DOCKETED	
Docket Number:	25-EPIC-01
Project Title:	Electric Program Investment Charge 2026–2030 Investment Plan (EPIC 5)
TN #:	265395
Document Title:	Sarah Kurtz Comments - Cost-Effective Off-Grid Rural Energy Systems
Description:	N/A
Filer:	System
Organization:	Sarah Kurtz
Submitter Role:	Public
Submission Date:	8/7/2025 10:42:10 PM
Docketed Date:	8/8/2025

Comment Received From: Sarah Kurtz
Submitted On: 8/7/2025
Docket Number: 25-EPIC-01

Cost-Effective Off-Grid Rural Energy Systems

We have a unique opportunity in California to create off-grid rural energy systems that can deliver electricity at lower cost than today's retail costs in many locations. Soaring electricity prices are killing farmers and the utilities can actually benefit by focusing on delivering more kWh to a smaller distribution grid.
See uploaded file for more details.

Additional submitted attachment is included below.

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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:

Sarah Kurtz, skurtz@ucmerced.edu, 303-881-5085.

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

University of California Merced. However, I am acting as an individual, not as an official representative of the university.

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?

A new opportunity: distributed systems that are *off grid*

Substantial investment has been made in *grid-connected* distributed systems. These can avoid upgrades to the distribution system but still require the distribution system to be reliable. What would it take to "cut the wire" and eliminate the cost of the distribution system entirely in rural areas? We suggest three things will be needed:

• Battery storage to balance supply and demand on short time frames

• System designs/applications that balance seasonal supply and demand

• System with lower electricity cost than is currently charged by the local utility.

We suggest that this is an ideal time to embrace this opportunity to change the paradigm because of two recent developments:

1. The cost of battery storage has dropped

2. The cost of electricity in California has increased

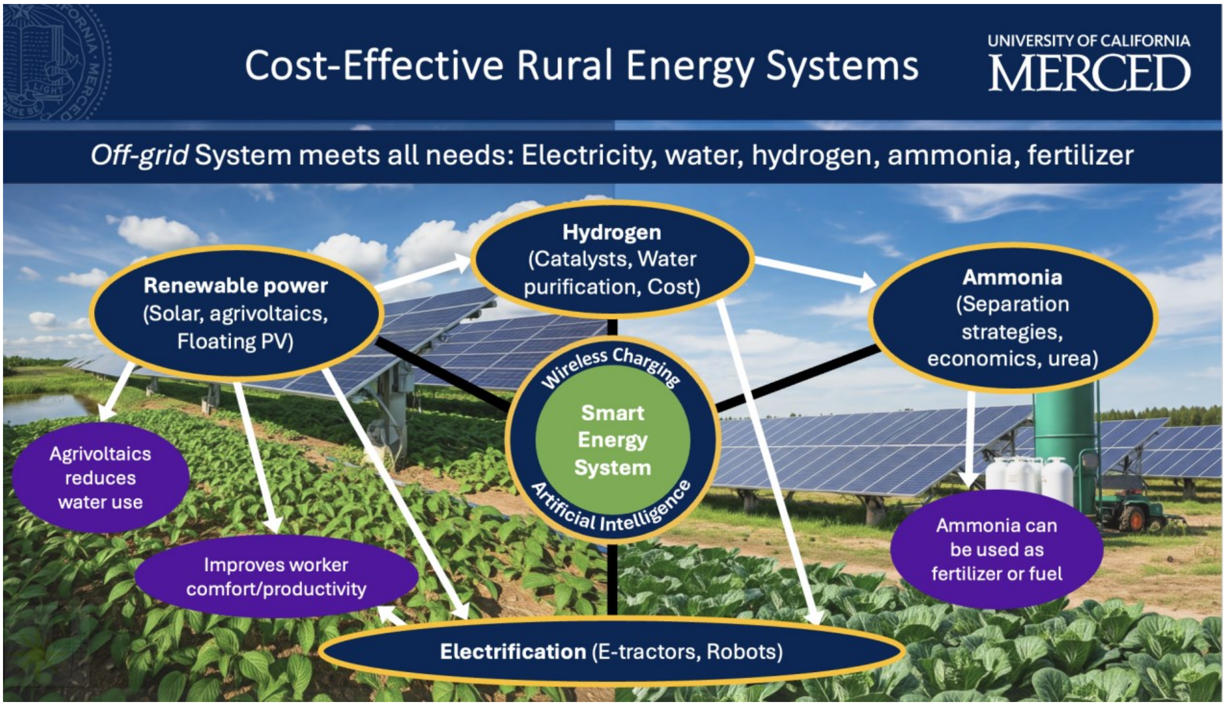
Even with these two developments, substantial work will be needed to be able to effectively "cut the wire".

