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Life Cycle Analysis of California Geothermal Power Plants Enabling Cost-Effective Solutions

Geothermal energy plays a key role in Californiaâ€™s clean energy strategy, but high material and maintenance costs remain a barrier to wider deployment. The proposed project will conduct a life cycle analysis (LCA) of geothermal power plants to identify cost-saving and low-impact material choices, especially for components exposed to harsh geothermal conditions.
Using lab testing, field data, and literature on corrosion and durability, the proposed study will evaluate the economic and environmental trade-offs of various alloys. The goal is to inform smarter design and maintenance decisions, reducing lifecycle costs while supporting Californiaâ€™s goals for affordable, reliable, and sustainable geothermal power. Complete solution in explained in the document attached.

Additional submitted attachment is included below.

CALIFORNIA ENERGY COMMISSION

CALIFORNIA NATURAL RESOURCES AGENCY

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:

   Dr Francois Ayello
   AMPP Fellow
   Principal Engineer, DNV USA, Inc.
   614 440 6056
   Francois.Ayello@dnv.com

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

   DNV USA, Inc.
   155 Grand Ave, Ste 500,
   Oakland, CA 94612

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?

   Life Cycle Analysis of California Geothermal Power Plants: Enabling Cost-Effective Solutions

Geothermal energy plays a key role in California's clean energy strategy, but high material and maintenance costs remain a barrier to wider deployment. The proposed project will conduct a life cycle analysis (LCA) of geothermal power plants to identify cost-saving and low-impact material choices, especially for components exposed to harsh geothermal conditions.
Using lab testing, field data, and literature on corrosion and durability, the proposed study will evaluate the economic and environmental trade-offs of various alloys. The goal is to inform smarter design and maintenance decisions, reducing lifecycle costs while supporting California's goals for affordable, reliable, and sustainable geothermal power.

4. In accordance with Senate Bill 96[i], 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)?

   This project directly supports Senate Bill 96 by enabling technological advancement that lowers the cost of reliable & clean geothermal energy in California. One of the most persistent barriers to geothermal development is the reliance on expensive, corrosion-resistant materials (e.g., nickel alloys, duplex stainless steels) due to limited long-term performance data. These materials are often overused, driving up capital costs and limiting wider deployment of new geothermal power plant.
   By conducting a comprehensive life cycle analysis of geothermal power plant materials, this project will identify cost-saving, lower-impact alternatives while maintaining safety and durability. The work leverages corrosion & scaling data generated in CEC project EPC-24-028.

   Technical and Market Barriers Addressed:
   - Barrier 1: Lack of affordable steel localized corrosion data in geothermal brines. Therefore, is it difficult to balance expensive high alloys vs affordable steels during the material selection process.
   - Barrier 2: Industry dependence on conservative, high-cost materials due to uncertainty and risk aversion.

- Barrier 3: High capital and O&M costs that limit geothermal's competitiveness with solar, wind, and natural gas.

Expected Breakthroughs and Benefits:

- Cost savings on key components (e.g., well casings, piping, heat exchangers).
- Improved energy reliability through increased deployment of new geothermal power plants.
- More predictable long-term costs, enabling smarter investment and planning decisions for developers and utilities.
- Supports SB 100 goals by making geothermal a more affordable, scalable clean energy option.

End Users and Impact:

- Geothermal developers will gain design-level guidance to reduce material costs and extend asset life.
- Utilities and regulators can better assess project value based on lifecycle economics.
- Ratepayers benefit from more affordable, reliable renewable energy options that reduce dependence on fossil fuels.
- Disadvantaged communities near geothermal resources gain access to clean, local energy with lower long-term 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]

   Anticipated Outcomes Include:

   - A publicly available material performance and life cycle cost model that enables confident substitution of high-cost alloys with lower-cost alternatives proven to withstand geothermal conditions (e.g., H_2S, CO_2, chlorides, high temperature).
   - Direct cost savings on plant components (e.g., piping, well casings, heat exchangers), which may reduce total CAPEX by several percentage points—translating to millions of dollars saved per project.
   - Lower design and permitting risk, as the availability of validated data reduces the need for conservative safety margins and allows for optimized material choices.

- Broader geothermal adoption, including in moderate-temperature regions or sites previously considered too costly or risky to develop.

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.

   1 - Material Cost Differentials and Performance Needs: U.S. Department of Energy (DOE), "*Geothermal Technologies Office: GeoVision Report*" (2019)
   Highlights materials and drilling costs as key barriers to geothermal scalability. Material selection is cited as a major cost driver, especially for wells and surface systems.
   Link: https://www.energy.gov/eere/geothermal/geovision
   Link: https://www.energy.gov/sites/default/files/2019/06/f63/GeoVision-full-report-opt.pdf

   2 - Cost Savings from Alloy Substitution NREL, "*Annual Technology Baseline - Geothermal*" (2016)
   Estimates that well construction and surface equipment account for 30–60% of total CAPEX, with materials being a significant contributor, therefore alloy substitution is a key lever for cost reduction.
   Link: https://atb.nrel.gov/electricity/2024/geothermal

   3- California Policy and Market Need California Energy Commission, "*Deep Decarbonization in a High Renewables Future*" CEC-500-2018-012 (2018)
   Emphasizes the role of geothermal energy in meeting SB 100 goals and identifies high upfront costs as a key barrier to scaling geothermal development in-state.
   Link: https://www.energy.ca.gov/sites/default/files/2021-06/CEC-500-2018-012.pdf

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 geothermal life cycle analysis model 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 reducing the cost of geothermal deployment, the project enables clean power generation closer to end users, particularly in California's densely populated regions located near major geothermal resources. This geographic advantage helps reduce transmission constraints and supports the integration of geothermal into distributed energy systems. As a firm 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.

(c) Building Decarbonization
Geothermal power supports electrification of building systems (e.g., heating, water heating, cooking) by providing non-intermittent clean electricity. Lower-cost geothermal projects, enabled by smarter material selection, increase the affordability of decarbonized building operations, particularly in areas with fewer renewable options or low-income communities where energy costs are a barrier to electrification.

(d) Achieving 100 Percent Net-Zero Carbon Emissions and the Coordinated Role of Gas
This is the primary goal supported by the proposed concept. By reducing the capital cost of geothermal plants through validated alloy substitution, this project removes a major barrier to the expansion of zero-emission baseload power. This supports the state's goal of 100% clean electricity under SB 100 and helps displace natural gas plants that currently provide firm capacity. It also improves cost competitiveness of geothermal relative to other clean technologies, facilitating better coordination between renewables and the declining role of gas in California's energy mix.

(e) Climate Adaptation

Geothermal energy is weather-independent and can operate reliably during extreme heat, wildfires, or drought—making it a critical asset for climate resilience. The proposed project supports climate adaptation by lowering the cost barriers to geothermal deployment in regions across California where the resource is abundant and communities face increasing climate-related risks. Notably, geothermal potential exists near several major population centers, including The Geysers near the San Francisco Bay Area, Coso near Southern California, and the Salton Sea region near San Diego. By enabling cost-effective development in these areas, the project helps deliver reliable, local clean energy and contributes to a more robust, climate-resilient grid under future conditions.

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

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i See section (a) (1) of Public Resources Code 25711.5 at: https://leginfo.legislature.ca.gov/faces/codes_displaySection.xhtml?lawCode=PRC&sectionNum=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