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RCAM Comments on Energy Storage Innovations to Support Grid Reliability Concept

Please find attached RCAM's comments in a PDF.

Additional submitted attachment is included below.

Comments on

DRAFT SOLICITATION CONCEPT

Subject Area: Energy Storage Innovations to Support Grid Reliability

Research Idea Exchange, Docket 23-ERDD-01

1/21/2024

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RCAM Technologies, Inc. (RCAM) is a growing climate tech startup based in Los Angeles, California that is developing a portfolio of products for offshore wind energy, floating solar, and subsea long duration energy storage (LDES). RCAM is developing an innovative marine pumped hydroelectric energy storage (MPH) that is deployed subsea. MPH has potential to provide ALL of the long duration energy storage needed by California to reach its 100% clean energy goals by 2045, while providing economic benefits and good jobs resulting from localized manufacturing and using abundant regionally-available construction materials. In order to achieve these benefits, it is essential that CEC consider and allow for technologies such as RCAM's innovative Marine Pumped Hydroelectric Storage Technology in future CEC EPIC grant opportunities. EPIC programs that encourage or support technology integration such as RCAM's Marine Pumped HydroElectric Storage systems will be critical to developing this new, timely California opportunity.

RCAM strongly supports the Commission's plans to support the development of emerging energy storage technologies and we appreciate the opportunity to provide these comments before the solicitation is released to help ensure the solicitation best meets the needs of California Stakeholders and Technology Developers. We offer the following public comments regarding the draft solicitation concept for the subject area *Energy Storage Innovations to Support Grid Reliability.* Our response includes:

1) An overview of RCAM and our subsea LDES concept (MPH) for context.

2) Select responses to CEC questions for the General, Group 1, and Group 2 topics.

Thank you for your consideration of these comments.

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MPH Technology Overview

New long duration energy storage is critical for the US to incorporate new renewable energy generation, increase grid reliability and resiliency, and reduce the usage of fossil-fuel plants to meet periods of peak electric demand. Pumped storage hydropower (PSH) is presently the dominant form of long-duration storage, supplying ~93% of US energy storage capacity due to its low cost, high round-trip efficiency, reliable operation, and long lifetime. However, new deployments of conventional PSH are limited by permitting challenges, geographic suitability, high costs, long development times, construction risks, and unrecognized energy storage valuation.[1]

Fig. 1: Illustrative co-deployment of MPH energy storage modules with offshore wind.

RCAM's marine pumped hydroelectric energy storage (MPH) is an innovative PSH technology that has potential to expand and accelerate PSH by creating new deployment opportunities in the ocean along US coastlines near America's most populous regions. MPH retains the benefits of conventional PSH while sidestepping many of the siting and development constraints that hamper PSH expansion on land. The US is the largest market for MPH with over 7.5 terawatts (TW) and 75 TWh of net technical potential in the Atlantic, Pacific, and Gulf of Mexico, which is more than two times the closed-loop PSH technical potential onshore (3.5 TW and 3,500 TWh).[2], [3]

MPH, which was awarded Storage Innovations Champion in the *DOE Energy Storage Innovations Prize*,[4] cycles water in and out of large concrete spheres on the seafloor to release and store energy on-demand. MPH can be deployed independently (in standalone plants) along America's coastlines or co-located with offshore wind plants **(Fig. 1)** to achieve synergistic cost reductions and new revenue streams. Installation of PSH in the sea allows it to be positioned relatively close to America's largest populations and load centers (i.e., Los Angeles, San Francisco, New York, Houston, Boston, etc.) in close proximity to a growing 50+ GW pipeline of planned US offshore wind deployments that need MPH to aid grid integration and reduce curtailments.[5] MPH is designed to be manufactured in in 2-MW to 5-MW modules in US ports using abundant regionally available materials and labor, benefitting from improved storage plant modularity while increasing local economic benefits and creating good-paying jobs for urban renewable energy ratepayers.

