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Low-speed Electrostatic Motor Drive and Power Generation

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:

   Kevin Lu
   Kevin.lu@candide.group
   510-578-8849

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

   The Candide Group, LLC (TCG)

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 innovation advances the development of high-efficiency electrostatic motors and generators as an alternative to conventional electromagnetic designs. Unlike traditional motors that depend on costly magnets and copper windings, electrostatic machines can operate without these materials, substantially reducing reliance on critical minerals and mitigating exposure to volatile commodity markets.

This technology delivers torque proportional to applied voltage rather than current, minimizing resistive heating and improving efficiency. It can achieve high torque output at low speeds without gearboxes, eliminating associated mechanical losses and maintenance requirements.

EPIC investment will accelerate prototyping, system integration, and performance validation of industrial-scale electrostatic motor/generator units for use in transportation, distributed energy resources, and building electrification. The funding is essential to bridge the gap between promising laboratory results and market-ready products, ensuring California can benefit from:

- Reduced lifecycle carbon emissions in manufacturing and operation.
- Lower total cost of ownership for electric systems.
- Improved resilience of supply chains by avoiding rare-earth magnets and high-purity copper.

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)?

The proposed electrostatic motor/generator platform eliminates reliance on rare earth magnets and minimizes copper content by using low-current, high voltage electrostatic forces. This approach redefines the core physics of electric motor design, addressing critical material supply chain risks and enabling scalable, efficient, and sustainable alternatives to conventional electromagnetic machines.

By validating a commercially viable, magnet-free, high-torque drive and generator, this project will enable California to deploy clean energy technology that is resilient to global material supply shocks, delivers superior efficiency in torque-critical applications, and supports decarbonization in both industry, manufacturing and marine sectors. Below summarizes the barriers to adoption, cost/performance targets

Technical & Market Barriers Addressed:

1. **Material Supply Chain and Cost Volatility**

- *Barrier:* High-performance electromagnetic motors rely on rare earth magnets (e.g., neodymium) and large quantities of copper, both of which have volatile prices, environmental extraction concerns, and limited domestic supply.
    - *Solution:* Our electrostatic design removes permanent magnets entirely and uses 90% less copper, replacing costly and geopolitically sensitive materials with standard PCBs, recycled aluminum, and commodity dielectric fluids.
    - *Impact:* Reduces material costs and insulates California's clean energy infrastructure from global supply disruptions.

2. **Efficiency Losses from Gearboxes and Magnetic Losses**
    - *Barrier:* Many industrial and marine torque applications require gearboxes, which add friction losses, increase maintenance, and limit efficiency.
    - *Solution:* Electrostatic torque generation allows high torque at low speeds without gearboxes, removing associated energy and maintenance costs. The system's lower current operation reduces resistive losses, and the use of dielectric cooling allows high-voltage operation without breakdown.
    - *Target:* Achieve >90% total system efficiency vs. ~65% for equivalent geared electromagnetic systems operating at low speeds.
3. **Market-Specific Pain Points**
    - *Marine/Ocean Energy:* Fully submersible, non-corrosive design enables direct coupling to point absorbers, tidal turbines, and other ocean energy systems without external sealing systems.
    - *Industrial Automation:* Silent operation, low maintenance, and energy savings up to $1,400/year for a 2 HP equivalent drive make it competitive in conveyor, HVAC, and process industries.

Scientific Analysis & Data Gaps Filled

- **Current Gap:** There is limited performance data for industrial-scale electrostatic drives in sustained, real-world, torque-critical applications.
- **Contribution:** This project will generate validated datasets on:
    - Long-duration operational efficiency (>1,000 hr tests) in variable torque loads.
    - Dielectric fluid breakdown thresholds and lifetime under cycling voltages.
    - Field performance in submerged or high-humidity environments.
- **End Users & Beneficiaries:**
    - *Industrial operators* seeking high-efficiency, low-maintenance torque drives.
    - *Marine renewable developers* seeking submersible, gearbox-free generators.

- *Utilities & policymakers* needing scalable alternatives to rare-earth-based machines to meet California's 2045 net-zero goals under SB 96.

Ratepayer benefits

To consider the statewide benefits, the greatest impact of an efficient motor and high-torque power generation would come from water treatment, industry automation, transport and renewable generation. The potential aggregate savings include:

Ratepayer Benefits	**Base Target**
Energy saved	2.1 TWh/yr
Demand reduction	240 MW
Ratepayer bill saving	$294M/yr
GHG Reduction	0.4 Mt CO_2/yr
O&M savings	$50M/yr

- **Water/Wastewater:** Direct-drive blowers, pumps, and mixers (duty-cycle heavy). A 1 MW plant-load with 25% savings → **250 kW** average reduction → **≈$300k/yr** bill savings at $0.14/kWh, plus maintenance avoided from gearbox removals.
- **Industrial automation & robotics:** Conveyor/AGV fleets save **20–30%** energy and cut downtime; quieter ops improve safety.
- **E-mobility & Robotics (depots, logistics):** Smaller battery packs or longer runtime for low-speed, high-torque platforms; depot demand charges reduced.
- **Hydro/tidal/wave generation (low-speed generation mode):** Gearbox-free power takeoff (PTO) improves mechanical-to-electric conversion by ~20–30%**,** reducing LCOE and maintenance intervals.

