

**DOCKETED**

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*Comment Received From: Pinakin Patel*  
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## **Triple-hybrid Energy System for grid support and decarbonization**

Details are presented in the attached document.

*Additional submitted attachment is included below.*



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

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:*

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

T2M Global, LLC

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?*

This input proposes two complementary research concepts aligned with California's grid reliability, decarbonization, and resource-efficiency goals. In both cases, the proposed research treats waste streams as inputs at the system boundary, with benefits evaluated based on the value created through conversion and reuse, independent of the original source or purpose of the waste.

- 1) The first concept is a triple-hybrid energy system that combines low-temperature waste-heat power generation, firm power generation, and battery energy storage, into a single system. By integrating these technologies, the concept seeks to create a flexible and dispatchable energy resource that makes productive use of low-grade waste heat while supporting grid reliability and renewable energy integration.

The purpose of this concept is to explore how integrated hybridization can deliver greater value than deploying these technologies independently. Each component addresses a different aspect of energy system needs in California. This includes reliable power generation, short-term grid balancing, and energy recovery. When combined, these technologies can operate to respond to changing grid conditions, reduce curtailment of renewable energy, and improve overall system efficiency and resilience.

EPIC funding is needed to support scale-up from kW-class level to 100 kW-class building blocks for multiple applications in California. Triple-hybrid system design, validation, cost-effective recovery of low-temperature waste heat and its upgrade to highly efficient electricity are needed. While individual components such as batteries and fuel cells or turbines are commercially available, low-temperature waste heat recovery technologies remain at an early stage of development. Additionally, their coordinated



integration within hybrid, grid-interactive systems has not been done. EPIC support would validate this concept at progressively larger scales, generate data needed to inform future deployment, and reduce technical and market risk for California-relevant applications.

- 2) The second concept is a multifunction nutrient generator that captures CO<sub>2</sub> emissions and combines them with nutrient-rich water effluents to produce a concentrated, low-carbon agricultural feedstock. The concept seeks to transform underutilized waste streams from energy, industrial, and wastewater systems into a valuable commercial product, supporting both emissions reduction and resource recovery.

The purpose of this concept is to explore a novel pathway for linking energy systems, waste management, and agricultural production. By converting captured CO<sub>2</sub> into a usable feedstock, the concept has the potential to greatly reduce lifecycle emissions, lower reliance on conventional fertilizer inputs, and improve the sustainability of food and biomass production. This research would focus on understanding system performance, product consistency, and potential application pathways, rather than near-term commercialization.

EPIC funding is needed to support early-stage research and validation of this integrated approach, which spans multiple sectors and offers broad public benefits. While the underlying elements are well understood individually, their combined application as a multifunction resource platform has not been widely evaluated. EPIC support would enable foundational studies, pilot-scale evaluation, and assessment of environmental benefits to inform future deployment pathways aligned with California's energy, climate, water, and agricultural goals.

4. *In accordance with Senate Bill 96, 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)?*

- 1) The triple-hybrid energy system would lead to technological advancement by enabling integrated utilization of low-temperature waste heat alongside energy storage and dispatchable generation. A key barrier to achieving California's statutory energy goals is that large quantities of low-grade thermal energy from data centers, industrial facilities, and power generation



assets remain unused because existing clean energy technologies are not designed to convert this heat into grid-relevant energy services. At the same time, customers face increasing electricity costs, constrained interconnections, and limited options for firm, clean on-site power.

By integrating waste heat to power, electrochemical storage, and firm generation within a coordinated architecture, the proposed concept addresses these barriers at the system level. The combined system enables waste heat to contribute to electricity production while storage and firm generation provide reliability and responsiveness. This approach supports increased adoption of clean energy by improving overall energy utilization, reducing peak grid demand, and enhancing resilience for critical infrastructure such as data centers, while remaining applicable to other commercial and industrial sites.