Current R&D Status: The operating principles of subsea energy storage were invented and proven by the Massachusetts Institute of Technology (MIT) and by the German Fraunhofer Institute for Energy Economics and Energy Systems (Fraunhofer IEE), a key RCAM partner who refers to subsea pumped hydro storage as "Stored Energy in the Sea" (StEnSea). Fraunhofer IEE tested a 2.5-m StEnSea sphere in a 100-m deep lake with a 100 kW pump-as-turbine (PAT) **(Fig. 2)**.[6], [7], [8] These activities advanced the basic technology readiness level (TRL) of StEnSea to TRL 5 "Component validation in a relevant environment," and successfully proved the technical feasibility at small scale (1/10 scale) in relatively shallow water. However, capital cost reductions in StEnSea are needed to make it more cost competitive with competing sources of energy storage such as onshore lithium-ion batteries.

RCAM Technologies, has conceived a lower cost, "2nd generation" StEnSea-based system (MPH) that reduces the levelized cost of storage (LCOS) of StEnSea by up to 42% (from $175 to $100/MWh) using three key innovations: (1) lower cost automated manufacturing of the spheres, (2) a patented multi-sphere design, and (3) optional integration with offshore wind.

RCAM is a climate tech startup based in Los Angeles, CA dedicated to developing 3D concrete printing (3DCP) technologies to accelerate the clean energy transition. RCAM has received initial support to assess and prove the MPH concept at small scale from four state, federal and UK organizations that demonstrate broad domestic and international interest in the technology and likelihood of attracting future public and private investments needed for commercialization. RCAM's awards, which total approximately $1.6M of funding to advance MPH, include the California Energy Commission (CEC), New York State Energy Research and Development Authority (NYSERDA), United Kingdom Department for Business, Energy & Industrial Strategy (BEIS), and DOE Small Business Technology Transfer program. In addition, the German government has recently allocated 3.4M Euro ($3.6M) to develop larger scale PAT systems that provides the cost share for the project.[9]

Fig. 2: Photos of the fabrication and 1/10 scale testing of Fraunhofer's first-generation subsea pumped hydroelectric system, StEnSEA.

RCAM has used its grants to perform techno-economic analysis, conceptual design, and fabrication of a subscale proof of concept by automated 3D concrete printing (3DCP) and testing in the Port of Los Angeles – achieving TRL 4 **(Fig. 3)**. RCAM recently ordered large-scale 3D printing equipment (12 m x 12 m x 4 m) needed to fabricate a 6-m diameter 3DCP sphere in the Port (TRL 4) and was selected to negotiate a \$8M project (a \$4M DOE award plus \$8M of cost match funding from CEC and Germany) to build and test the sphere in deeper water outside the Port.

Fig. 3: RCAM tested a 3D printed and test its multi-sphere MPH in the Port of Los Angeles.

This pending DOE project will provide essential funding to perform critical next steps in MPH commercialization including design, fabrication, and deepwater ocean testing of a larger scale (~6-m diameter) multi-sphere prototype (TRL 6) and planning of a grid-connected pilot demonstration to occur after the project for which RCAM will seek CEC funding such as the draft agreement.

Project Goal: The overall DOE project goal is to advance the development and testing of RCAM's innovative MPH technology by performing tasks that de-risk the PAT, sphere construction process, multi-sphere configuration, and system integration. In addition, the project includes environmental and technical analyses and permitting activities needed for a long-term grid-connected pilot demonstration at a US ocean test site or commercial offshore wind installation. The primary project deliverables are (1) a complete 1/3 scale MPH prototype, (2) operational test data in deep water, and (3) a front-end engineering design (FEED), financing and permitting plans for a grid-connected pilot demonstration after project completion.

