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Generations in the Progress of Wind Energy: Foreshadowing a Pathway for Airborne Technology

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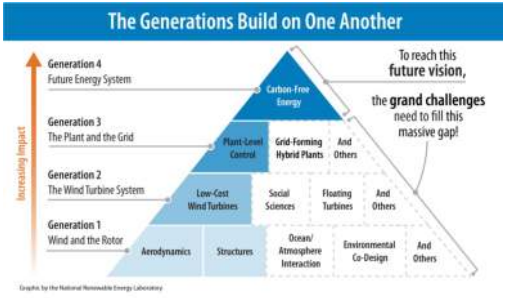
Traditional wind energy systems have progressed from stand-alone operations for off-grid and water pumping applications to a major source of global electricity supply over the last half century. An examination of this history could be informative for the future path of airborne wind systems. Figure 1 illustrates how achieving an increasing impact with wind energy requires an expanding base of scientific knowledge. While each generation's achievements increased wind energy's impact (shown in the blue blocks on the left side of the pyramid in the figure), some underlying science was left unresolved (shown in the white blocks on the right in Figure 1). In this work, Generation 1 delivered working energy conversion systems that can survive the most challenging operating conditions and focused on energy extraction with the rotor. The rotor also must be able to protect itself from extreme winds autonomously to enable continuous, unrestricted operation. Generation 2, the installation of large numbers of machines, requires low-cost and reliable wind turbines, and expanded the scope from aerodynamics to structural system optimization. Generation 3 is beginning to provide controllable wind plants that support the grid, requiring new capabilities in electrical and plant-flow controls. The aspirational goal of Generation 4 is a carbon-neutral future energy system, with deployments expanding into deep waters offshore and into low-resource sites on land that further expand the technical, social, and environmental demands. Wind energy can be the foundation for the fourth generation, but not until the gap left behind by the previous generations is addressed.

These generations will be required of airborne wind as well, but the sequencing may be somewhat different. For example, airborne wind uses less construction material (affecting system cost trade-offs) and the grid integration and support requirements are currently in flux. However, getting past Generation 1 remains crucial.



Generations in development leading up to wind as a foundation to a carbon-free energy system. Taken from [1].

References:

*[1] Veers, P., Dykes, K., Basu, S., Bianchini, A., Clifton, A., Green, P., Holttinen, H., Kitzing, L., Kosovic, B., Lundquist, J. K., Meyers, J., O'Malley, M., Shaw, W. J., and Straw, B.: Grand Challenges: Wind energy research needs for a global energy transition, Wind Energy Science, **7**(6), 2491–2496, 2022. doi:10.5194/wes-7-2491-2022*