Systems Engineering Applications to Wind Energy Research, Design, and Development

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Abstract

Over the last few decades, wind energy has evolved into a large international industry involving major players in the manufacturing, construction, and utility sectors. Coinciding with the industry's growth, significant innovation in the technology has resulted in larger turbines with lower associated costs of energy and more complex designs in all subsystems. However, as the deployment of the technology grows, and its role within the electricity sector becomes more prominent, so have the expectations of the technology in terms of performance, reliability, and cost. The industry currently partitions its efforts into separate paths for turbine design, plant design and development, grid interaction and operation, and mitigation of adverse community and environmental impacts. These activities must be integrated to meet a diverse set of goals while recognizing trade-offs between them.

To address these challenges, the National Renewable Energy Laboratory (NREL) has embarked on the Wind Energy Systems Engineering (WESE) initiative to use methods of systems engineering in the research, design, and development of wind energy systems. Systems engineering is a field that has a long history of application to complex technical systems. The work completed to date represents a first step in understanding this potential. It reviews systems engineering methods as applied to related technical systems and illustrates how these methods can be combined in a WESE framework to meet the research, design, and development needs for the future of the industry.

Systems Engineering & Wind

Wind energy is a complex system involving input from various stakeholders and designers from many disciplines. Figures 1, 2, and 3 illustrate a systems engineering perspective of the wind energy system.

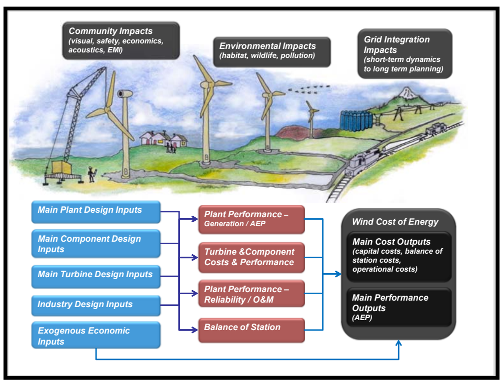


Illustration by Rick Hinrichs, PWT Communications

Figure 1: *Design of wind energy systems depends on many variables for components, turbines, and plants and these decisions all affect ultimate performance, cost, and community impacts.*

Figure 2: *The cartoon, based on an airplane cartoon by C. W. Miller, depicts what ideal turbines would be like if a single discipline dominated the design process.*

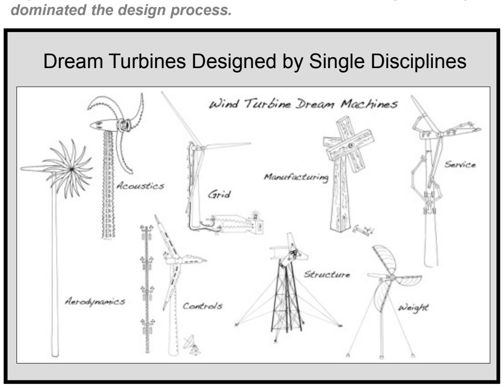


Illustration by Rick Hinrichs, PWT Communications

Figure 3: *Noise is used as an example to show how many different wind energy system design decisions are intertwined and have impacts both on system performance and cost as well as external system impacts (noise in this case).*

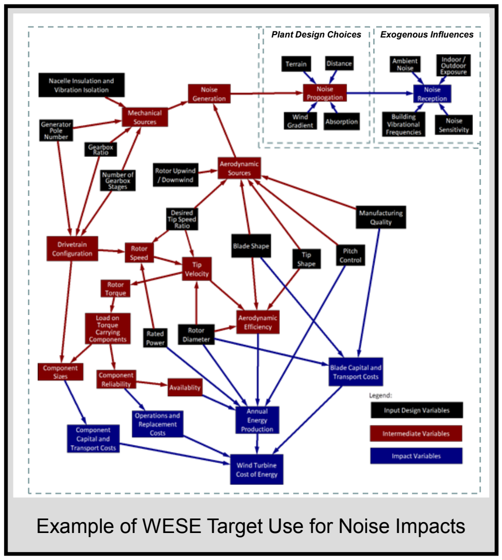


Illustration by Katherine Dykes, NREL

NREL WESE Tool

Shown below in Figure 4, the tool currently under development at NREL involves the coupling of engineering and cost analysis tools at all levels of the turbine – component to plant – to be able to perform system level analyses such as uncertainty quantification and optimization. Initially, models will be relatively simple, but ultimately, multiple levels of fidelity will be incorporated into the tool to support a variety of analyses. The overall tool involves the integration of NREL's and other wind energy models into an architectural framework for analysis based on NASA's Open Multiple Disciplinary Analysis & Optimization (OpenMDAO) software.