Project Impact: RCAM is targeting a 42% reduction in the Levelized Cost of Storage (LCOS) of sea-based energy storage, from \$175/MWh to \$100/MWh, in a typical installation when commercialized. The DOE project funding is critical to continuing the advancement of MPH and realizing the approximately 75 TW of new PSH deployment opportunities in US oceans along with the jobs and economic benefits

MPH offers. The project will advance MPH from TRL 3 to TRL 6, sufficiently de-risking the innovative technology to attract larger amounts of public and private funding for grid-connected demonstration, scale-up, and deployment.

The US has a timely opportunity to develop MPH and avoid it being "locked-out" from US markets by competing storage technologies such as hydrogen storage, flow batteries, and lithium-ion batteries that lack many benefits PHS offers.

Long-term Constraints and Climate Resilience Strategy: Key advantages of MPH include the use of abundant, regionally available materials for construction (concrete, steel, and copper) and operation (seawater), its "invisible" installation at the bottom of the seafloor, and its inherent immunity to fires, floods, freezing, heatwaves, storms, droughts, and terror events. These characteristics minimize long term constraints on natural resources and make it one of the most resilient energy storage technologies available.

MPH provides rich community benefits including grid resiliency, jobs, and economic benefits for local electricity ratepayers while minimizing land-use and environmental impacts. MPH is installed in very deep, cold, and dark depths of 500 to 2000 m where there is little marine life or fishing activity. However, permitting uncertainties, perceived concerns on fishing activity, tribal lands, and potential environmental impacts (e.g., noise and seabed disturbances) need to be addressed. RCAM has been studying these issues as part of a University of Michigan School for Environment and Sustainability M.S. Capstone project and will address them in more detail in the project. Additionally, the pump is installed in the center of a concrete sphere with walls up to 2m thick, resulting in very little noise emissions. Installations will occur in Federal waters, 3 to 30 miles from shore in areas unlikely to have tribal or community conflicts. In addition, projects will likely be co-planned with floating offshore wind deployments by experienced offshore wind developers with established stakeholder outreach processes and staff.

MPH operating principles. The operating principles of subsea PSH for a single sphere were invented and proven by MIT and Fraunhofer IEE **(Fig. 2)**. MPH uses the pressure head at the bottom of an ocean or lake to store and release electrical energy in a process like that of onshore PSH **(Fig. 4)**. One or more hollow concrete spheres 20-30 m in diameter is installed in an ocean at a depth of 500-2000 m (RCAM uses 1000 m as its technical reference). A reversible pump/turbine (pump-as-turbine, or PAT) charges the system by pumping water out of the sphere against the surrounding water (50 to 200 bar depending on depth). Electricity is generated by running the PAT in turbine/generator mode, refilling the sphere. The energy storage capacity of a sphere is directly proportional to the pressure of the surrounding water and internal sphere volume.

