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Enhanced Geothermal Systems

The proposed concept is titled: Improving the Economic Viability of Enhanced Geothermal Systems Through Materials and Operational Optimization

Enhanced Geothermal Systems (EGS) and Hot Dry Rock (HDR) systems that do not rely on the geologically produced water or steam for power generation promise to significantly expand the geothermal resource base for electricity generation in California. They can also be used to resuscitate depleted geothermal fields. They have been studied since the 1970s but have not been developed as a commercially viable power source. Among the many barriers to the successful implementation of EGS in California are materials compatibility with various working fluids, especially non-aqueous systems, the cost of working fluids, and their environmental effects due to discharge. Because EGS are done at great depths, the materials for tubing and casing, sub-surface components (e.g., sub-surface safety valves and packers), and surface components (e.g., tubing hangers, surface valves) are critical. EGS can be operated using working fluids other than water, such as supercritical or dense phase CO₂. In the latter case, EGS can be used as a way to reduce greenhouse gas emissions, but also involves significant questions related to the compatibility of materials in supercritical CO₂, especially in the presence of various acid-producing impurities.

The purpose of this concept is to develop a model along with specific data to assess the materials compatibility issues related to EGS and help EGS developers better design EGS. Typically, the focus of geothermal developers is in site characterization and testing of the EGS concept. EPIC funds on this concept will be critical to EGS developers to assess the economics of the resources and optimize them so they can proceed speedily to scale-up.

Additional submitted attachment is included below.



Electric Program Investment Charge 2026–2030 (EPIC 5) Research Concept Proposal Form

The California Energy Commission (CEC) is currently soliciting research concept ideas and other input for the Electric Program Investment Charge 2026–2030 (EPIC 5) Investment Plan. For those who would like to submit an idea for consideration, please complete this form and submit it to the CEC by **August 8, 2025**. More information about EPIC 5 is available below.

To submit the form, please visit the e-commenting link:
<https://efiling.energy.ca.gov/EComment/ECommentSelectProceeding.aspx> and select the Docket **25-EPIC-01**. Enter your contact information and then use the “choose file” button at the bottom of the page to upload and submit the completed form. Thank you in advance for your input.

1. Please provide the name, email, and phone number of the best person to contact should the CEC have additional questions regarding the research concept:

Darrell Gallup
Thermochem, Inc.
3414 Regional Parkway
Santa Rosa, CA
USA 95403

Narasi Sridhar
MC Consult LLC
31510 Sweetwater Circle
Temecula, CA 92591

2. Please provide the name of the contact person’s organization or affiliation:

Thermochem, Inc.
3414 Regional Parkway
Santa Rosa, CA
USA 95403

3. Please provide a brief description of the proposed concept that you would like the CEC to consider as part of the EPIC 5 Investment Plan. What is

the purpose of the concept, and what would it seek to do? Why are EPIC funds needed to support the concept?

The proposed concept is titled: **Improving the Economic Viability of Enhanced Geothermal Systems Through Materials and Operational Optimization**

Enhanced Geothermal Systems (EGS) and Hot Dry Rock (HDR) systems that do not rely on the geologically produced water or steam for power generation promise to significantly expand the geothermal resource base for electricity generation in California. They can also be used to resuscitate depleted geothermal fields. They have been studied since the 1970's but have not been developed as a commercially viable power source. Among the many barriers to the successful implementation of EGS in California are materials compatibility with various working fluids, especially non-aqueous systems, the cost of working fluids, and their environmental effects due to discharge. Because EGS are done at great depths, the materials for tubing and casing, sub-surface components (e.g., sub-surface safety valves and packers), and surface components (e.g., tubing hangers, surface valves) are critical. EGS can be operated using working fluids other than water, such as supercritical or dense phase CO₂. In the latter case, EGS can be used as a way to reduce greenhouse gas emissions, but also involves significant questions related to the compatibility of materials in supercritical CO₂, especially in the presence of various acid-producing impurities.

The purpose of this concept is to develop a model along with specific data to assess the materials compatibility issues related to EGS and help EGS developers better design EGS. Typically, the focus of geothermal developers is in site characterization and testing of the EGS concept. EPIC funds on this concept will be critical to EGS developers to assess the economics of the resources and optimize them so they can proceed speedily to scale-up.

