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RCAM Technologies' Comments on Landbased and Offshore Wind Initiatives

Please see attached document.

Additional submitted attachment is included below.

RCAM Technologies Comments on the Preliminary Draft Research Roadmap

July 12, 2019

Jason Cotrell, Founder and CEO of RCAM Technologies

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Project Title: Research Idea Exchange

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RCAM Company Background

RCAM Technologies is a startup company dedicated to developing new support structure technologies for land-based and offshore wind turbines. RCAM has offices in Irvine, California and Boulder, Colorado. It was founded by Jason Cotrell as a result of research and development activities begun at the National Renewable Energy Laboratory in 2015.

In June 2017, RCAM partnered with the University of California, Irvine (UCI), on a research project funded by the California Energy Commission to develop a 3D Concrete Printing (3DCP) process for manufacturing land-based wind turbine towers on-site. The project is developing, demonstrating, and testing a reinforced concrete additive manufacturing technology for building low-cost ultra-tall wind turbine towers on site at the wind plant that capture more wind energy from faster winds. The advance manufacturing technology eliminates the transportation and logistics constraints by manufacturing structurally efficient large-diameter towers within the wind plant. The towers are made with locally available cementitious materials supplied by standard concrete trucks, or an existing concrete batch plant within the wind plant. The proposed manufacturing technology is faster and safer while providing new transformative design possibilities that reduce costs and energy consumption by using less concrete than conventional construction, less labor, and eliminating concrete formwork. The scope of the ongoing CEC project includes design of an ultra-tall, land-based tower and small-scale 3DCP printing and testing at sizes of approximately 1 m in diameter and height. Anticipated project benefits for California ratepayers include

1) Increasing new and repowered wind capacity deployment potential 10-fold

2) Reducing CO_2 emissions 85 times on a lifecycle basis compared to electricity generated with natural gas in a natural gas power plant.

3) Reducing LCOE of wind generated electricity in moderate speed wind sites up to 11% which will lower the cost of clean electricity for California ratepayers.

4) Creating research and development jobs in California during the EPIC project, and creating expected future construction, operations and maintenance jobs for new and repowered wind turbines built with ultra-tall RCAM towers.

In July 2018, the U.S. Department of Energy (DOE) awarded a Phase I Small Business Technology Transfer (STTR) project to RCAM to assess the feasibility of using 3DCP to manufacture offshore support structures and towers-- the first-ever assessment of its kind. The outcomes of the completed project indicate that RCAM's next-generation 3DCP fixed-bottom support structure is expected to solve the cost, production rate, supply chain, vessel availability, and noise challenges associated with conventional support structures, thereby reducing levelized cost of energy (LCOE) up to 27%. In addition, RCAM's 3DCP foundations can be built on-site at existing California concrete plants or ports, and be transported and installed virtually noise-free at the installation site without wind turbine installation vessels.

RCAM's General Comments on Offshore Wind

RCAM strongly encourages and supports the Commission's efforts to develop a roadmap that includes offshore wind. California alone has 112 GW of offshore wind capacity in areas with mean wind speeds greater than 7 m/s and water depths less than 700 m, which is about 40% more than the total existing electrical generating capacity of California (approximately 80 GW). **A substantial portion of this offshore resource capacity, about 43 GW or 40%,[1] is in relatively shallow water depths less than 60 m that is accessible today using available, conventional, relatively low cost fixed-bottom support structures technologies.** Fixed-bottom offshore wind is, and is projected to be the lowest cost offshore wind technology for at least the next 10 years. Moreover, RCAM's concrete fixed-bottom support structures have potential to further reduce the levelized cost of energy of fixed-bottom offshore turbines by as much as 27%, and install fixed-bottom technologies in even deeper waters up to 100 m.