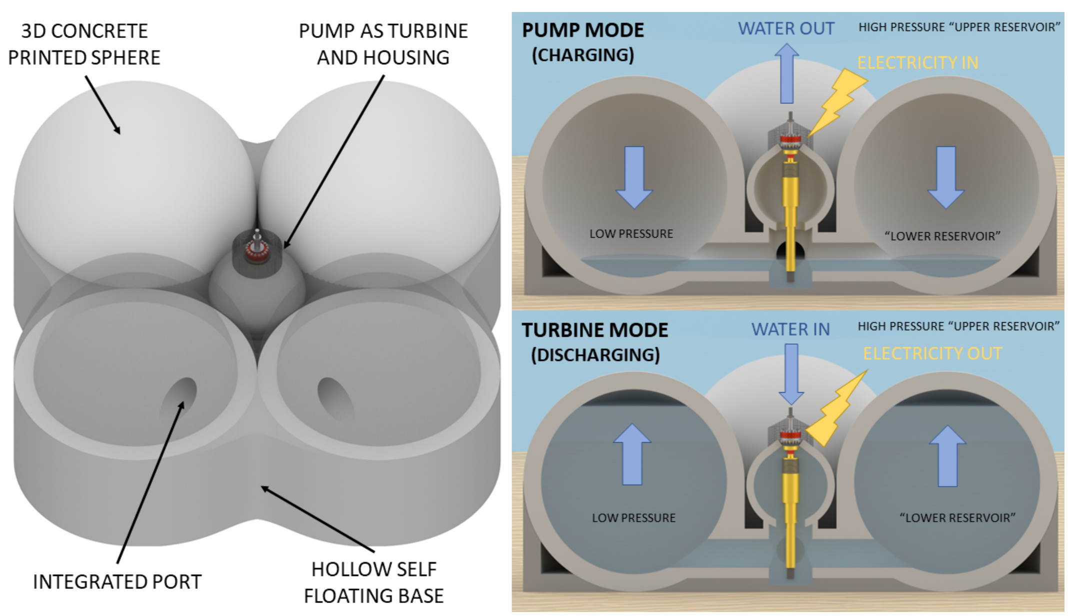

Fig. 4: (left) Schematic of quad-sphere MPH and **(right)** schematic illustration of charging / discharging cycles.

Steady ambient high-pressure water surrounds the spheres and the pressure inside the sphere remains very low throughout operation, resulting in only compressive stresses in the sphere for which concrete is a near-ideal, low-cost material and requiring little reinforcement. The near constant pressure differential between sphere exterior and interior, and the steady temperature at the seafloor results in negligible fatigue stresses and a near infinite fatigue life for the concrete components. Corrosion of concrete in marine environments is well understood through decades of offshore oil and gas and marine infrastructure applications. RCAM is working to verify that 3DCP materials and designs will be equally durable.

Target Market. MPH can be installed independently or combined with offshore wind plants by locating it just off the continental shelf which ranges from 0.6 miles from the coastline in California to at most 120 miles in the New York Bight.[18] The US is the largest market for MPH with over 7.5 TW and 75 TWh of net technical potential, much of which is near a 40 GW US pipeline of offshore wind projects and BOEM Wind Call Areas **(Fig. 5)**.[19,5]