4. In accordance with Senate Bill 96ⁱ, please describe how the proposed concept will "lead to technological advancement and breakthroughs to overcome barriers that prevent the achievement of the state's statutory energy goals." For example, what technical and/or market barriers or customer pain points would the proposed concept address that would lead to increased adoption of clean energy technology or innovation? Where possible, please provide specific cost and performance targets that need to be met for increased industry and consumer acceptance. For scientific analysis and tools, provide more information on what data and information

gaps the proposed concept would help fill, and which specific parties or end users would benefit from the results, and for what purpose(s)?

A recent paper by Aljubran et al. suggested that the installed EGS capacity in California could generate as much as 25-60% of total electricity capacity by 2045. However, the CAPEX costs shift upwards dramatically as cumulative capacity is exceeded, depending on the scenario. CAPEX values ranging from \$2500 to greater than \$7500/kW were estimated. The authors argue that technological innovations could reduce these costs dramatically so that higher cumulative capacities can be attained. Although technoeconomic assessments of EGS, such as that by Aljubran et al. have been done, they have been at a global level and did not consider the details of system design and materials performance. The proposed concept would quantitatively optimize the overall system design with respect to increasing the integrity of wells and surface operations, thus reducing life cycle costs.

5. Please describe the anticipated outcomes if this research concept is successful, either fully or partially. For example, to what extent would the research reduce technology or ratepayer costs and/or increase performance to improve the overall value proposition of the technology? What is the potential of the innovation at scale? How will the innovation lead to ratepayer benefits in alignment with EPIC's guiding principles to improve safety,ⁱⁱ reliability,ⁱⁱⁱ affordability,^{iv} environmental sustainability,^v and equity?^{vi}
 - EGS has been explored by Calpine in the northwest Geysers where high temperature wells exist. Greenfire Energy has conducted tests at the Bottle Rock site. There are other potential sites in California that could host EGS. The economic viability is an important consideration in going from R&D to a production scale.
 - The project would result in a model with associated data for assessing the effects of system design on life cycle costs of EGS so that alternatives in terms of working fluids, depth of source rock, etc. can be evaluated with greater resolution.
 - The project will help quantitatively assess the use of CO₂ as a working fluid for EGS. At a broader level, other non-aqueous working fluids may also be assessed in terms of system CAPEX and OPEX.
 - The tools and database developed in such a program would be valuable for EGS developers and regulators.
 - Expanding the geothermal resource base will benefit the overall electric power availability for California electricity consumers.

6. Please provide references to any information provided in the form that supports the research concept's merits. This can include references to cost targets, technical potential, market barriers, equity benefits, etc.

The references provided below discuss the benefits of EGS and barriers for successful EGS involving materials, among other factors. The effect of supercritical and dense phase CO₂ along with its impurities are continuing to be evaluated by a number of organizations and modeling tools for assessing their effects are now available.

1. D. L. Gallup, *Geothermics*, Production engineering in geothermal technology: A review, 2009, **38**(3), 326–334.
2. P. Olasolo, M. C. Juárez, M. P. Morales, S. D'Amico, and I. A. Liarte, Enhanced geothermal systems (EGS): A review, *Renewable and Sustainable Energy Reviews*, 2016, **56**, 133–144.
3. J. W. Tester, B. J. Anderson, A. S. Batchelor, D. D. Blackwell, R. DiPippo, E. M. Drake, J. Garnish, B. Livesay, M. C. Moore, K. Nichols, S. Petty, M. N. Toksoz, R. W. Veatch, R. Baria, C. Augustine, E. Murphy, P. Negraru, and M. Richards, Impact of enhanced geothermal systems on US energy supply in the twenty-first century, *Philos Trans A Math Phys Eng Sci*, 2007, **365**(1853), 1057–1094.
4. M. J. Aljubran, D. M. Saad, M. Sodwatana, A. R. Brandt, and R. N. Horne, The value of enhanced geothermal systems for the energy transition in California, *Sustainable Energy & Fuels*, 2025, **9**(5), 1317–1337.
5. F. Ayello, K. Evans, N. Sridhar, and R. Thodla: 'Effect of liquid impurities on corrosion of carbon steel in supercritical CO₂', 2010 8th International Pipeline Conference, 2010, American Society of Mechanical Engineers, 111–123.