RCAM's Comments on Offshore Wind Initiative 5.1: Cost Reduction of Offshore Floating Systems with a Focus On Platform and Anchoring Systems

1. RCAM supports Wind Initiative 5.1 Cost Reduction of Offshore Floating Systems; however, the Commision's presentation on Initiative 5.1 incorrectly states that "Any development of the offshore resource in California above small scale will require the development of floating platforms". This is a common misperception (and a roadmap gap) that is contradicted by the 43 GW of California offshore resource capacity in depths less than 60 m identified by NREL. Furthermore, the 50-m depth limit cited in the initiative is still increasing for both conventional monopile technologies, and next-generation fixed-bottom technologies in development by companies such as RCAM. Monopiles for water depths up to 55 m or even 60 m are presently in the planning stages. Next generation technologies could extend the depths for fixed-bottom foundations to as deep as 100-m. For these reasons, **RCAM strongly recommends that the Commission examine the potential for near-term and long-term fixed-bottom deployments in California, and add fixed-bottom deployments to this initiative or create a separate initiative.**

[1] Musial, Walter, Philipp Beiter, Paul Schwabe, Tian Tian, Tyler Stehly, Paul Spitsen, Amy Robertson, and Vahan Gevorgian. n.d. "2016 Offshore Wind Technologies Market Report," page 49.https://www.energy.gov/sites/prod/files/2017/08/f35/2016%20Offshore%20Wind%20Technologies%20Market%20Report.pdf

Such deployments of lower-risk and lower-cost fixed-bottom technologies will accelerate California's offshore deployments and build the supply chain needed to support floating offshore technologies as they are developed.

2. RCAM would like to highlight an emerging R&D trend and leadership opportunity that has potential to further reduce both fixed-bottom, and floating offshore wind technologies. The use of multi-material or hybrid materials (such as structures that include concrete, steel, polymer, and composite components) in combination with advanced manufacturing methods (such as additive manufacturing) and advanced control methods to build lighter weight, more flexible, fixed and floating support structures has substantial cost reduction potential, and presents an opportunity for California R&D leadership. Examples of such technologies include (1) the European FLOATANT project that uses plastic-concrete hybrid systems,[2] (2) NREL's Spider Float system,[3] and (3) turbines being sought by the DOE ARPA-E ATLANTIS program.[4] California's extensive and advanced R&D companies and universities, its established cleantech innovation ecosystem, its world-class concrete, aerospace industries, vast offshore fixed bottom and floating resources, and progressive energy policies could work synergistically to continue its innovation legacy in floating offshore structures especially in this emerging field.

3. Using automated production methods with concrete in particular has substantial potential to reduce the cost of energy of both fixed-bottom and floating offshore wind deployments, as well as solve numerous other supply chain challenges facing offshore wind. RCAM's concrete support structure can be manufactured at or near an existing California ports or precasting plants using 3D-printing technologies with low-cost, regionally sourced concrete materials. The support structure can be floated and towed to the installation site using common tugs with the tower and turbine partially or fully assembled to reduce or eliminate the need for wind turbine installation vessels. Using suction piles or a gravity base allows the support structure to be installed quietly, solving environmental concerns with competing monopile technologies. Furthermore, the highly scalable 3DCP manufacturing and installation processes and "high-overturning-capacity" suction-pile support structure vastly increases deployable regions for the fixed-bottom support structures several times, and increases the maximum turbine size that can be installed to 20 MW or potentially larger.

A suction pile (also called a "suction bucket" or "suction caisson") is a low-cost, removeable method of anchoring support structures in marine sediment by creating a negative pressure inside a steel bucket with a suction pump (figure 1). Numerous suction-pile support structure designs have been successfully deployed in recent years in Europe to anchor steel truss substructures. Building the substructure (e.g., the stem, hub, and legs) using 3DCP

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[2] Coker, Rob. 2019. "Plastic-Concrete Hybrid Will Enable Floating Wind Farms." EPPM. July 10, 2019. https://www.eppm.com/api/content/62342196-a30a-11e9-af53-12f1225286c6/.

[3] "Energy I-Corps." n.d. Accessed July 12, 2019. https://energyicorps.energy.gov/content/spiderfloat-national-renewable-energy-laboratory.