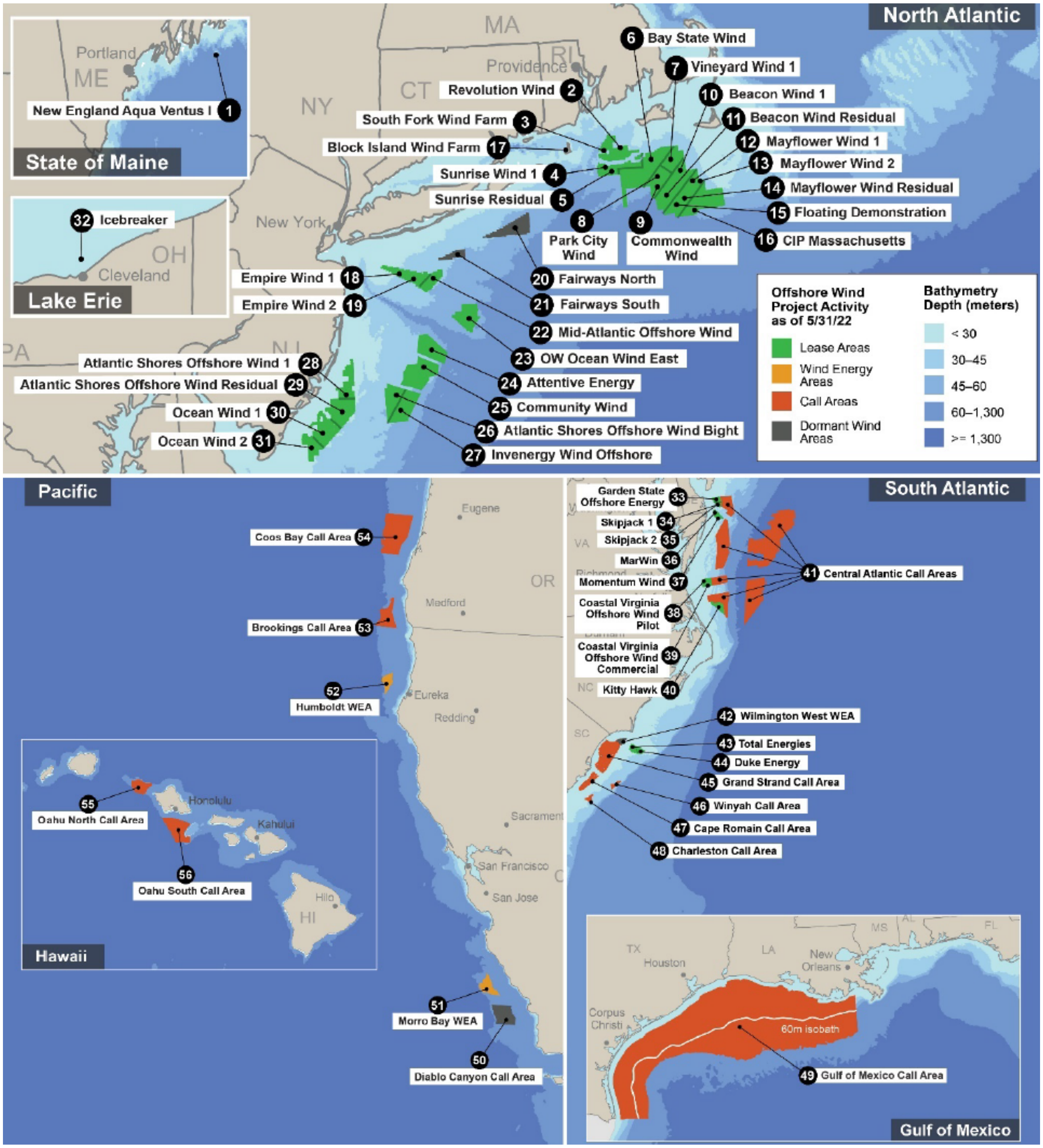

Fig. 5: 54 locations of the 40+ GW offshore wind pipeline and Call Areas in which MPH can be co-deployed.[20]

RCAM's first target market (beachhead) for MPH are the marine planning areas and the wind energy call areas in the Pacific and Atlantic, in particular the Morro Bay and Humboldt Bay Wind Energy Areas in California and deep-water areas of the Central Atlantic Planning Area.[2,3] These sites have 11,000 km^2 of seafloor area, providing over 4.7 GW of **gross** technical potential over 500 times the California and New York LDES 2030 targets (assumes 0.43 GW/km^2 MPH capacity derived using 50% pod spacing, one 5 MW pump per pod and six 35-m diameter spheres). The market barriers are similar to those affecting offshore wind technologies include awareness and acceptance of MPH, perceived concerns about fishing, and potential environmental impacts on marine life including noise and seabed disturbances. This project and the subsequent grid-connected demonstration have been structured to help address the awareness and acceptance barriers.

Customers. RCAM primarily targets large grid-connected markets powered by the fast-growing offshore wind industry. Target customers are leading developers in the Northeast, West Coast, and Gulf Coast who seek (1) competitive advantage for offshore plants by integrating storage and (2) additional revenue streams from expanded grid services. Offshore wind developers are typically European oil and gas firms such as Equinor, Shell, BP, and CIP or joint ventures.

Customer Value Proposition. MPH has potential to provide ALL of the long duration energy storage needed by California to reach its 100% clean energy goals by 2045 while providing economic benefits and good jobs resulting from localized manufacturing and using abundant regionally-available construction materials. In order to achieve these benefits, it is essential that CEC consider and allow for technologies such as RCAM's innovative Marine Pumped Hydroelectric Storage Technology in future CEC EPIC grant opportunities. EPIC programs that encourage or support technology integration such as RCAM's MPH systems will be critical to developing this new timely California opportunity.

