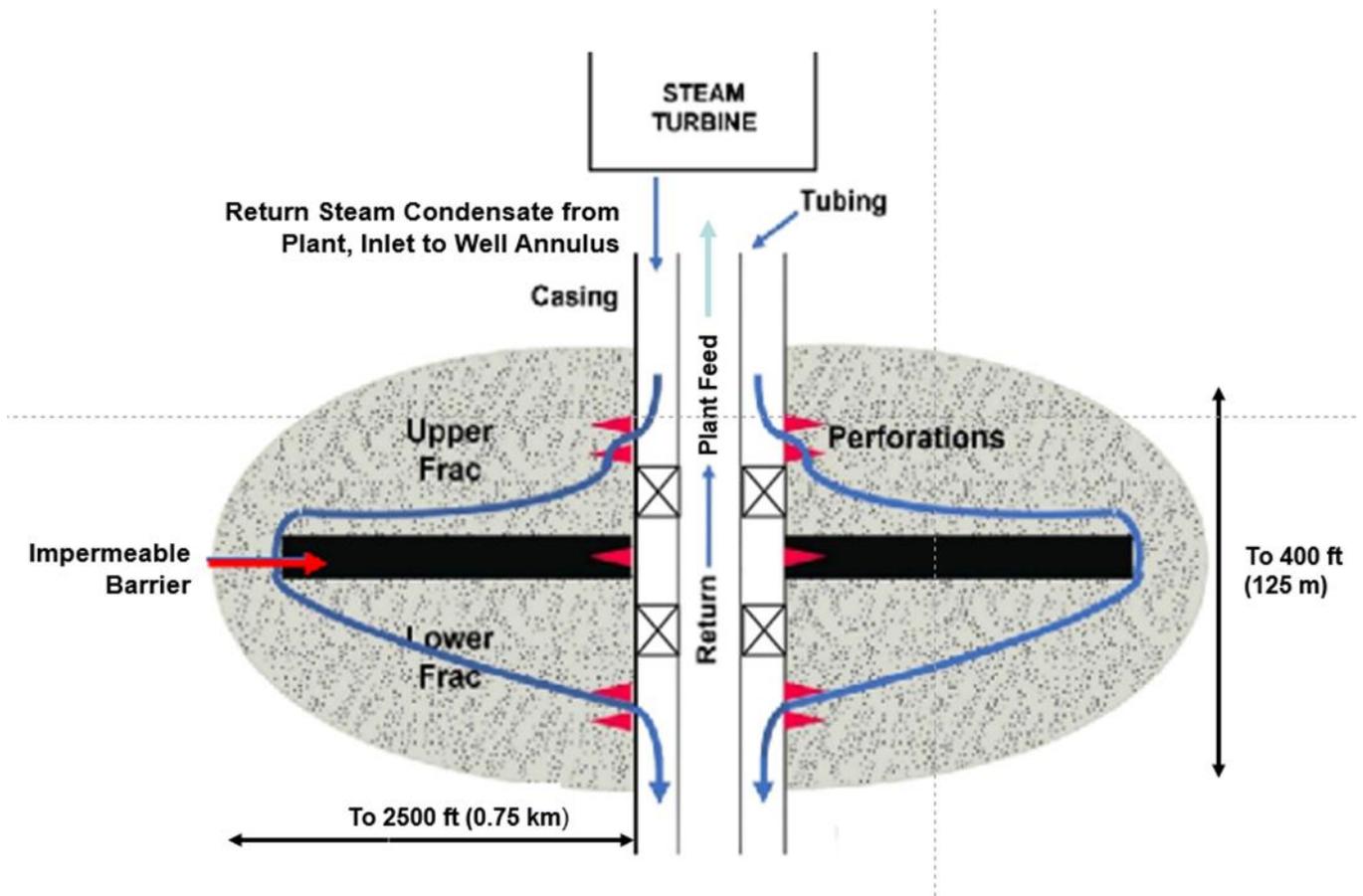
Figure 3: Basic single-stage VegaGeo 3.0 HSLS operation: (1) Pump water down the casing-tubing annulus, (2) Water is diverted through upper perforations into the fractured reservoir, (3) Guided by a barrier structure, water collects heat as it travels across the hot reservoir rock, (4) Superheated steam enters the well through lower perforations and flows up the tubing to cascading steam turbines, and (5) condensate water is recycled back to the well

Outlets and inlets in the wellbore are separated by proprietary isolation equipment placed between the insulated production tubing and the well casing. Multiple stages, each exceeding one mile in length, will be constructed, creating a reservoir surface area of approximately 60,000,000 square feet (~5650 hectares) at temperatures up to 400°C. Based on its massive production surface area and the creation of high hydraulic sweep efficiency, VegaGeo 3.0 is the sole means by which 50 MW can be reliably brought to a wellhead, levels that are some 10 to 30 times higher than those of EGS systems. The VegaGeo 3.0 system is expected to achieve 1 GW of hourly production from approximately 2,800 acres and 10%+ global Total Energy by 2050, provided suitable investment and infrastructure are in place.

The performance potential of VegaGeo 3.0 is extraordinary. A 20-stage VegaGeo 3.0 HSLS placed through a 6 km (~20,000 ft) vertical interval creates 630 hectares (1,557 acres) of HDR or SHR surface area with 50+ MW gross output from 175 to 370°C rock. It can produce 260°C water at 2,000 gal/min, yields 50 MW wells, and approximately 6X to 30X output over alternatives. Furthermore, cascading flash steam turbines make the system 3X more efficient than organic Rankine cycle (ORC) methods.

Below is a five-point summary of the VegaGeo 3.0 solution to EGS, AGS, and Bellows/Storage issues:

A single vertical well performs injection and recovery functions that offer the most economical drilling with maximum heat access/highest enthalpy approach; two directional boreholes can triple the cost.

