Grand Challenges in the Science of Wind Energy

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And many others

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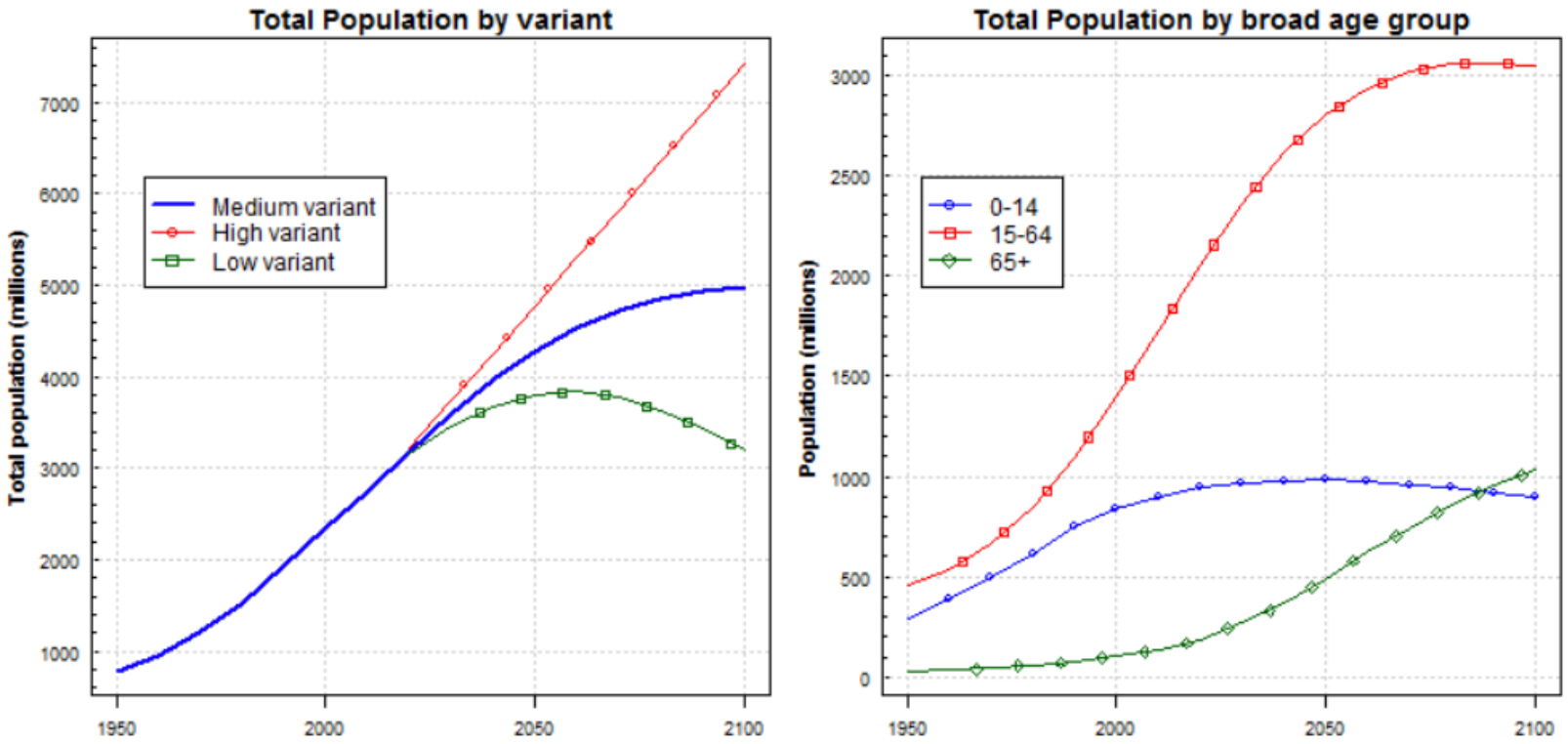
Trondheim, Norway

Overview

1. Global Trends and Energy Use
2. Changing Paradigms and Needs for Wind Energy
3. Grand Challenges in the Science of Wind Energy
4. Expertise to Achieve Success

Global population is expected to reach 9.8 billion by 2050, up from about 7.6 billion in 2017