The US offshore wind market presently relies on highly competitive auctions for ocean lease areas. Developers with access to additional revenue streams, such as those who can also sell energy-storage services from integrated MPH plants, will be able to bid higher for lease areas, winning the rights to develop offshore wind plants. A key benefit of MPH is that it uses the existing and domestic supply chain for materials, assembly, installation, equipment, and manufacturing equipment. There are no major supply chain gaps. **(Fig. 6)** provides an example of the supply chain members that RCAM is or plans to start working with to develop and commercialize MPH in the US. Partners include ports, heavy-lift companies, and engineering, procurement, and construction firms to manufacture MPH for developers. RCAM will license its IP to engineering, procurement, and construction (EPC) firms. The spheres, which are the largest cost portion of MPH, will be manufactured and assembled in, and deployed from, ports and harbors in partnership with leading construction firms and marine transport providers.

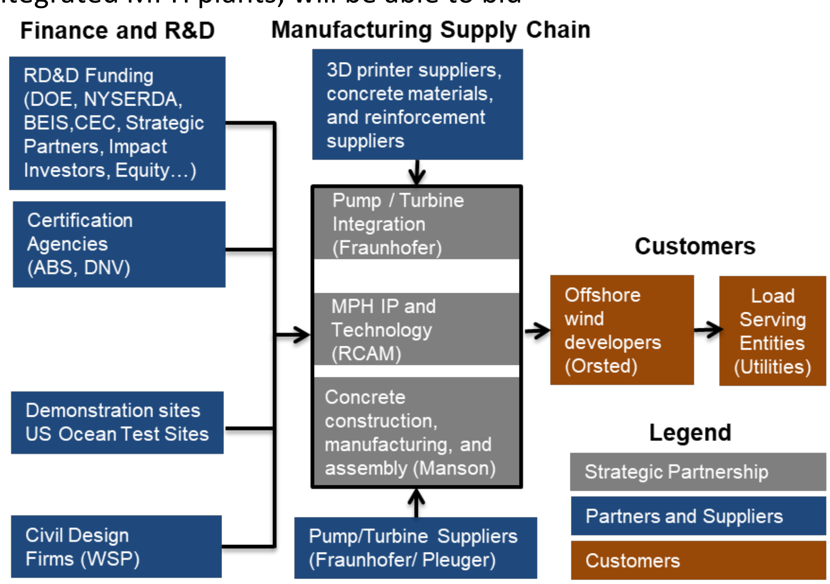

Fig. 6: Partners and supply-chain members needed to commercialize MPH.

Competition. MPH complements inland PSH technologies. Like onshore PSH, MPH is cost competitive with battery storage at longer durations especially near large cities with limited land availability and high cost of land. Moreover, because MPH contains no significant quantities of hazardous chemicals, it presents essentially zero environmental-release risk. The primary emerging competition for MPH is experimental onshore PSH and its variants (GLIDES, Hydrostor, GravityStore, and others), CAES-based systems, and batteries. RCAM envisions MPH will complement these emerging technologies if they prove to be cost effective; however, MPH is the only feasible technology that can be sited at floating wind plants near the source of variable generation. Two other marine pumped hydro storage systems (FLASC and Ocean Grazer) are being explored, but they are not cost-competitive with MPH in deep water due to the elegance of using low cost concrete in compression and efficient spherical shapes.

Responses to Questions

General

1. Do the Project Groups described in Section IV.A address the primary objectives of the solicitation to enable more strategic and high-value implementation of energy storage to support grid reliability?

RCAM believe the project groups will enable more strategic and high-value implementation of energy storage to support grid reliability. However, it appears that the technology advancement areas identified does not include TRL 5 technologies (Group 1 is TRL 3 and 4, and Group 2 is TRL 6). RCAM requests that Group 1 TRL levels be extended to TLR 5.