    A.   Technology harvests virtually unlimited, deeper, stable HDR and SHR:
- 10+% of Earth's land area overlies ~5 MW / km heat potential.
- Stable geology mitigates problematic drilling and completion operations.

    B.   Controllable massive reservoir creation: dimensions, intersection, and integrity are well within current engineering capabilities.

    C.   Successively extended path flow diversion/heat recovery that provides unrivaled energy production.

    D.   Coplanar well-reservoir arrangement/defined boundaries results in tunable, high-efficiency hydraulic and thermal sweeps that maximize energy harvesting.

E. Greatly reduced surface land use, including compact wellheads and a highly efficient production plant, means that multiple plants can be placed on small acreages and multiply energy production at a given site.

7. HOW IT WORKS[15]

The VegaGeo 3.0 HSLS single vertical well and inline propped fractured reservoir structure performs both non-intermittent injection and production roles from HDR and SHR. Flow diverters placed across the midpoint of its induced propped fractured reservoirs help direct heat-carrying fluids far from the well annulus. These fluids become superheated during their return journey. Supercritical heat transfer occurs as the fluids pass through fifteen 4M ft² reservoir stages, covering a total of 1,300 acres of rockface surface area at temperatures between 300 and 750+°F. With about 1,100 ft spacing between the propped fractured reservoirs, baseload energy is recharged over 20 hours of downhole exposure and brought to the surface via insulated production tubing.

VegaGeo 3.0's aligned wellbore-perforation-reservoir configuration enables full hydraulic connectivity and flow proficiency among the three parts. Highly transmissive flow regimes freely feed uniform proppant bed volumes, resulting in two important benefits: First, finely controlled reservoir flooding over 100s of feet of reservoir height assures complete rockface contact and energy sweep, thus recovering most of the potential energy; and second, such flows and extraction are conducted without parasitic injection pressure costs or atmospheric release.

8. DETAILS OF THE SIX VEGAGEO 3.0 COMPONENTS

VegaGeo 3.0's Technology consists of five distinct, but synergistic elements: (1) Use of extended-life PDC Drilling Bit Technology, (2) Dimensionally controlled highly conductive propped hydraulic fractures created with a high-temperature stable fracture fluid (>350°C), (3) Engineered bifurcating flow diverters constructed in the propped fractures, defining precise hydraulic circulation pathways, (4) Thermally variable production packer assemblies to divert fluid flow in and out of the hydraulic fractures,(5) Full-fracture volume sweep capability approaching 100% energy recovery, and (6) a proprietary flash turbine configuration that takes advantage of the superheated fluids produced by the HSLS configuration to eliminate water loss, vampire chilling and pumping costs, and maximize energy capture.

A. Single Vertical Well Construction that performs Inlet and Recovery Functions – VegaGeo 3.0 applies current high penetration rate PDC drilling technologies through stable, high-strength rock geology. Standard well construction methods modified for high-temperature environments permit installations in rock as hot as 800°F.

B. Massive Induced Propped Fracture, High Conductivity, Highly Separated Reservoirs – Use of proprietary VegaGeo 3.0's Silica Gel Fracturing Fluid (SGFF), which is a high-temperature inorganic viscosifier, enables massive fracture creation and high conductivity proppant placement into 400+ ft reservoir heights and reservoir lengths exceeding 2500 ft and to an estimated 750°F. VegaGeo 3.0 fracturing operations use only environmentally inert component compositions. Large reservoir dimensions, a high heat gradient, and substantial separation between fracturing stages facilitate a long-term 50 MWt utility baseload.

C. Impermeable Barrier Placement in the Propped Hydraulic Fractures – Constructed in each created HDR or SHR reservoir from solidifying polymers or carved out of native rock, diverting barriers, or plugs, direct heat-carrying fluid thousands of feet away and back into the well, contacting some 60M ft^2 at variable flow rates. Barrier development technology is based on longstanding water conformance/water control practices used for decades, primarily in oil and gas operations. Five material families, including organic, cementitious, and elastomeric products, apply to this and several other construction approaches.[16]

D. Thermally Adaptable Wellbore Isolation – VegaGeo 3.0 will apply a TAM International Single-set Geothermal FREECAP swellable isolation packers or equivalent with a 575°F rating, Figure 4, placed two per stage (positioning shown in Figure 3) on the insulated production tubing assembly. This positioning causes heat-carrying fluid to exit the well annulus, enter the upper portion of reservoir circuits, and then guide the return flow through the next circuit stages. The TAM International hydraulic circuit design facilitates precise management of both hydraulic and heat sweep efficiencies. Control inputs include circulation rate changes, where the flow rate may become turbulent, and where fluids seek relief vertically, sweeping the entire reservoir height. Other hydrological adjustments include fluid elevation level changes, variations to inlet and outlet elevations, fluid density alterations, and changes in flow direction Figure 5.[17]

Figure 4: TAM International Geothermal FREECAP Swellable Isolation Packer
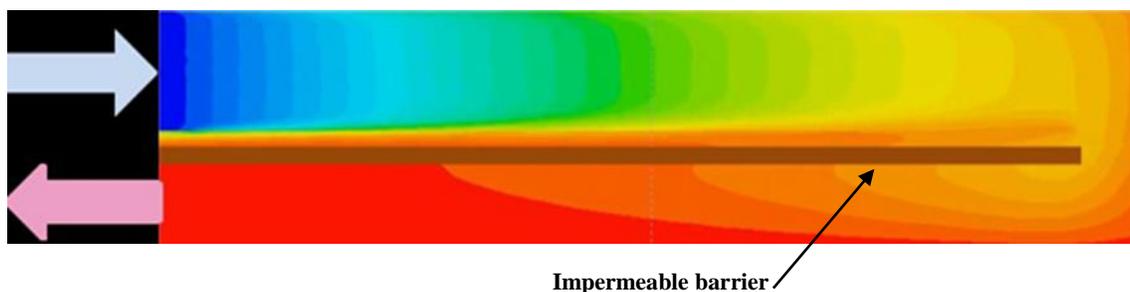
Impermeable barrier

Figure 5: Streamlined velocity profile and temperature change are seen in a one-quarter reservoir system view.