While envisioning this new energy system, we note that we are still a long way from "cutting the wire" for the average home because of the need to address the seasonal mismatch between supply and demand. We propose off-grid systems in rural areas for applications that CAN balance seasonal supply and demand in a cost-effective way.

Cost-Effective *Off-Grid* Rural Energy Systems

California's agricultural productivity is being squeezed by water scarcity and increasing costs of electricity. As electricity prices now exceed 50 cents/kWh in many locations, water pumping and other electrical loads are making it increasingly difficult for farmers to make ends meet.

Vision: Off-grid rural energy systems can deliver electricity (and other value) at a fraction of the current cost, providing cost-effective off-grid rural energy systems.



Solar electricity is already 27% of the electricity generated in the state of California, sometimes meeting 100% of California's active load in the middle of the day, motivating huge investment in battery storage. California is at a pivotal point where off-grid rural systems can balance supply and demand in situations with load profiles that are similar to solar generation profiles (*e.g*. water pumping). EPIC funding could accelerate the validation and deployment of many new technologies (such as solid-state batteries, hydrogen, biogas generators, agrivoltaics etc.), providing California's agricultural sector with lower cost electricity than is available today.

We first describe the potential benefits/opportunities and then the challenges that need EPIC funding to realize those benefits.

Benefits/opportunities of the off-grid rural energy system concept:

Solar electricity innovations:

- *Off-grid system*
  - *Avoid the time and expense* for grid interconnection.
  - *Provide retail value* (competing with ~50 cents/kWh) rather than wholesale value (competing with < 5 cents/kWh). When benchmarked against retail value, a solar array that costs twice as much as a utility scale system and throws away half of the electricity because of not effectively balancing supply and demand over the year would still be able to deliver electricity at less than half of a typical retail rate.
  - *Reduce risk of electricity price increases.* Once the system is installed, the electricity price is effectively defined, while utility electricity rates in California have been climbing and are expected to climb more.
  - *Avoid risk of public safety shutoffs.*
- *Agrivoltaics* (combining solar and agriculture)
  - *Reduce water use* to grow the same produce
  - *Grow food on the same land* where the electricity is generated
  - *Enable growth of crops not currently viable in the Central Valley*
  - *Provide shade* for workers, enhancing their quality of life and productivity
- *Floating PV* (solar panels floating on pond or reservoir)
  - *Reduce evaporation* from the body of water
  - *Reduce plant growth* in the body of water
  - *Generate electricity without taking crop lands out of production*

Electrification innovations and implementation:

- *Electric water pumping* for off-grid system
  - Aligns with solar generation profile *minimizing need for storage*.
- *Electric tractors, robots and farm equipment* charged/powered by off-grid system
  - *Accelerates adoption of electric tractors/hardware* by providing a practical energy source (*e.g.* it's difficult today to obtain hydrogen on a farm)
  - *Provides energy independence* (no need for an outside power source)
  - *Avoids risk of increased fuel prices*
  - *Reduces air pollution*
  - *Reduces strenuous labor*
  - *Improves flexibility and consistency*
- *Smart control systems*, e.g. using artificial intelligence
  - *Improves efficiency by being proactive rather than reactive*
  - *Improves consistency by being proactive rather than reactive*

    - *Reduces cost*

Complete energy system has many features

- *Hydrogen* generated from solar electricity
    - *Provides local fuel for fuel-cell vehicles* (energy independence)
    - *Reduces cost of hydrogen for farmer* (while wholesale hydrogen may be $2/kg, retail hydrogen is typically $16-30/kg).
- *Ammonia* generated from the hydrogen
    - *Provides local source of fertilizer*
    - *Reduces cost of ammonia in locations with high distribution costs*
    - *Provides easier storage for clean fuel* (used as ammonia or hydrogen)
- *Wireless charging*
    - *Provides ease of use*, especially for autonomous vehicles that can position themselves next to the charger, with no need to physically plug in. All robotic systems can be powered by wireless charging to facilitate their dynamic performance
- *Smart control systems*, e.g. using artificial intelligence and predictive control
    - *Improves efficiency*
    - *Improves consistency*
    - *Reduces cost*
    - *Improves safety*

The above describes the benefits/opportunities. Why are EPIC funds needed?

Some of these concepts require business investment more than research, but investment requires confidence that the proposed systems will reduce energy costs.

EPIC funds are needed to:

• **Identify and demonstrate the locations, applications and choices of technologies/innovations for which these off-grid systems will be cost effective**. (As noted above, in most locations, it's not yet cost effective for a residence to go off-grid because of winter loads.)

• Support **demonstration projects of agrivoltaics**. These demonstration projects need to identify standardized (low cost) implementations of agrivoltaics that will guide farmers in selecting appropriate hardware and crop implementation so that the added revenue is greater than the added costs.