In addition, it is not clear how the CEC will compare and evaluate short duration energy storage technologies with longer duration technologies. It would add clarity and reduce applicant uncertainty about the competitiveness of proposals if subcategories for LDES were added to the solicitation.

2. In addition to the target performance metrics outlined in Section IV.A regarding LCOS, calendar life, and roundtrip efficiency, what other metrics should be reported?

It's not clear how "Calendar Life" is defined. In addition to "Calendar Life", overall "System Life" is important to RCAM's technology. We believe the primary components of our MPH LDES technology can be designed to last 50 to 80 years, with retrofits of the pump as turbine assembly every 7 years.

Additional performance metrics that RCAM believes merit inclusion are for lifecycle assessment and estimates of domestic content and jobs produced for California ratepayers.

3. CEC is considering releasing this funding opportunity as a two-phase solicitation that includes a Pre-Application Abstract phase and Full Application phase. Projects that are successful in the Abstract phase will have two months to prepare a Full Application. Is this approach preferable to applicants or should the CEC consider a one-phase solicitation without the Pre-Application Abstract phase?

RCAM strongly endorses the two-phase solicitation approach as contained in the draft application to help reduce the amount of effort applicants expend completing a full application that may not be competitive or within the area of interest that CEC seeks.

4. Are the draft funding levels and match requirements appropriate to achieve the desired outcomes of each Group?

There are elements of RCAM's LDES technology that would benefit from both Group 1 and Group 2 categories. However, unlike battery systems, RCAM's LDES technology is less modular at small scales and is better suited to larger, MW-scale increments. Accordingly, RCAM believes that more funding, both the funding size and award size, for Group 1 technologies would be beneficial. For example, at a minimum, RCAM recommends increasing at least $6M of funding for Group 1 to allow for at least 4 $1.5 Group 1 awards. Ideally, the maximum size of Group 1 could also be increased to $2M and the amount increased to $8M allowing for 4 $2M Group 1 awards.

RCAM also recommends reducing the minimum size of Group 2 awards to $2M to provide applicants with more flexibility in preparing applications for different technologies that require different amounts of funding, and possibly allowing for more Group 2 awards.

Group 1

1. Is a three-year project timeline feasible for Group 1 projects to meet the objectives of the solicitation? Are there any potential barriers or challenges in implementing these types of projects over three years?

RCAM believes a three-year project timeline is an appropriate amount of time for achieving the desired technology development objectives, and is consistent with other grants of this size we have received for other technologies we are developing.

2. What level of analysis would an applicant be able to provide to demonstrate supply chain sustainability improvements of a proposed innovation? For example, could applications be expected to describe the source and lifecycle impacts of relevant materials, ethics or workforce implications, and/or manufacturing scale-up capabilities?

RCAM could provide most of these metrics except for ethics. It's not clear how these could be best quantified. RCAM has provided metrics for past projects including the source and lifecycle impacts of relevant materials, workforce implications (jobs and domestic content), and manufacturing scale-up capabilities.

3. What data would be useful to gather and publish to validate technology improvements and accelerate commercialization?

RCAM would seek to publish data from these projects regarding manufacturing cost, performance (efficiency), and system specifications, job creation, and local economic benefits to raise awareness and investor interest in our LDES technology.

4. What emerging technologies can be demonstrated to further reduce energy storage safety risks?

RCAM is very concerned that the draft oscillation only identifies "advanced battery components or materials" as technologies of interest. As written, this seems to indicate a bias in the solicitation that would limit feasible and promising LDES storage alternatives for California ratepayers including flow batteries and innovative hydroelectric storage technologies such as RCAM's subsea marine pumped hydroelectric (MPH) LDES technology.