E. VegaGeo 3.0 Surface Operations – Recycled fluids flow from the conversion plant to the well annulus. Depending on the well's bottom hole temperature, thermally advantageous fluid properties enable the recirculated fluid to enter the well's annulus under a vacuum. Note in Table 1.[18]

Table 1: Thermally Advantaged Fluid Properties of Water

Temperature, °F	Density, lb/gal	Viscosity, cp	Saturation pressure, psia
705*	2.76	0.045	3,206
440	5.78	0.118	382
210	8.00	0.285	14

*Critical temperature of water

As condensed steam is directed into the well annulus, upon entry, this fluid's density is nearly three times greater than the fluids occupying the same space at total depth. Near the bottom of the system, a gas-weighted fluid U-tube from the well annulus runs up the production tubing. A pressure difference of several thousand psi between the annular and tubing fluid columns creates a vacuum in the annulus and high pressure in the production tubing at the surface as cooler, denser condensed fluids from the steam turbines continually refill the annular void. The vacuum in the well annulus not only eliminates traditional parasitic injection costs but also reduces steam turbine back pressure and improves condensing and cooling performance, resulting in enhanced turbine performance and overall plant efficiency.

F. Proprietary Steam Flash Turbine Design – The fluid that arrives at the flash turbines is a supercritical and highly pressurized plasma. This concept presents several advantages, including maximum energy recovery, no requirement for chillers or pumps, and a virtually negligible fluid loss. And, unlike ORCs, flash turbines are readily available and cheaper. Condensed steam is directed to the well annulus for recirculation and heat harvesting.

9. GEOTHERMAL AS A LUCRATIVE MAJOR CLEAN ENERGY SOURCE

Requires top performance in at least eight areas.

A. **Always-On Baseload Power** –Owing to its 24/7 basis, hot and superhot rock leads all. The resources are endless, accessible, and extractable. VegaGeo 3.0's five-fold+ mass-energy-revenue creates cost economies, optimizes capital, and attains meaningful scale towards climate impact.

B. **Financing-Friendly Risk**–Large HDR and SHR targets have drilling and production properties that improve with depth cut exploration and development risk. Performance in deep hot geology is predictable at 90%+ confidence, allowing capital acquisitions before drilling. Production testing is verification-focused, rather than traditionally speculative.

C. **Mitigation of External Reliances and Cost** –Generic developmental expenses, especially those subject to oil & gas market cyclicality, are more preferably internally performed, assuring a minimum of 40% pricing discounts, availability, and crew quality. Reliable manufacturing facilities add similar value.

D. **Strong ROI and Attractive Payback** – Sub-five-year payback capability. VegaGeo 3.0 delivers four times the usual utility ROI, enhancing its attractiveness to debt financing. A high capacity factor means more MWh per dollar invested.

E. **Peak Conversion Efficiency and Lowest CAPEX/OPEX**–-Ranging to 30% recovery efficiency, flash turbine conversion is critical for maximizing revenue: in contrast with 8% -12% ORC-binary conversion and 2X investment. In addition to enjoying the lowest CAPEX, even high-corrosion service flash systems commonly require negligible maintenance, with only a few days of inspection and cleaning at approximately 2- to 3-year intervals.

F. **Elimination of Parasitic Wastes** –Reinjection and atmospheric venting work customarily account for a 30% loss of gross energy. VegaGeo 3.0's creation of a negative-pressure annular recycling force, use of multi-flash plant design, and incorporation of basic ideal gas law effects eliminate the traditional sources of waste.

G. **High Energy Density and Small Footprint** – Geothermal produces large amounts of power from a very small land area with minimal visual and environmental impact.

H. **Expanding Technology Upside**-–Advances in drilling, completion, reservoir engineering, and heat extraction (e.g., EGS, hybrid semi-loop systems, hybrid designs) are lowering costs and expanding viable locations. Oil & gas expertise and infrastructure are directly transferable.

10. COMPUTATIONAL FLUID DYNAMICS (CFD) THERMAL ANALYSIS[19]

Prolonged commercial heat quantities cannot now be harvested from current EGS, AGS, and Bellows/Storage systems, mainly due to insufficient heat transfer areas or accelerated rock cooling. Modeling the VegaGeo 3.0 HSLS indicates that long-term economic continuous baseload capacity relies on the creation and effective heat transfer of circulating water through an extensive network of highly conductive, propped fractured reservoirs. The depth of the uppermost VegaGeo 3.0 reservoir is assumed to be 10,000 ft.