Assumptions:

- ≈60 TWh/yr in California industrial electricity use.
- ≈42 TWh/yr (70% of industrial use) in motor-driven systems
- 8.4 TWh/yr with ≈20% efficiency improvements in addressable savings applicable to low-speed/torque drives (conveyors, pumps, mixers, fans, materials handling
- ~ 25% in overall savings from electrostatic direct-drive vs. geared EM systems (e.g., efficiency, eliminated gearbox, and reduced parasitics)
- Industrial tariff $0.14/kWh; CO_2 intensity 0.19 kg/kWh (CA grid average).
- ~50,000 potential industrial retrofit & $1,000/year per-site savings.

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]

Reducing to practice a low-cost, high-efficiency torque motor and a low-speed generator platform based on electrostatics will deliver transformative benefits to California ratepayers, industry, and the environment.

1. Cost Reduction and Value Proposition

- **Reduced Operating Costs:** By eliminating gearboxes and operating at >90% efficiency, end users can expect annual energy savings of up to $1,400 per 2 HP equivalent drive in industrial duty cycles. In large-scale deployments, such as conveyor networks or pump stations, lifetime savings could exceed **$100,000 per site** when factoring in energy, maintenance, and downtime reductions.
- **Lower Capital Costs at Scale:** Manufacturing from standard PCBs, recycled aluminum, and commodity dielectric fluids removes reliance on rare earth magnets and significantly reduces copper use (~90% reduction), insulating against global material price volatility and reducing upfront costs.
- **Extended Service Life:** The non-contact plate design and integrated dielectric cooling system reduce mechanical wear, lowering replacement frequency and lifecycle costs.

2. Increased Performance

- **High Torque at Low Speeds:** Direct-drive capability removes the need for torque-multiplying gearboxes, enabling smoother operation, faster control response, and reduced system complexity.
- **Silent Operation:** Near-zero acoustic emissions make the technology ideal for applications where noise is a barrier (e.g., residential energy systems, robotics in public spaces).
- **Submersible, Harsh-Environment Operation:** Fully enclosed dielectric fluid system allows deployment in underwater and high-humidity environments without additional sealing, opening marine and renewable generation markets.

3. Potential at Scale

- **Reduce Industrial Load Demand:** Deploying high-efficiency torque drives in manufacturing, water treatment, and logistics could lower peak demand and annual consumption, reducing strain on the grid.

- **Enable New Clean Energy Architectures:** As a generator, the same platform can be integrated into low-speed renewable sources like dam outflows, tidal turbines, and ocean wave point absorbers without intermediate gearing, improving mechanical-to-electrical conversion efficiency by 20–30%.
- **Decarbonize Transportation & Robotics:** Scaled into e-mobility (e-buses, cargo bikes, automated guided vehicles) and heavy-duty robotics, the platform could reduce drivetrain energy consumption and battery size requirements, lowering total cost of ownership.

4. Alignment with EPIC's Guiding Principles

- **Safety:** Low operating current and integrated dielectric insulation improve operator and environmental safety compared to high-current electromagnetic systems.
- **Reliability:** Fewer moving parts and no gearbox result in higher mean time between failures (MTBF), reducing downtime in critical applications.
- **Affordability:** Lower energy use, reduced maintenance, and supply chain resilience directly lower ratepayer and operator costs.
- **Environmental Sustainability:** Magnet-free design eliminates rare earth mining impacts; reduced energy demand supports California's decarbonization pathway under SB 100 and SB 96.
- **Equity:** Modular, scalable, and low-maintenance design allows deployment in underserved communities, remote facilities, and microgrids without reliance on specialized maintenance teams.

5. Key Applications

- **Industrial Automation:** Direct-drive conveyor systems, high-torque robotics, and precision assembly lines.
- **Robotics:** Heavy-lift autonomous systems, agricultural robots, and automated warehouse vehicles.
- **E-Mobility:** Direct-drive cargo bikes, last-mile delivery vehicles, and small marine craft.
- **Renewable Generation:** Dam tailwater generation, tidal stream turbines, and point-absorber wave energy systems where gearbox-free operation improves efficiency and reduces maintenance.