• **Reduce cost of floating solar** and demonstrate the low-cost implementation. While floating PV has been growing rapidly, the cost of the mounting hardware is still higher than for ground mount. Floating PV avoids the need for engineering of supports in rocky vs sandy soil, but it requires engineering a tethering system. With EPIC development of innovation and economies of scale, hardware and installation costs for floating PV could be less than for ground mount, reducing the cost of solar electricity.

• Develop **autonomous agricultural equipment**, especially those that can be small (to work around an agrivoltaic system), efficient, and effective. These need to be demonstrated to reduce cost without damaging produce.

• **Electrify agricultural equipment** including tractors, harvesters, and other equipment. Currently, it is unclear whether such equipment will be powered by batteries or fuel cells and how they can be recharged or refueled. Rural energy systems as described above could help to identify the best solutions, including how to generate and store hydrogen for fuel cell vehicles and how to recharge battery-powered vehicles. Note that the time to refuel a fuel cell vehicle with hydrogen is anticipated to be a lot less than charging a battery in a similar vehicle, but that the electricity needed to generate that hydrogen is substantially greater. So, it's not clear which will be the better solution.

• Improve **small-scale, hydrogen-generation systems** that can use local solar electricity and local water to generate and store hydrogen.

• Develop **small-scale ammonia generators**. Some companies, like Talus, have been developing ammonia generators that are of interest, but they are too large for the average California farm; smaller systems could better meet the needs of California farmers.

• Develop **catalysts or other technical improvements to electrolyzers and fuel cells** to improve efficiency and/or reduce costs of the multiple approaches.

• Develop strategies for **storing hydrogen or ammonia for use on a farm**. An interesting strategy could be to convert ammonia to urea, which is easier to store and transport than ammonia but equally useful as a fertilizer.

• Develop **wireless charging** strategies to enable agricultural equipment (including robots) to charge themselves.

• **Develop AI tools** that can enable the complex systems described above to function most efficiently without the need for frequent human intervention.

• Explore non-solar sources of electricity (e.g. **biogas**) as part of off-grid rural energy system

• **Explore hybrid energy storage systems** capable of high-power, high-efficiency bidirectional energy flow.

• Explore and document how the above energy systems can **improve the quality of life and productivity of farm workers**.

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)?

Success metrics that will lead to increased adoption of clean energy

Lower cost relative to today's *retail* costs (electricity, hydrogen, ammonia)

An off-grid, solar-powered energy system would be viewed as lower cost as long as it could deliver electricity at a lower cost than retail value of electricity (which is about 50 cents/kWh for some locations). Compared with densely populated states, California's utilities need to pour money into maintaining a distribution system that can reach every corner of California. While the distribution lines already exist in many locations, the cost of trimming trees and repairing lines is significant[1], especially when the number of users per length of line is small. Thus, the wide-scale deployment of rural energy systems could eventually provide the farmers with lower cost energy while also reducing the cost of electricity delivered to cities.

Similarly, while green hydrogen is still struggling to match conventional wholesale costs, the described rural energy systems may be able to deliver hydrogen at a cost that is lower than current *retail* costs, especially for tractors that cannot be easily driven to a hydrogen fueling station.

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[1] At my own home (a mile from the UC Merced campus), the wires have needed to be repaired twice in the last couple of years. Each time, PG&E sent a truck out to identify the problem, then ended up having 2 or 3 trucks at our house off and on between about 10 pm and 6 am the next morning as they detected where the break was in the wire, figured out where to dig to fix it, then after fixing it, put everything back. Even the 50 cents/kWh that we pay probably didn't cover the cost of those repairs.

High reliability of power delivery

New power electronics solutions for the energy management system can feature a highly reliable and efficient power delivery architecture.

In California, power demand is rising rapidly due to the widespread adoption of electric vehicles and the growing needs of data centers and AI infrastructure. Over the next decade, demand is projected to increase by more than 100%.

An intelligent off-grid system, incorporating hybrid energy storage solutions and expanded solar power utilization may be the best way to meet this challenge, both for the off-grid customer and as a capacity-expansion strategy that will reduce pressure on the main grid.

Wireless power systems

The next generation of electric vehicles and robotic systems will favor wireless power transfer, as it eliminates conductive components, enhancing reliability and reducing maintenance needs. Magnetic power distribution systems further complement this approach by enabling efficient, contactless energy transfer over short to medium distances—ideal for dynamic charging of mobile agricultural robots or automated guided vehicles in farm environments. These technologies collectively simplify power delivery operations while minimizing energy losses associated with physical connectors. Additionally, the reduced wear-and-tear and elimination of manual charging interventions will significantly lower manpower costs, creating a more scalable and maintenance-free energy infrastructure for rural applications.