A computational model incorporating both steady-state and transient CFD, along with conjugate heat transfer analysis, was created to predict the production temperature and megawatt thermal (MWt) output for both a single-stage system (see Figure 3) and a 15-stage VegaGeo 3.0 reservoir system. Figure 6 shows the ¼th computational model for thermal analysis, and Figure 7 shows the enlarged view of the propped fracture. Figure 8 shows the computational mesh.
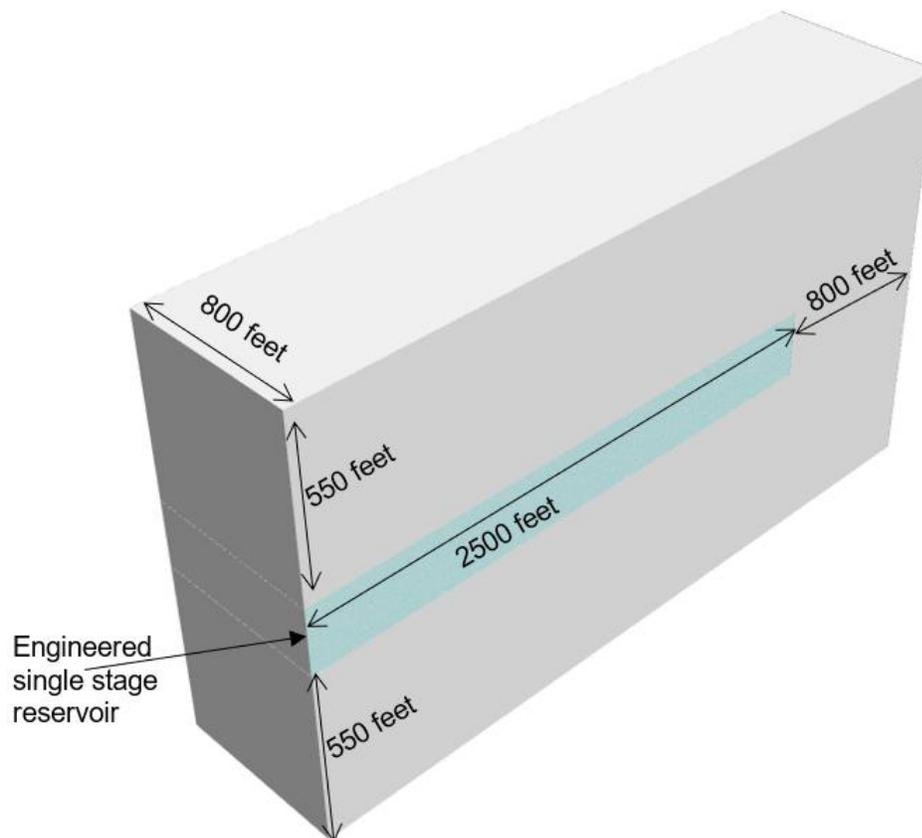

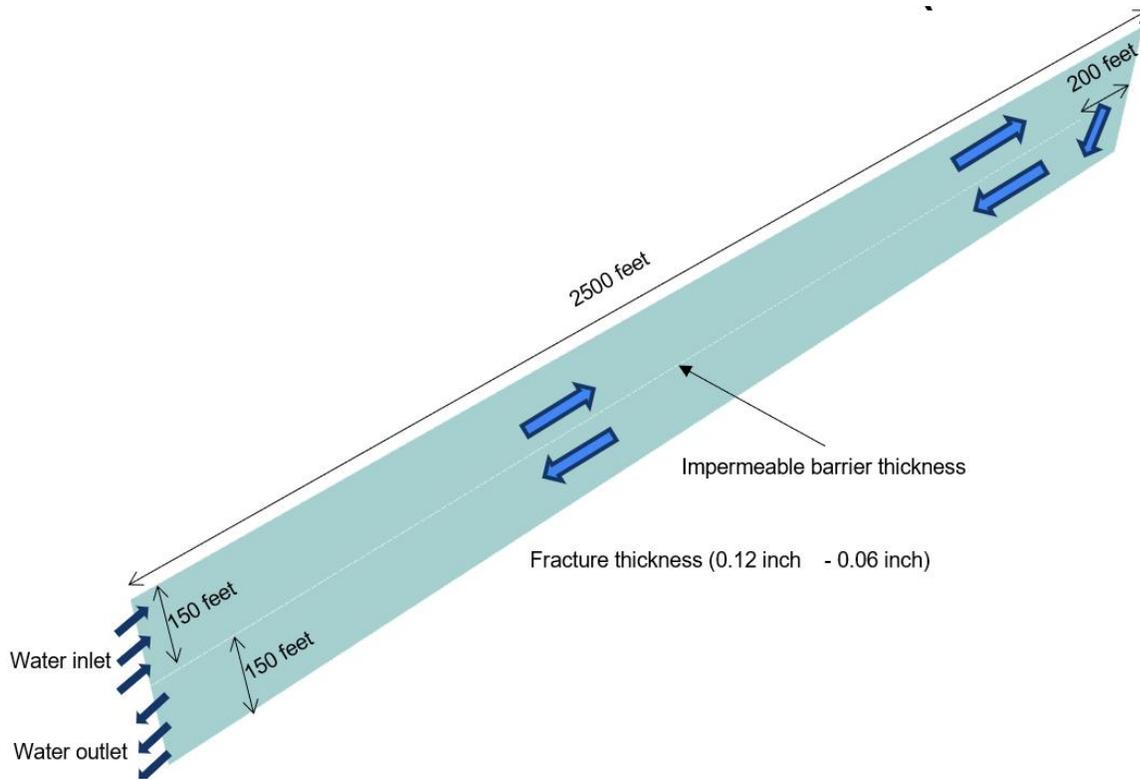**Figure 6: Computational model of the propped fracture with rock in a single stage**