[4] "ARPA-E | ATLANTIS." n.d. Accessed July 12, 2019. https://arpa-e.energy.gov/?q=arpa-e-programs/atlantis.

methods instead of steel substantially reduces costs by using more affordable materials and automated manufacturing methods.

RCAM's concrete substructures, when used with suction piles, will reduce the size and cost of the steel suction piles for a given site (or the overturning resistance increased if the suction pile size is kept the same) because the heavier mass of the concrete substructure increases the suction pile uplift resistance and overturning resistance. In addition, the scalable concrete geometry and low-cost materials allow the 3DCP tripod suction-pile foundation legs to be built cost effectively with a larger leg radius that further increases the overturning resistance if desired.

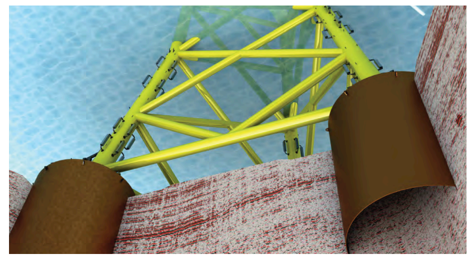

Figure 1. 3DCP can be used with a variety of fixed and floating foundation types. Steel suction piles are used to anchor the support structure to the seabed to facilitate fast, quiet, reversible installations in a variety of U.S. installation sites.

Furthermore, 3DCP support structures have the ability to incorporate geometries and features, such as a low center of mass and integration of buoyancy chambers in the hub or legs to help float the support structure during towing.

Reinforced concrete has a long history of successful use in the offshore oil and gas industry dating back to the 1970s, partly because of its low cost, scalability, stiffness, design flexibility, and resistance to marine corrosion. Concrete's inherent resistance to fatigue loads and corrosion make it feasible to build concrete offshore structures that last twice as long as steel offshore structures. Reinforced concrete is still the material of choice in many offshore oil and gas platforms, such as the giant, $14-billion, 600,000-ton Hebron floatable gravity-based oil platform that was deployed off the coast of Newfoundland in 2017 (Figure 2).

3DCP is an automated manufacturing process for constructing large-scale concrete structures by depositing additive materials in successive horizontal layers. 3DCP reduces manufacturing capital cost by eliminating construction formwork, reducing labor, and using low-cost, corrosion-resistant, and domestically available concrete materials. Formwork used in conventional concrete construction is one of the largest cost components comprising 50%–60% of the cost of a completed concrete wall. 3DCP eliminates the high cost and material waste of formwork and associated labor in assembling, disassembling, and maintaining giant forms. In addition, 3DCP allows the form geometry to be changed for each project, or even each support structure, if desired, without creating new formwork. 3DCP also facilitates complex stress-reducing shapes that use less concrete and reinforcement materials than conventional concrete construction methods. The lighter concrete structures can be built in longer sections, thereby reducing

Figure 2. Concrete's durability offshore has been demonstrated in numerous oil and gas applications (left) and wind turbine gravity-base foundations (right).

assembly time and costs without increasing crane size. The U.S. Army Corps of Engineers CERL, and several other international organizations have successfully demonstrated the ability of 3DCP to build reinforced concrete structures such as bridges and buildings (Figure 3); however, the potential for 3DCP offshore applications is still entirely unexplored except for RCAM's Phase I STTR project.

Figure 3. The U.S. Army Corp of Engineers has used 3DCP equipment to print a concrete building in 24 hours.

