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Automated concrete construction can reduce the cost of land-based and offshore wind and expand California economic development

Please find a the attached 3 page PDF document

Additional submitted attachment is included below.

Automated concrete construction can reduce the cost of land-based and offshore turbines and expand economic development in California

This public comment was drafted by RCAM Technologies with support from U.S. concrete expert researchers and practitioners specifically in response to CEC's key question: *Aside from cost, what new features and capabilities are needed to improve the value proposition of the next-generation wind energy technologies and real-time monitoring systems?*

Increasing the size of wind turbines (larger rated generator capacities, blade lengths, and tower heights) has been one of the most important factors in reducing the levelized cost of both land-based and offshore wind generated electricity (LCOE). A survey of 163 wind experts indicates that larger rotors, taller towers, new foundation designs, new manufacturing methods, and more durable/reliable components have potential to further reduce the LCOE of land-based wind plants up to 35%, and offshore wind plants up to 41% (Wiser etc. al. 2016).* New automated domestic manufacturing methods that use low cost, durable cementious materials such as concrete can help build new land-based and offshore wind deployments in California by reducing the capital, installation, and maintenance cost of the most expensive wind turbine components: the tower and foundation/substructure which represent approximately 50% of the capital cost of a next-generation land-based turbine and even more for offshore turbines.

Low cost cementitious materials, such as concrete, have potential to reduce the cost of supporting larger land-based and offshore fixed-bottom and floating turbines in California especially when combined with on-site or near-site automated manufacturing methods. Automated on-site or near-site manufacturing methods can further improve the production rate and reduce the cost of concrete structures by enabling 24/7 production of components at or close to the installation site. Concrete's inherent corrosion resistance, fatigue insensitive design, and scalability to larger sizes make it especially ideal for large offshore wind turbines. In land-based applications, concrete's extremely low cost, excellent suitability for on-site construction, and suitability for using tower-climbing cranes make concrete the best choice for ultra-tall towers as has been demonstrated in Germany.

The next generation of land-based turbines (such as the GE 5.3 MW Cypress turbine) produces approximately 50% more annual energy production compared to a conventional 3-MW class turbine. However, a 5-MW class turbine requires shipping blades and towers in sections, and on-site assembly to accommodate road and highway weight and size limits. On the new GE turbine, each 77-m long wind turbine blade can be transported in two pieces before assembly at the site, thereby effectively solving the blade transportation problems. However, the accompanying 160-m hybrid concrete tower must be shipped in approximately 30 concrete sections plus two or three longer steel sections for the top of the tower. In addition, conventional ultra-tall concrete towers, such as those installed in Germany over the past 10 years, require grinding every mating surface to a flatness less than 0.1 mm at the factory, trucking each piece separately to the installation site, and stacking with a very costly super-heavy lift crane. This expensive tower manufacturing and assembly approach has (and will for the foreseeable future) prevent cost-competitive installation of larger 5-MW class turbines in California.

Offshore wind turbines are even larger than land-based turbines because they can be manufactured in or near ports, and because larger turbines are needed to offset the more expensive capital and installation costs of offshore support structures. 10-MW offshore turbines are already commercially available today, and the next generations of offshore turbines are expected to reach 20 MW. However, conventional offshore wind plants rely on expensive, low production rate, steel foundation and substructure designs and manufacturing methods developed for the oil and gas industry. As an example, RCAM Technologies estimates that an offshore 10-MW fixed-bottom steel jacket substructure and foundation costs approximately $5 M per wind turbine. In Europe, the high cost of these steel structures, the required specialized construction expertise and facilities, and the ease of shipping finished structures over water has led to offshoring the manufacturing of the structures to foreign countries (such as in the Middle East) up to 10,000 km away by sea. Concrete provides a low cost manufacturing alternative to steel that can be manufactured locally using lower cost and readily available domestic materials, labor, and facilities. For example, unfinished steel costs about $1,000 per ton—200 times more than the cost of unfinished concrete (approximately $50 per ton). Even though concrete structures tend to be several times heavier, this substantial cost difference more than offsets the additional weight. In addition, the heavier weight of concrete structures encourages local production and sourcing. Furthermore, concrete materials are expected to be several times more durable, corrosion resistant, and insensitive to fatigue resulting in longer lifetimes.