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Figure 7: Enlarged view of the propped fracture with an installed impermeable barrier
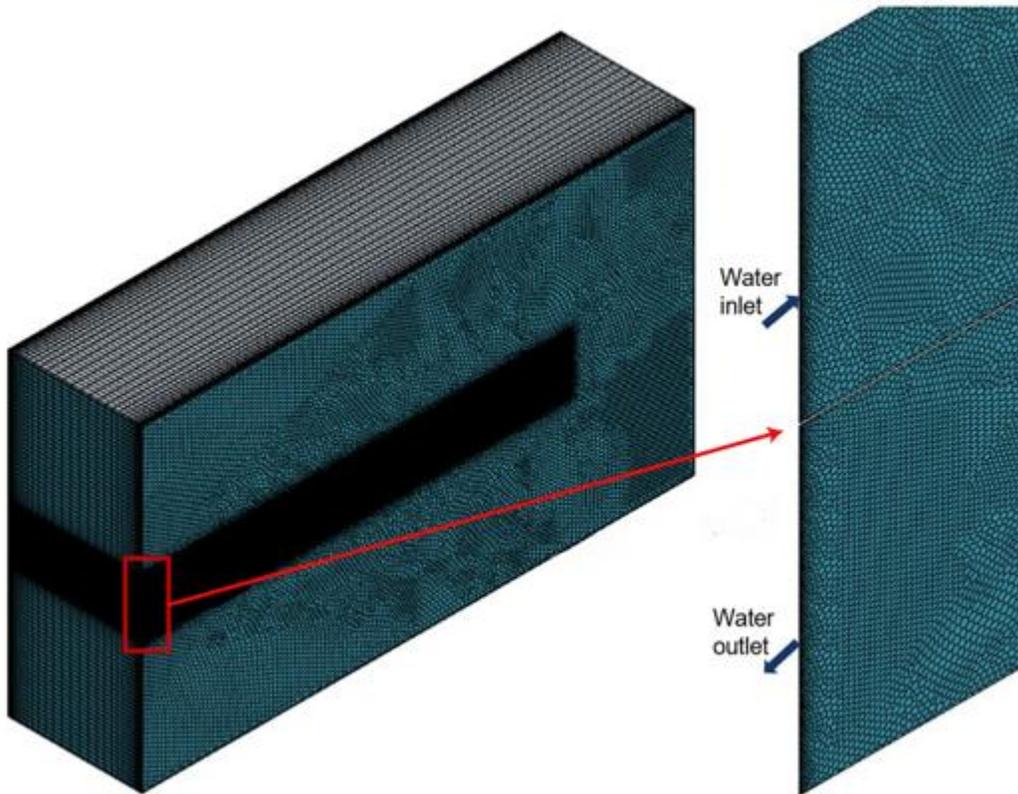

Figure 8: Computational mesh

Water is a heat-carrying fluid. Production temperature is predicted as a function of water flow rate (500 – 1300 gal/min or gpm), propped fracture dimensions, surface water inlet temperature (210°F), rock thermal gradient (0.025°F/ft), number of VegaGeo 3.0

propped fracture reservoirs, their depths, and distance between reservoirs. Figure 9 shows typical temperature contours in the rock, and Figure 10 shows the water temperature rise contours as it travels through a single VegaGeo 3.0 propped fracture.

The results of parametric simulations indicate that raising the reservoir height leads to an increase in temperature gain. The Increase in reservoir separation also results in higher temperature gain but fewer reservoirs can be accommodated in the same depth, so the optimum was found based on parametric thermal analysis. Figure 11 shows typical rock temperature contours in a VegaGeo 3.0 multi-reservoir system, and Figure 12 shows the water temperature inside the reservoirs. Figure 13 presents the VegaGeo 3.0 15-stage reservoir system, with each reservoir spaced 1100 feet apart from center to center.

Figure 14 and Table 2 show the VegaGeo 3.0 15-stage reservoir System Temperature as a function of time up to 10 years, for various continuous circulation rates and a constant inlet temperature of 210°F, approaching steady-state performance. At each circulation rate, the water temperature declines rapidly over a few months and, after four years, flattens out. At the four circulation rates in Table 1, steady-state MWt exceeded 20.
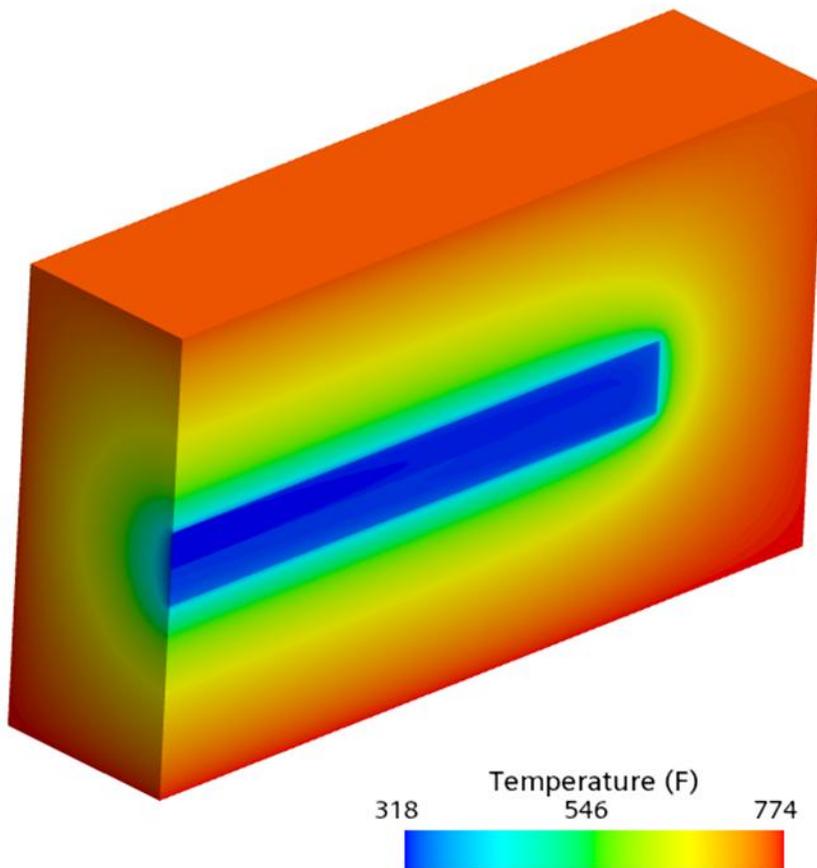

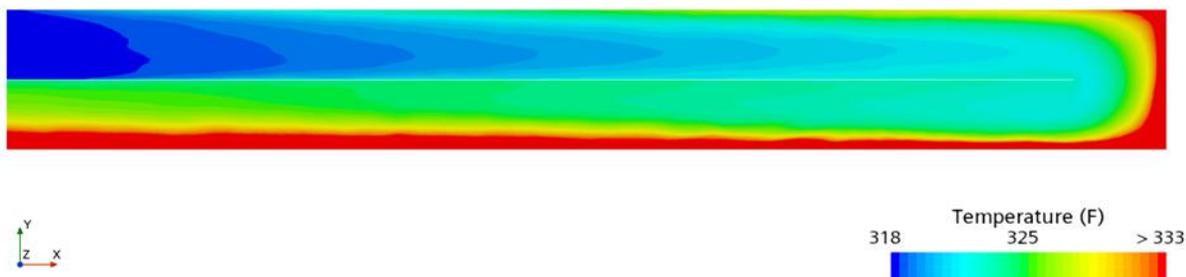**Figure 9: Temperature contours in the rock surrounding the propped fracture**