The very low cost of concrete and reinforcement materials compared with the cost of extensively worked steel structures (which are machined, welded, quality controlled, and painted), and the highly automated production method are the primary sources of capital cost reduction compared with the steel jacket and tower. Material cost is an important cost reduction factor compared with steel support structures. The approximate average cost of concrete and basalt reinforcement material is only $100/ton, 60 times less than the finished cost of a jacket structure per unit mass ($6,000/ton) listed in a University of Delaware study.[5] The assembled cost of an RCAM support structure with suction piles delivered to the Delaware Marshalling site is approximately $2.1 million less than University of Delaware's cost estimate for a truss suction pile ($5.2 million)—a capital cost reduction of about 40% less, which results in an LCOE reduction of 9%. In addition, the RCAM support structure reduces the port assembly area by 50%, can be produced with an existing West Coast supply chain, and is more stable, allowing it to be towed to the installation site with the tower, nacelle, or rotor partially or fully installed on the support structure. The scalability of RCAM's foundation provides a support structure and heavy-lift-vessel alternative to install larger turbines, which have the largest effect on reducing the LCOE. For example, the University of Delaware estimated doubling the turbine size results in an additional LCOE reduction of approximately 31%. A more recent and detailed study by BVG Associates projects an 18% LCOE reduction by doubling turbine size.[6] **Summing the LCOE contributions for the lower installed CapEx of RCAM's support structure (9%) and reduction in LCOE due to scaling to 20 MW (18%) results in a 27% LCOE reduction for RCAM's modular concrete support structure** compared to a steel-truss support structure with suction piles.

The primary technical, performance, and cost goals for RCAM's modular concrete suction-pile support structure and heavy-lift-vessel alternative for 10-MW and 20-MW turbine classes are listed in Table 1. An RCAM interview with a leading wind turbine original equipment

[5] Kempton, W. 2017. "Industrializing Offshore Wind Power with Serial Assembly and Lower-Cost Deployment - Final Report." DOE-UDEL-0005484. Univ. of Delaware, Newark, DE. https://doi.org/10.2172/1412660.

[6] Mills, Stephen. "Updated Future Costs of Energy for Offshore Wind - BVG Associates," November 30, 2017. //bvgassociates.com/updated-future-costs-of-energy-for-offshore-wind/

manufacturer indicated that 20-MW class turbines may exist by the time RCAM's foundations are fully commercialized in 2030.

Table 1. Estimated Technical, Performance, and Cost Improvements for Conventional and 3DCP Support Structures When Fully Commercialized in 2030

Support Structure	Monopile or Steel Truss Suction Pile	3DCP Suction-Pile Support Structure
Turbine Rating	10 MW	20 MW
Maximum Water Depth	50 m	Up to 100 m
Peak Installation Noise for 6-m-diameter monopile at a 750-m exploration distance, without and with two noise mitigation systems (Bellman 2014)	205 decibels without and 185 decibels with	Negligible noise
West Coast Supply Chain Production Capacity	0%	Up to 100%
Design Life	25 years	Up to 50 years
Production Rate Compared to Conventional Concrete Manufacturing	N/A	14 times
Installed Support Structure CapEx	0%	>40% reduction
LCOE Change from Installed CapEx Change	0%	-9%
LCOE Change from Larger Turbine	0%	-18%
Total LCOE Change	**0%**	**-27%**

RCAM's Comments on Offshore Wind Initiative 5.2: Establishment of Local Manufacturing Capabilities for Offshore Tower Components.

1. RCAM supports this initiative but recommends that the Commission replace the term "tower" with more specific and commonly accepted terms for offshore wind support structures that include the terms "foundation", "substructure", and "tower" as defined in IEC offshore wind standards and design guidelines.

2. RCAM also would like to note that automated 3D concrete printing technologies could produce offshore modular foundations and substructures on-site at existing California ports, or at nearby precasting facilities.

RCAM's Comments on Land-based Wind Initiatives

RCAM strongly supports the Commission's planned activities for land-based wind. The cost of the least expensive U.S. offshore wind deployments expected in coming years ($74 / MWh for Vineyard wind) are still approximately 3 times as expensive as the current average cost of U.S. land-based wind (about $25 / MWh). Continued exploration of cost reducing avenues for land-based wind (such as taller towers, bigger rotors, and tower climbing cranes), and efforts to mitigate public acceptance of land-based wind are critical to increasing land-based wind deployments in California. Innovative tower climbing cranes are an especially important technology to develop as a means of facilitating cost effective deployments of turbines with larger rotors, heavier larger power capacity nacelles, and taller towers that are now available in Europe.