Social acceptance

In many cases, local people are opposing installation of solar arrays because they feel that solar is displacing agriculture from valuable farmland, effectively taking away their identity. Using agrivoltaics would enable continued agricultural production while also increasing access to lower cost electricity. EPIC’s success may be quantified by evaluating statistics for approval of proposed projects.

Agrivoltaic systems that preserve farmland can also power on-site EV charging stations for farm equipment, creating a closed-loop energy ecosystem. When paired with innovative energy storage solutions like hydrogen or hybrid batteries, these systems can ensure reliable power for agricultural operations and electric farm vehicles. Wireless charging infrastructure embedded in fields could enable autonomous electric tractors and harvesters to operate without manual charging interruptions. This integrated approach transforms opposition into opportunity by demonstrating how solar arrays can actively support, rather than displace modernized farming operations through clean energy technologies.

Information gaps to be filled

Agrivoltaics (AgPV)

Currently, the best strategies to design and operate an AgPV system for use in California are unknown or at least undemonstrated. Farmers need to be confident that AgPV will be cost-effective before they will be willing to invest in AgPV systems. Farmers need to know what crops are compatible with shade and how to manage the system so that AgPV provides value.

Component and system design optimization

Investigations to address each of the technical challenges listed above in Section 3 will result in new information. For example, the optimal design for an electrolyzer operating on a farm may benefit from a catalyst that is not poisoned by well water. While each component of the energy system needs to be optimized, ultimately, the optimal design needs to be done at the system level where an improvement in one component may allow the cost of a complementary component to be reduced. For the sake of brevity, we have not added an exhaustive list here.

Use of artificial intelligence and predictive control

The new capabilities for AI opens doors for new strategies for controlling complex systems. Studies of the optimal approach for controlling off-grid energy systems will fill this information gap.

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?

Anticipated outcomes:

- **Reduced energy costs** for farmers and rural communities through localized production (electricity, hydrogen, fertilizer), insulating users from volatile market prices.
- **Lower grid infrastructure costs** for IOUs by avoiding transmission/distribution maintenance in remote areas. (Initially costs may be

reduced by avoiding upgrades, but if off-grid systems are widely adopted, the systems can be removed altogether from low-population areas)

- **Enhanced grid resilience** through decentralized energy systems, reducing outage risks during extreme weather or peak demand.
- **Reduced use of water** while continuing agricultural production and reducing strain on the state's electricity resources
- **Safer agricultural operations** by replacing diesel/fossil-fuel-based equipment with clean electrified alternatives and storage.
- **Improved air quality** in rural areas by eliminating diesel generators and use of internal-combustion engines for agricultural equipment.
- **Speed up** the adoption of advanced energy storage and power delivery, **advancing toward meeting the goals of 100% zero carbon emissions**.

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

Metrics of impact:

- Cost of electricity compared to retail electricity rates
- Cost of hydrogen compared with retail hydrogen delivered to farmer
- Cost of ammonia or urea compared with retail delivered to farmer
- Local acceptance as reflected by number of energy projects approved or rejected
- System efficiency (%) of power conversion, storage, and delivery
- Reduction in energy losses compared to conventional systems
- Return on investment (ROI) timeline for infrastructure deployment
- Job creation metrics (e.g., local employment in installation, and maintenance)
- Capacity growth potential (e.g., % increase in power output achievable with modular expansion)
- Power stability improvements (e.g., number of outages)
- Patents filed or technologies licensed from the research
- Training programs implemented for local technicians/operators

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.

Study (in press) quantifies alignment of seasonal water pumping requirements with seasonal availability of solar electricity.

Study (in development) quantifies how California has a unique opportunity for agrivoltaics to be valuable.

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

   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

The primary purpose of this concept is to tackle:

(b) Distributed Energy Resource Integration by identifying strategies for creating cost-effective distributed energy systems without incentives. While historically, distributed energy resources have been grid tied, we suggest that this is the year when California should explore creating *off-grid* distributed systems, thereby avoiding interconnection delays and reducing strain on the main grid. These will reduce the cost per kWh for the centralized grid by reducing the need to maintain an extensive grid in remote rural areas while still providing those customers with reliable electricity.

The concept also supports

(a) **Transportation electrification** The electrification of farm equipment is complicated by the expense of keeping the equipment powered. These rural energy systems could provide hydrogen where and when it is needed, reducing costs of transporting and storing the hydrogen, and providing EV charging stations in remote agricultural areas, bridging gaps in IOV service territories.

(d) Achieving 100 Percent Net-zero Emissions: This rural energy system concept would enable moving an entire farm to net-zero (or even negative) carbon emissions, and

(e) Climate Adaptation: Agrivoltaics provides a way to reduce the heat stress of the growing crops, adapting to the higher temperatures that are being experienced most years in California. These off-grid, distributed energy systems would enhance community resilience to grid disruptions from wildfires or extreme weather.