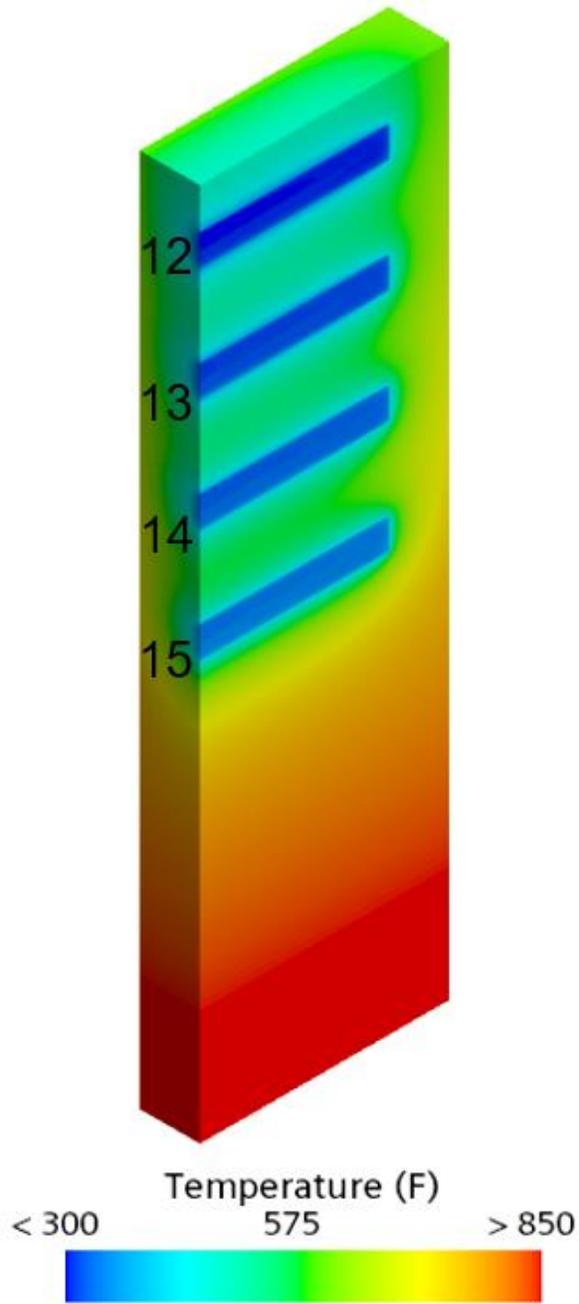**Figure 10: Temperature contours in the water inside the propped fracture**

Figure 11: Rock temperature contours in the multi-reservoir propped fracture system
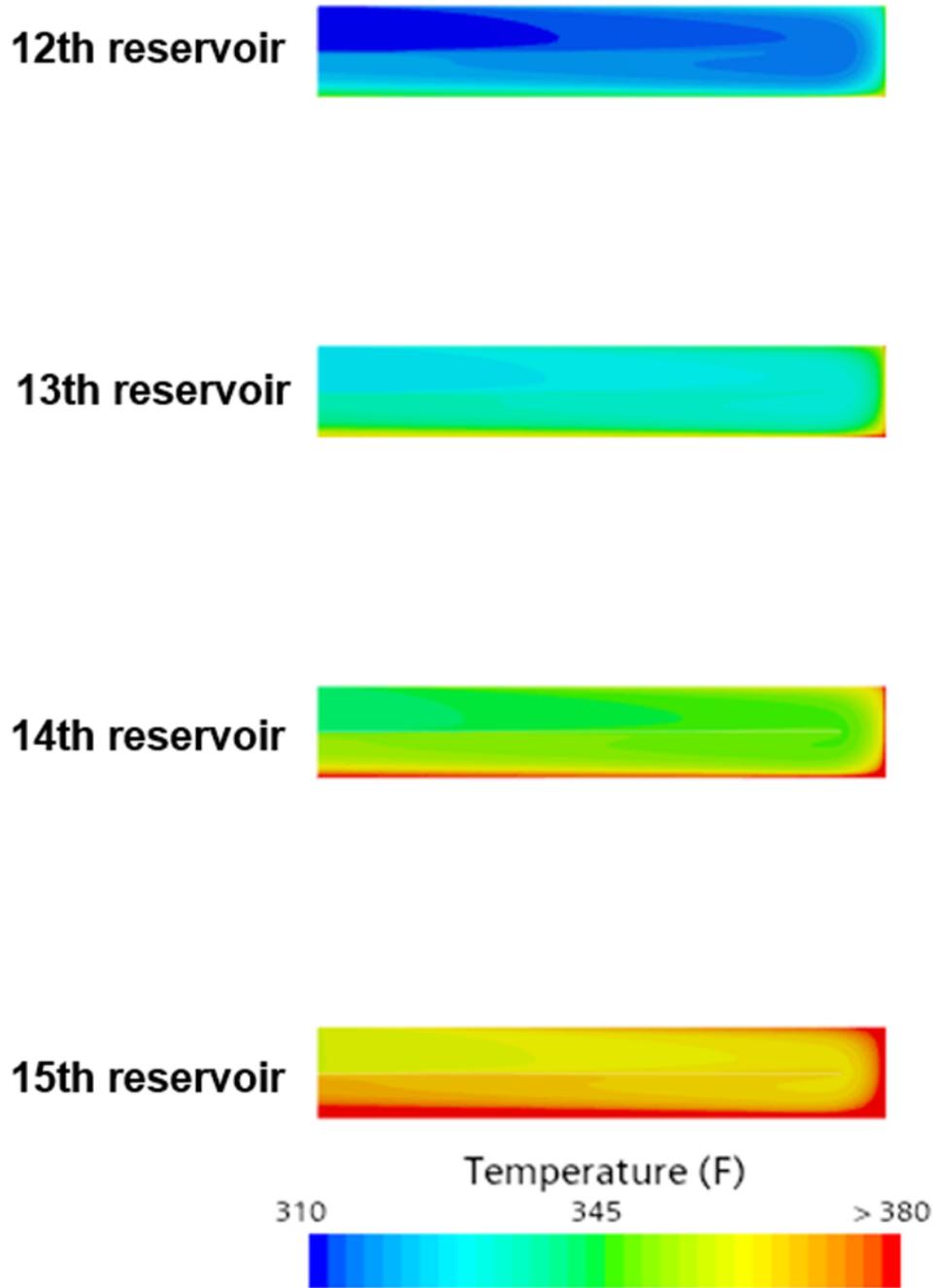
12th reservoir