Key advantages of MPH include the use of abundant, regionally available materials for construction (concrete, steel, and copper) and operation (seawater), its "invisible" installation at the bottom of the seafloor, and its inherent immunity to fires, floods, freezing, heatwaves, storms, droughts, and terror events. These characteristics minimize long term constraints on natural resources and make it one of the most resilient energy storage technologies available. RCAM recommends that at a minimum, advanced hydroelectric storage alternatives be included as an alternative of interest.

5. Are there additional energy storage applied R&D or innovation opportunities not captured by this Group 1 concept?

No comment

6. Should there be separate qualifications or target metrics for short-duration and long-duration storage within Group 1?

Yes, as described in our response to the general comments, it is not clear how the CEC will compare and evaluate short duration energy storage technologies compared to longer duration technologies. It would add clarity and reduce applicant uncertainty about the competitiveness of proposals if subcategories for short duration and LDES were added to the solicitation.

7. Should real-world field demonstrations be required or optional for Group 1 projects?

Real-world field demonstrations should be optional. For our subsea LDES technology, real-world demonstrations require between $3M and $10M of funding to perform because they must be done in the ocean. This amount of funding is well beyond the available funding range in the draft solicitation. Adding this requirement would greatly restrict our ability to propose the most impactful project scope. In addition, it appears that Group 2 serves this purpose (demonstration) well.

Group 2

1. Is a four-year project timeline feasible for Group 2 projects to meet the objectives of the solicitation? Are there any potential barriers or challenges in implementing these types of projects over four years?

RCAM believes a four-year project timeline is an appropriate amount of time for achieving the desired technology development objectives, and is consistent with other grants of this size we have received for other technologies we are developing.

2. Are there any use cases missing from Table 1 that should be included?

Avoided renewable energy curtailment, a primary benefit of RCAM's LDES technology, is mentioned in the text for Group 2, but it is not clear where it fits in Table 1. RCAM requests that the commission consider adding it explicitly to Table 1.

3. What are some examples of innovative use cases for commercial Li-ion batteries that are worth exploring in this solicitation?

No comment.

4. Is the minimum scale of demonstration (>100 kW capacity) reasonable?

RCAM believes a >100 kW is an appropriate demonstration scale of time for achieving the desired technology development objectives.

5. Do the Group 2 requirements sufficiently encourage projects to be in and benefitting disadvantaged communities, low-income communities, or Native American tribes?

No, the Group 2 incentive to provide less cost share for projects located in disadvantaged communities systematically biases against solutions such as RCAM's subsea energy storage technology that are located out of site in locations where no one lives, but that still provide benefits to all ratepayers including disadvantaged communities including 1) manufacturing an operations jobs, 2) improved grid reliability, and 3) lower cost clean electricity by integrating with offshore wind.

As a result, when considering our subsea energy storage technology, the incentive actually acts against the interests of disadvantaged communities, low-income communities, or Native American tribes. It forces energy storage solutions, including flammable and imported batter solutions, to be located in these communities.

RCAM critically requests that the Commission remove the requirement that projects be located in these communities and retain the requirement that they benefit these communities in measurable ways to be documented in proposals.

6. To maximize the impact and benefits of Group 2 demonstrations, what partnerships are most critical?

For RCAM, partnerships with local marine construction firms, offshore wind developers, and marine environmental groups are the most critical. Partnerships with stakeholders including local laborers are also important.

7. What barriers and opportunities exist for partnerships with utilities or other stakeholders to demonstrate transmission or distribution-connected energy storage use cases?

Given the early stage of our technology and offshore wind in California, it is challenging to get utilities engaged in our R&D and demonstration projects.

8. What data would be useful to gather and publish for measurement and verification purposes and to inform bankability and replicability?

RCAM would seek to publish data from these projects regarding manufacturing cost, performance (efficiency), and system specifications, job creation, and local economic benefits to raise awareness and investor interest in our LDES technology.

9. Is the 12-month minimum demonstration period requirement reasonable for Group 2 projects?

No, for our purposes we could demonstrate these benefits in as little as one to three months. The 12 month requirement unnecessarily increases project cost.

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