7. The EPIC 5 Investment Plan must support at least one of five Strategic Goals:^{vii}

- a. Transportation Electrification
- b. Distributed Energy Resource Integration
- c. Building Decarbonization
- d. Achieving 100 Percent Net-Zero Carbon Emissions and the Coordinated Role of Gas
- e. Climate Adaptation

Please describe in as much detail as possible how your proposed concept would support these goals.

(a) Transportation Electrification

While not directly focused on electric vehicles, the proposed material database indirectly supports transportation electrification by enabling the expansion of geothermal power, a reliable, zero-carbon baseload resource.

(b) Distributed Energy Resource (DER) Integration

The project supports DER integration by enabling a more stable and reliable grid. Unlike solar and wind, which are variable and weather-dependent, geothermal energy provides continuous, always-available power that can be counted on at any time. By expanding the geothermal resources, the project enables clean power generation closer to end users. This geographic advantage helps reduce transmission constraints and supports the integration of geothermal into distributed energy systems. As a baseline renewable resource, geothermal complements variable renewables by improving grid stability, reducing curtailment, and enhancing the resilience of microgrids and hybrid systems, especially in urban and underserved communities. By expanding the geothermal resource base, the concept will help California field geothermal plants in communities that did not have hydrothermal resources, further enhancing local economies.

(c) Building Decarbonization

The ability to utilize CO₂ as a working fluid will enable combining the need to sequester CO₂ with expanding the geothermal energy base.

(d) Achieving 100 Percent Net-Zero Carbon Emissions and the Coordinated Role of Gas

This supports the state's goal of 100% clean electricity under SB 100 and helps displace natural gas plants that currently provide firm capacity.

(e) Climate Adaptation

Geothermal energy provides a clean, baseline electric power. The ability to use CO₂ and other non-aqueous working fluids further reduces the emission of global warming gases.

About EPIC

The CEC is one of four EPIC administrators, funding research, development, and demonstrations of clean energy technologies and approaches that will benefit electricity ratepayers of California's three largest investor-owned electric utilities.

EPIC is funded by California utility customers under the auspices of the California Public Utilities Commission.

To learn more about EPIC, visit: <https://www.energy.ca.gov/programs-and-topics/programs/electric-program-investment-charge-epic-program>

EPIC 5 documents and event notices will be posted to:
<https://www.energy.ca.gov/proceeding/electric-program-investment-charge-2026-2030-investment-plan-epic-5>

Subscribe to the EPIC mailing list to stay informed about future opportunities to inform the development of EPIC 5:

<https://public.govdelivery.com/accounts/CNRA/signup/31897>

i See section (a) (1) of Public Resources Code 25711.5 at:

https://leginfo.legislature.ca.gov/faces/codes_displaySection.xhtml?lawCode=PRC§ionNum=25711.5.

ii EPIC innovations should improve the safety of operation of California's electric system in the face of climate change, wildfire, and emerging challenges.

iii EPIC innovations should increase the reliability of California's electric system while continuing to decarbonize California's electric power supply.

iv EPIC innovations should fund electric sector technologies and approaches that lower California electric rates and ratepayer costs and help enable the equitable adoption of clean energy technologies.

v EPIC innovations should continue to reduce greenhouse house gas emissions, criteria pollutant emissions, and the overall environmental impacts of California's electric system, including land and water use.

vi EPIC innovations should increasingly support, benefit, and engage disadvantaged vulnerable California communities (DVC). (D.20-08-046, Ordering Paragraph 1.) DVCs consist of communities in the 25 percent highest scoring census tracts according to the most recent version of the California Communities Environmental Health Screening Tool (CalEnviroScreen), as well as all California tribal lands, census tracts with median household incomes less than 60 percent of state median income, and census tracts that score in the highest 5 percent of Pollution Burden within CalEnviroScreen, but do not receive an overall CalEnviroScreen score due to unreliable public health and socioeconomic data.

vii In 2024 the CPUC adopted five Strategic Goals to guide development of the EPIC 5 Investment Plan. A description of the goals can be seen in Appendix A of CPUC Decision 24-03-007 available at:

<https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M527/K228/527228647.PDF>