13th reservoir

14th reservoir

15th reservoir

Temperature (F)

310   345   > 380

Figure 12: Water temperature contours in the multi-reservoir propped fracture system
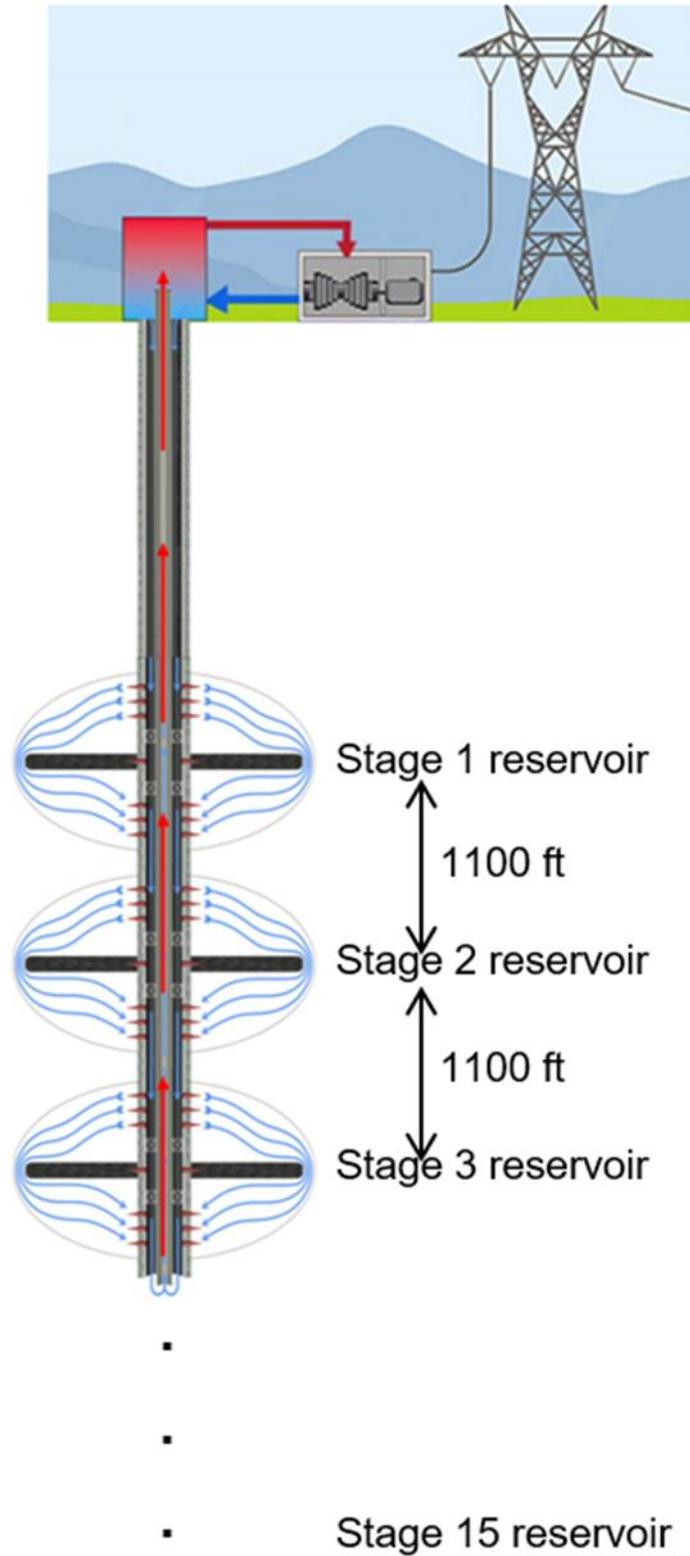
Figure 13: 15 Stage propped fracture reservoir system

SYSTEM TEMP AS FUNCTIONS OF TIME, RATE & INLET T

Various pump rate regime geothermic reductions over 10 years. 210ºF system inlet temperature level precludes scaling deposition.
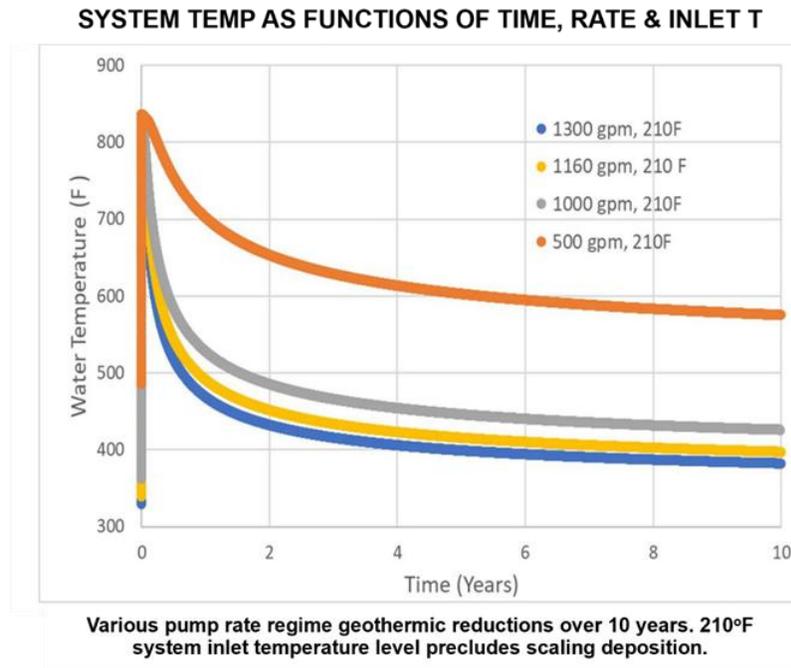
Figure 14: VegaGeo 3.0 15 propped fracture reservoir temperature over time