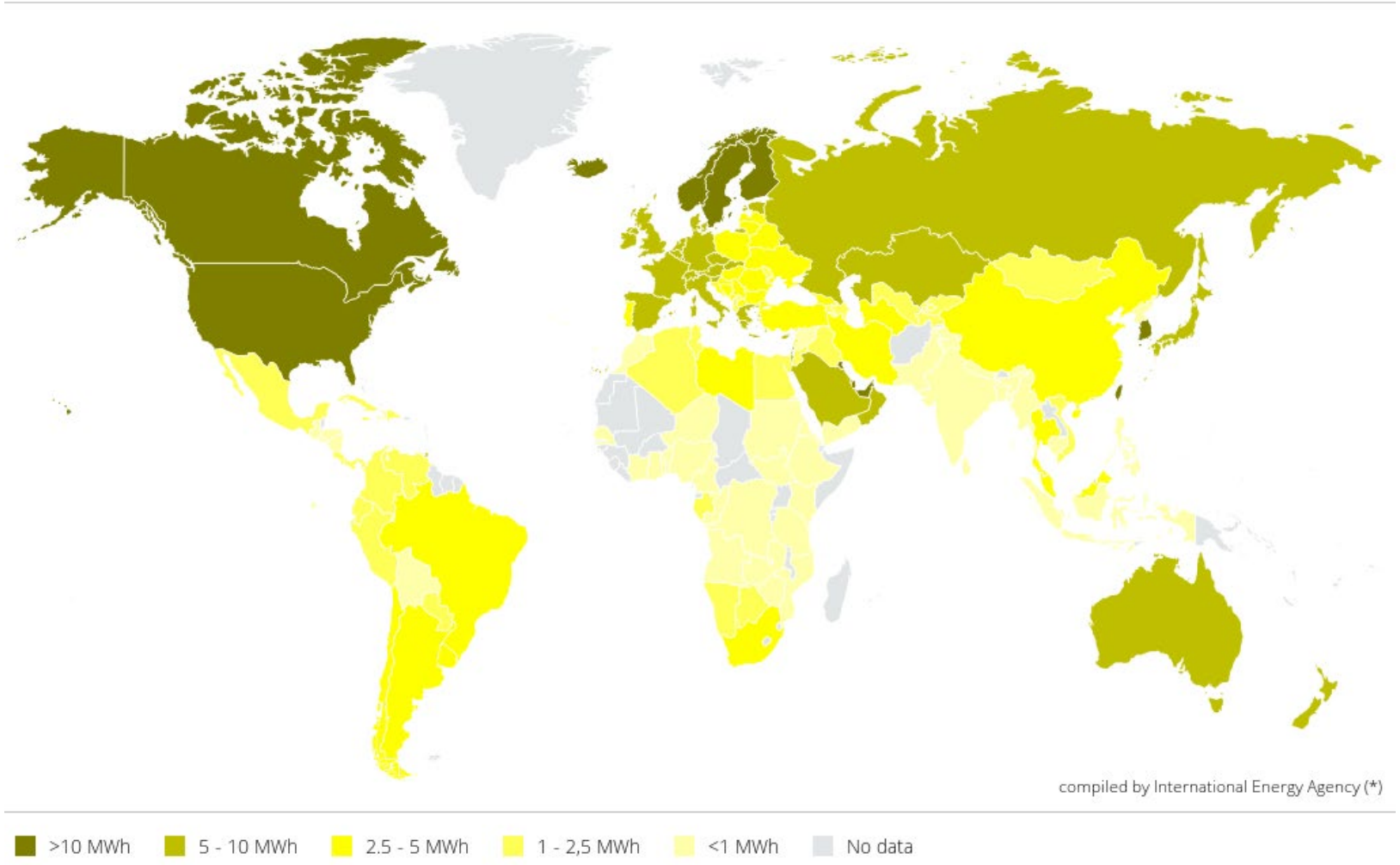
Population Trends: Lower Middle Income Countries



Source: UN World Population Prospects 2017

Increasing access to electricity coupled with growing population could support increased demand for clean electricity as the developing world strives for a higher standard of living