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

In addition to equipment and operational cost, the following performance metrics are summarized for the motor drive and power generator:

<u>Motor</u> Metric	Unit	Description	Measurement Method
Rated Speed	RPM	Most efficient operating range	Power vs. speed measurement
Rated Power	Hp	Most efficient operating range	Torque vs. speed measurement
Torque Output per Volume	Nm/L	Compactness metric, critical for retrofit applications	Lab measurement
Low-Speed Torque Density	Nm/kg	Torque capability without gearing	Lab measurement
Mean Time Between Failures (MTBF)	months	Reliability measure	Field data & failure logs
Thermal Stability	°C rise at load	Max temp rise over ambient	Temperature sensors during stress tests

<u>Generator</u> Metrics	Unit	Description	Measurement Method
Nominal Input Speed	RPM	Nominal operating range	Power vs. speed measurement
Nominal Output power	kW	Nominal operating range	Torque vs. speed measurement
Specific Electrical Output	W/L	Compactness metric, critical for retrofit applications	Lab measurement
Mechanical efficiency	%	Mechanical input to output shaft work ratio	Lab measurement
Electrical efficiency	%	Electrical AC input to DC output work	AC-DC conversion
Mean Time Between Failures (MTBF)	months	Reliability measure	HALT/HASS;
Thermal Stability	°C rise at load	Max temp rise over ambient	IEC 60034-11

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 Bs, equity benefits, etc.

Academic & Technical Literature

- **Electret-based Electrostatic Motor/Generator for Micro-turbines** - This paper presents a design of an electret-based electrostatic motor/generator intended for micro-machined gas turbines. It predicts an output power of 30.4 W at rotational speeds of 1 M rpm and describes a novel LC-resonant circuit to minimize parasitic losses, achieving over 80% of theoretical output. ScienceDirect+15ResearchGate+15Wikipedia+15ResearchGate
- **Electrostatic Vibration Energy Harvesting** (Boisseau, Despesse & Seddik, 2012, arXiv):
  Offers a comprehensive survey of electrostatic converters used to harvest energy from vibrations—covering both electret-free and electret-based designs, including modeling and prototype implementations. arXiv
- **Ion Wind (Corona Discharge) Simulation for Thermal Management** (Cagnoni et al., 2013, arXiv):
  Describes a numerical model coupling Navier–Stokes fluid mechanics, electrostatics, charge transport, and heat transfer, enabling simulation and validation of corona-discharge–based electrohydrodynamic devices for cooling power electronics. Google Patents+8arXiv+8Hackaday+8
- **Carbon Nanotube "Electron Windmill" Nanomotor** (Bailey, Amanatidis & Lambert, 2008, arXiv):
  Proposes a CNT-based nano-motor where electron flux through a chiral inner nanotube creates sufficient torque to overcome friction, causing rotation—revealing a novel nano-scale electrostatic actuation mechanism. arXiv+1

Commercial & Applied Research

- **C-Motive Technologies: Electrostatic Motors at Industrial Scale**:
  A startup in Middleton, Wisconsin, is developing modern electrostatic motors—reviving Benjamin Franklin's concept—to overcome limitations of conventional motors. The Wall Street Journal+2designfax.net+2

8. 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

a. Transportation Electrification

- *High-torque, low-speed efficiency*: Electrostatic motors can deliver full torque at low RPM without heavy gearboxes, improving drivetrain efficiency for EVs, e-bikes, and last-mile delivery vehicles.

- *Reduced critical materials use*: No rare-earth magnets or large copper windings, lowering material cost, supply chain risk, and embodied carbon in vehicle manufacturing.

- *Lightweight and quiet operation*: Beneficial for urban electric transit where low noise and compact form factor are critical.

b. Distributed Energy Resource Integration

- *Bidirectional operation*: Electrostatic machines can act as both motor and generator, enabling vehicle-to-grid (V2G) and stationary storage systems to provide ancillary grid services.

- *High efficiency at variable loads*: Well-suited for integration with renewable sources like wind, micro-hydro, and kinetic energy recovery systems in distributed microgrids.

c. Building Decarbonization

- *High-efficiency HVAC fans & pumps*: Electrostatic motors could replace less efficient induction motors in air handling, refrigeration, and water circulation, cutting operational energy demand.

- *Scalable retrofits*: Modular design allows drop-in replacements for existing mechanical systems in residential and commercial buildings.

e. Climate Adaptation

- *Resilient, submersible design*: Electrostatic motors can operate in wet, flooded, or dusty environments, supporting critical infrastructure like water pumping during climate-driven flood events.

- Decentralized energy resilience: Their ability to run from renewable or stored electricity enables operation during grid outages caused by extreme weather.

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