Table 2: Flow Rate vs. Time, Peak and Average MWt to Steady State Performance

Flow rate (gpm)	Peak and Average MWt							
	Peak	1 year	2 year	3 year	4 year	5 year	10 year	Steady State
500	44.5	39.6	36.4	34.4	33.2	32.2	29.4	21.1
1000	87.9	57.6	49.6	45.7	43.2	41.4	36.8	27.3
1160	100.4	61.2	52.1	47.8	44.7	43.1	37.9	27.9
1300	111.5	63.3	53.5	49.0	46.0	44.0	38.8	27.9

11. SUMMARY & CONCLUSIONS

A. Figure 14 and Table 1 present the VegaGeo 3.0 15-stage reservoir system temperature over 10 years for different circulation rates at a constant inlet temperature of 210°F, showing its steady-state performance. At each circulation rate, the water temperature declines rapidly over a few months and then levels off after four years. At the four circulation rates in Table 1, steady-state MWt exceeded 20.

B. It has the lowest unsubsidized LCOE of US$24/MWh and is deployable now.

C. Modeling output at various circulation rates at a rock thermal gradient of 0.025°F/ft peaked initially and then declined after 10 years to significant Average MWt values.

D. Truly, geothermal energy anywhere, as VegaGeo 3.0 can be applied in any region that contains a significant heat source, is within 25,000-30,000 ft of the surface.

E. VegaGeo 3.0 is working directly and in conjunction with a focused set of vendors and suppliers of the technology discussed above. VegaGeo 3.0 aims to execute a proof-of-concept in a shallow low-temperature well to test and validate the current wellbore and fracture design with a barrier installed in the propped fracture.

F. Currently planning a deep test wellbore to ~20,000 ft TVD, which will encounter hot granitic or plutonic rock with downhole temperatures more than 300°C.

REFERENCES

[1] U.S. Energy Information Administration, "Electric Power Monthly," February 2024.

[2] Barber, Gregory. "A Vast Untapped Green Energy Source Is Hiding Beneath Your Feet." Wired. ISSN 1059-1028, August 8, 2023.

[3] Gutiérrez-Negrín, Luis C.A., "Evolution of Worldwide Geothermal Power 2020-2023, Geothermal Energy." 2024.

[4] GeoEnergy, ThinkCurrent. "ThinkGeoEnergy's Top 10 Geothermal Countries 2023 – Power Generation Capacity," January 8, 2024.

[5] "Data Page: Geothermal energy capacity," part of the following publication: Hannah Ritchie, Pablo Rosado, and Max Roser (2023) - "Energy". Data adapted from the International Renewable Energy Agency. Retrieved from https://ourworldindata.org/grapher/installed-geothermal-capacity [online resource].

[6] Energy Efficiency & Renewable Energy Office at GTO, "Hydrothermal Resources." 2023.

[7] U.S. Energy Information Administration, "Levelized Costs of New Generation Resources." March 2022.

[8] Pollack, A., Horne, R., and Mukerji, T.: "What Are the Challenges in Developing Enhanced Geothermal Systems (EGS)?" Observations from 64 EGS Sites, Proceedings, World Geothermal Congress 2020+1, Reykjavik, Iceland, April - October 2021.

[9.] McCarthy, Will, Yale Climate Connections, "The Pros and Cons of Enhanced Geothermal Energy Systems." February 6, 2020.

[10] Patel, Sonal. "Geothermal Breakthrough in South Texas Signals New Era for ERCOT," Power Magazine, September 2, 2025.

[11] Patel, Sonal, "EGS, AGS, and Supercritical Geothermal Systems: What's the difference?" Power, News & Technology for the Global Energy Industry, April 4, 2023.

[12] Mackenzie, Aldan, Datta, Arnab, and George, Ashley, Infrastructure, "Barriers to Next-Gen Geothermal, Part Three." November 16, 2023.

[13] Pauling, Hannah, Simpkins, Douglas, Rivas, Mauricio, and McGuire, Victoria, "Thermal Analysis of Sage Geosystems HeatCycle technology for District Heating in Bucharest, Romania," 50th Workshop on Geothermal Reservoir Engineering,' Stanford University, February 10-12, 2025.

[14] IBID.

[15] Ott, William K., and Spray, Jefferey A., "DGS High Capacity, Single Well, Full Hydraulic Circuit Technology Refinements for EGS. "48th Workshop on Geothermal Reservoir Engineering," Stanford University, February 6-8, 2023.

[16] Liu, S., and Ott, W.: Sodium Silicate Applications in Oil, Gas & Geothermal Well Operations, Journal of Petroleum Science and Engineering, 195 (2020), 107693.

[17] Multiphysics, C.: "Introduction to COMSOL," Multiphysics Extregistered, COMSOL Multiphysics, 1998.

[18] The Engineering Tool, www.EngineeringToolBox.com

[19] Simcenter STAR-CCM+ CFD software "Users guide version 18.06.006," Siemens Industries Digital Software, 2023.