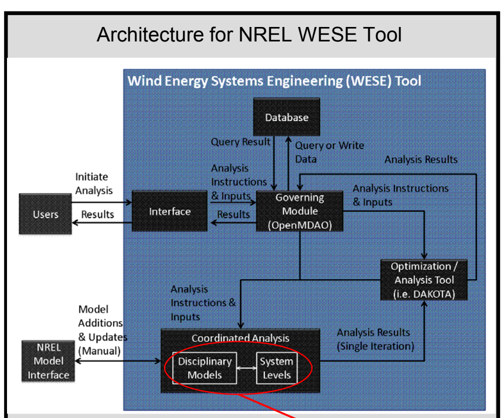


Figure 4: *The NREL systems engineering tool involves phased integration of engineering and cost models for wind energy within a governing architecture based on NASA's OpenMDAO and Sandia's DAKOTA software.*

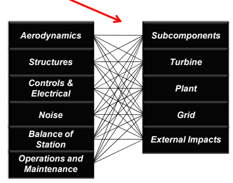


Illustration by Katherine Dykes, NREL

Figure 5: *The initial tool development is based on the integration of wind plant cost models, and engineering-based wind turbine component cost and sizing models, into a system LCOE analysis framework.*

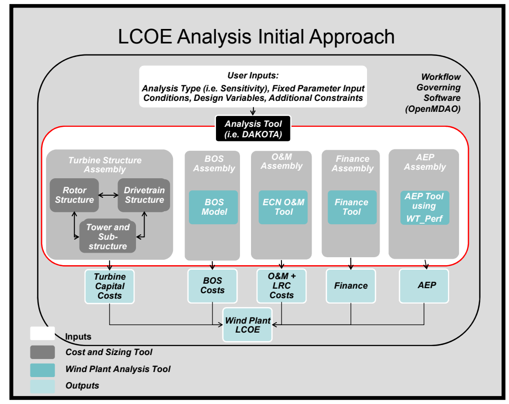
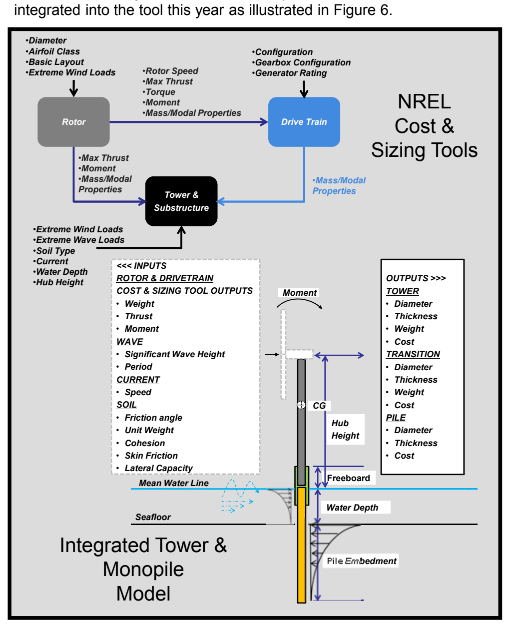


Illustration by Katherine Dykes, NREL

In each phase of tool development, a critical objective is to have a full system representation for levelized cost of energy (LCOE) analysis. In the first year, as illustrated in Figure 5, this entails the use of relatively simple models for each factor that contributes to LCOE. Subsequent development will build upon the foundation with increasing levels of model fidelity. Analysis objectives for the first year include demonstration of the tool for sensitivity analysis on key global design parameters that impact LCOE.

Support Tool Development

Various supporting models are currently under development and will be integrated into the tool this year as illustrated in Figure 6.



Top Illustration of Figure 6 by Rebecca Meadows, NREL;
Bottom Illustration of Figure 6 by Senu Sirnivas, NREL

Figure 6: *In the first year, simplified models are being developed for sizing and costs of a turbine based on extreme loads. The models provide coupling across the entire turbine design. An example is provided in the lower part of the graphic for the tower and monopile. Later, development of the tool will involve integration of higher fidelity models for the turbine structure, including use of NREL's FAST aeroelastic design code suite.*

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