Increased industry acceptance will depend on demonstrating reliable operation and meaningful energy recovery under real-world conditions. Indicative performance targets include consistent conversion of low-temperature waste heat into usable electricity and system-level performance that supports reduced peak demand and improved energy utilization. Cost-related targets focus on delivering energy and resilience services at levels competitive with existing distributed energy alternatives such as standalone battery storage or conventional backup generation, while providing additional value through waste heat recovery.

- 2) The multifunction nutrient generator would advance California's statutory energy and climate goals by enabling beneficial reuse of carbon dioxide emissions within energy and infrastructure systems. A barrier to broader clean energy adoption is the lack of integrated, cost-effective pathways for carbon capture and reuse that create tangible system value for energy producers and ratepayers. Many emerging carbon management approaches focus on sequestration or disposal rather than productive utilization, limiting their economic and operational attractiveness.

This concept addresses system-level pain points by converting captured CO<sub>2</sub> into a usable product stream, creating a value-generating pathway for emissions associated with distributed energy resources, backup generation, and other infrastructure. Data centers and other large energy and infrastructure sites represent priority applications due to their concentrated emissions profiles and co-located resource streams, with additional applicability across industrial and wastewater facilities.

Increased adoption will depend on demonstrating effective carbon capture integration, reliable carbon utilization performance, and measurable reductions in lifecycle emissions relative to conventional carbon management pathways. Performance targets at this stage include efficient conversion of captured CO<sub>2</sub> into stable, usable products and predictable output composition suitable for downstream use. Cost considerations focus on establishing pathways toward lower-cost carbon management and reuse



relative to conventional capture and disposal approaches, thereby improving the value proposition of carbon mitigation strategies for energy system operators and ratepayers.

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, reliability, affordability, environmental sustainability, and equity?*

- 1) If successful, the triple-hybrid energy system would recover low-level waste heat, creating savings of over \$50 billion in fuel savings. In addition, it would provide electricity without any additional fuel use or emissions. At 50% of this heat recovery and 10% cycle efficiency, it has a potential to produce approximately 30,000 GWh of emission free electricity. At 15 ¢ per kWh, this translates to \$4.5 billion per year in monetary savings to the rate payer, approximately 6 million metric tons of CO<sub>2</sub> reduction, and grid capacity support of 3,300 MW. The demonstration data will establish readiness of this technology to meet the critical needs of the California grid using wasted resources. Even partial success would provide meaningful outcomes, including validated performance data showing improved site-level energy utilization, reduced peak electricity demand, and enhanced operational flexibility for high-energy-use facilities such as data centers, as well as industrial and commercial sites.

At scale, the innovation has the potential to reduce ratepayers costs by offsetting grid electricity purchases, deferring or avoiding costly grid infrastructure upgrades, and reducing reliance on conventional backup generation. By converting underutilized waste heat into electricity and coordinating it with storage and firm generation, the system can improve effective capacity utilization of installed assets, thereby lowering the cost per unit of useful energy delivered. These improvements directly enhance the value proposition for customers while supporting broader grid efficiency.

For ratepayers, the anticipated benefits include improved grid reliability and resilience through reduced peak demand and increased availability of distributed, dispatchable resources. By lowering stress on the grid during high-load periods, the system can help stabilize electricity costs and reduce the likelihood of outages. Environmental benefits include reduced greenhouse gas emissions through improved energy efficiency and increased utilization of existing thermal resources. Equity benefits arise from the potential to deploy such systems at community-serving facilities and critical infrastructure, improving reliability and resilience in areas that are most vulnerable to disruptions.



- 2) Decarbonization of California industrial and power sectors requires reducing over 100 million metric tons of CO<sub>2</sub> emissions. At a conservative cost of \$20 per ton of CO<sub>2</sub> captured, this translates to over \$2 billion just in capture alone. If successful, the multifunction nutrient generator would provide a win-win solution to pollution from power plants and other sources. The captured CO<sub>2</sub> will be available to increase agricultural productivity, a significant collateral multi-billion dollars benefit.