With over 840 miles of coast line and 164,000 square miles of land area, California has some of the best offshore and land-based wind resources in the Country. In addition, it has a wealth of concrete industrial suppliers, concrete fabricators, and concrete researchers. However, because the wind industry has relied on the use of steel to manufacture previous generations of smaller land-based and offshore wind turbines, the wind industry has begun looking closely at using concrete for land-based and offshore turbines. However, substantial risks and uncertainties remain about using concrete for wind applications. Research funding from the CEC is needed for specific concrete R&D and demonstration projects to de-risk, develop, and commercialize next-generation land-based and offshore wind systems for California.

Specific investments needed for offshore wind include:

1. Development and demonstration of innovative offshore concrete foundation, substructure, and tower designs and manufacturing methods
2. Methods and materials for improving the corrosion resistance of concrete reinforcing materials
3. California port infrastructure, logistics, and economic development studies for offshore wind plants built with concrete components
4. An annual or semi-annual offshore wind foundation and substructure workshop (this does not exist yet in the U.S.)
5. An ocean testbed in which to evaluate the efficacy of sensing and monitoring strategies for site characterization, health monitoring, and performance assessment.

6. The ability to evaluate the extent of fatigue and other damage degradation (concrete cracking and degradation, corrosion, fouling, etc.), and to predict remaining lifespan of structures in the field. This is pertinent for both operational control and repowering decisions.
7. Significant experimental testing campaigns that produce the needed public data for advancing basic science, improving standards, advancing computational models, and driving innovation. California has been leaders in such campaigns for advancing seismic design and assessment practices, and a similar opportunity exists to be global leaders in wind energy because of the proprietary nature of data collected in international research campaigns. A few examples of needed research include concrete fatigue damage accumulation for uniaxial and biaxial states of stress; interface shear transfer across joints; effectiveness of fiber and textile reinforcements for controlling cracking and other damage; anchorage of reinforcements and post-tensioning; and the ability to produce concretes with predictable material stiffness characteristics.
8. Improved standards and computational modeling tools that are derived from both field performance data and laboratory test data.
9. Development of a state, national, and international technical community in wind energy and concrete. Such communities are very effective in other fields in which there are significant state and national investments and the need for finding the right balance between costs and resilience.
10. Research to characterize reinforcement corrosion in marine environment for new materials and construction methods (such as 3D concrete printing).
11. Research to explore alternative concrete materials (such as geopolymer concrete) that are potentially more corrosion resistant and have smaller CO_2 footprints.
12. Environmental studies to understand how whale and bird migration, fish habitat, and marine traffic are affected. How does offshore wind affect coastal communities?
13. Mapping of areas of highest residual grid capacity and most cost effective grid connection that could help guide where the most cost effective large-scale wind energy development could take place.

Specific investments needed for land-based wind include:

14. Improved characterization of the wind shears across California wind deployment sites to help quantify and verify the business case for taller towers and larger turbines in California
15. An “open-source” next generation large turbine reference model, concrete tower model, and logistics model performed for one or more potential California wind deployment sites
16. Large scale demonstration of an automated concrete tall tower manufacturing technology
17. An annual or semi-annual land-based wind tower and foundation workshop (this does not exist yet in the U.S.; it could be combined with the offshore wind foundation and substructure workshop described above)
18. Items described above for offshore wind are also pertinent for land-based wind

* Wiser, Ryan, Karen Jenni, Joachim Seel, Erin Baker, Maureen Hand, Eric Lantz, and Aaron Smith. “Expert Elicitation Survey on Future Wind Energy Costs.” *Nature Energy* 1, no. 10 (October 2016): 16135. https://doi.org/10.1038/nenergy.2016.135.