At scale, the innovation has the potential to reduce the net cost of carbon management for power generation and industrial energy infrastructure by creating productive outlets for captured emissions. By enabling carbon utilization at or near the point of capture, the concept could improve the economic viability of emissions mitigation strategies and reduce the need for more infrastructure-intensive carbon handling approaches. Downstream applications, including agricultural use, represent a utilization pathway that supports carbon reuse while extending the emissions reduction benefits beyond the energy sector.

Ratepayer benefits would stem from reduced lifecycle emissions associated with power and industrial energy systems, as well as the potential to lower total system costs tied to carbon mitigation compliance. By improving the cost-effectiveness of carbon capture and reuse, the concept supports more affordable pathways to decarbonization while maintaining reliability of energy infrastructure. Additional benefits include improved environmental performance of energy assets and expanded options for managing emissions in alignment with California's long-term climate goals.

6. *Describe what quantitative or qualitative metrics or indicators would be used to evaluate the impacts of the proposed research concept.*

- 1) The impacts of the triple-hybrid energy system may be evaluated using both quantitative performance metrics and qualitative indicators that reflect system value, grid relevance, and customer outcomes.

Quantitative metrics may include:

- Amount of low-temperature waste heat utilized, expressed as recovered thermal energy (target 80%) and converted electrical output (target 10%)
- Changes in greenhouse gas emissions intensity compared to baseline energy supply
- Estimated cost impacts, including reductions in purchased electricity or avoided backup generation usage.

Qualitative metrics may include:

- Demonstrated ability to coordinate multiple energy technologies within a single operating framework

- Flexibility of the system to operate under different load, thermal, and grid conditions
  - Applicability of the hybrid architecture across priority use cases such as data centers, as well as other commercial and industrial sites.
- 2) The impacts of the multifunction nutrient generator may be assessed using metrics focused on resource utilization, environmental performance, and downstream usability. Qualitative indicators are related to system integration and applicability.

Quantitative metrics may include:

- Amount of carbon dioxide captured and utilized within the system
- Quantity and concentration of nutrients recovered or converted into the agricultural feedstock
- Consistency and stability of feedstock composition over time
- Estimated reductions in lifecycle greenhouse gas emissions compared to conventional nutrient or fertilizer pathways
- Energy and water intensity of feedstock production relative to baseline practices.

Qualitative metrics may include:

- Flexibility of the system to integrate with different sources of CO<sub>2</sub> and nutrient-rich effluents
- Potential for co-location with data centers, wastewater treatment facilities, or industrial sites.

7. *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) References Supporting the Triple-Hybrid Energy System:

- **Patel, Pinakin, et al.** *Waste Heat to Ultra-High Efficiency Osmotic Power (WHOP): Final Project Report.* California Energy Commission, March 2024. Publication No. CEC-500-2024-019.

This report documents the technical basis, performance potential, and development status of Waste Heat to Osmotic Power for converting low-temperature waste heat into electricity.

- **Greene, Michael, et al.** *Demonstrating Replicable, Innovative, Large-Scale Heat Recovery in the Industrial Sector.* California Energy Commission, 2025. Publication Number CEC-500-2025-001.

This report This report documents the technical basis, performance potential, and development status of low temperature heat recovery equipment that enables technologies such as the triple-hybrid.



- **Areola, R. I., et al.** *Integrated Energy Storage Systems for Enhanced Grid Efficiency: A Comprehensive Review of Technologies and Applications*, Energies, Vol. 18, No. 7, 2025.

This study shows that combining multiple energy vectors improves grid efficiency and flexibility in high-renewable scenarios.

- **U.S. Department of Energy.** *Waste Heat to Power Systems*. U.S. Environmental Protection Agency / DOE Combined Heat and Power Partnership.

This report outlines the technical potential and system-level benefits of waste heat to power technologies, including their role in improving energy efficiency and reducing grid demand.

- **International Energy Agency (IEA).** *Energy Efficiency 2023*. International Energy Agency, 2023.

This report highlights the significant untapped potential of waste heat recovery as a cost-effective pathway to improve system efficiency and reduce emissions across industrial and commercial sectors.

- **California Energy Commission.** *2024 Integrated Energy Policy Report Update*, CEC-100-2024-001.

The IEPR provides context on grid reliability, affordability, and the need for innovative distributed energy and efficiency solutions aligned with state statutory goals.

## 2) References Supporting the Multifunction Nutrient Generator:

- **Brondi, M., et al.** *“Recovering, Stabilizing, and Reusing Nitrogen and Carbon from Nutrient-Containing Liquid Waste as Ammonium Carbonate Fertilizer.”* Agriculture, 2023.

This peer-reviewed study demonstrates technical pathways for recovering carbon and nutrients from waste streams and converting them into usable agricultural inputs.

- **Roy, E. D.** *“Navigating the Four C’s of Nutrient Recycling to Support More Sustainable Resource Management.”* ACS Sustainable Resource Management, 2025.

This paper discusses the importance of nutrient recycling for reducing emissions, improving resource efficiency, and overcoming adoption barriers in agricultural systems.

- **U.S. Department of Agriculture (USDA).** *Sustainable Fertilizer and Nutrient Management Initiatives.*



These materials provide context on market drivers and policy interest in low-carbon and recycled nutrient inputs for agriculture.

- **California Department of Food and Agriculture (CDFA).** Fertilizer Research and Education Program (FREP).

This program highlights California's interest in improving fertilizer efficiency, reducing emissions, and supporting innovative nutrient management approaches.

8. *The EPIC 5 Investment Plan must support at least one of five Strategic Goals:*

1) Triple-Hybrid Energy System

**Distributed Energy Resource Integration:** The triple-hybrid system directly supports distributed energy resource integration by combining waste heat recovery, energy storage, and dispatchable generation into a flexible, grid-interactive platform. The system is designed to operate behind the meter or at the distribution level, reduce peak demand, provide load flexibility, and improve coordination between on-site resources and the grid.

**Building Decarbonization:** The concept supports building decarbonization by improving overall energy efficiency and reducing reliance on grid electricity and fossil-based backup generation. Applications include large commercial buildings, campuses, and data centers where low-grade waste heat is abundant and clean, on-site power reduces operational emissions.

**Achieving 100 Percent Net-Zero Carbon Emissions and the Coordinated Role of Gas:** The hybrid system aligns with net-zero goals by enabling higher utilization of existing energy resources and supporting the integration of low-carbon fuels where applicable. Fuel cells or turbines within the system can operate on renewable or low-carbon fuels, while waste heat recovery reduces energy input required to meet site demand.

**Climate Adaptation:** By enhancing on-site resilience, reducing dependence on centralized infrastructure, and improving the ability of critical facilities to operate during grid disruptions, the system contributes to climate adaptation. These capabilities are particularly relevant for facilities exposed to extreme heat events, wildfires, and grid reliability challenges.

2) Multifunction Nutrient Generator

**Achieving 100 Percent Net-Zero Carbon Emissions and the Coordinated Role of Gas:** The multifunction nutrient generator supports net-zero objectives by enabling beneficial reuse of carbon dioxide emissions and reducing the lifecycle emissions associated with conventional fertilizer production. By converting CO<sub>2</sub> into a useful agricultural input, the concept contributes to carbon management strategies that complement clean energy deployment.



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**Climate Adaptation:** The concept supports climate adaptation by improving resource efficiency and resilience across energy, water, and agricultural systems. By creating value from nutrient-rich effluents and carbon streams, the system can reduce environmental stressors, support sustainable agricultural practices, and improve resilience to climate-driven disruptions such as drought and extreme weather.