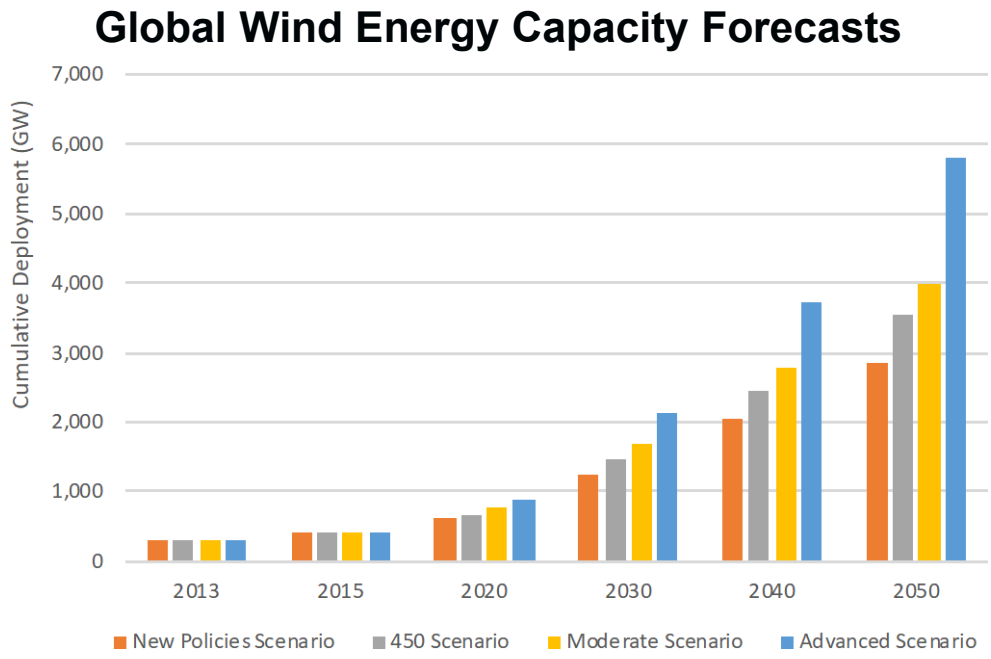
Electricity Consumption (MWh/capita, 2016)



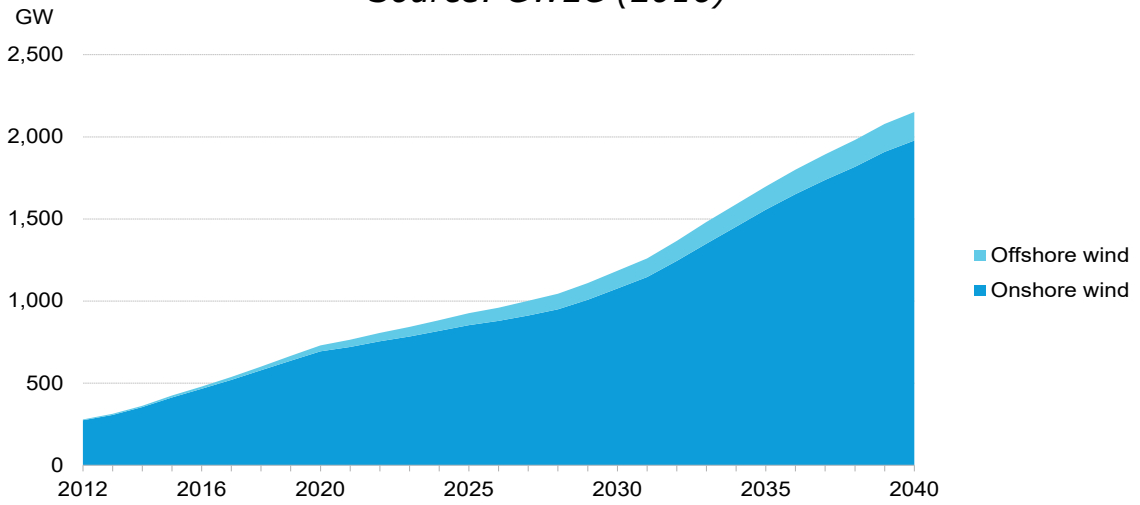
Source: International Energy Agency, Atlas of Energy

Global wind penetration is estimated at approximately 5%

Projections suggest global wind capacity could increase from about 0.6 TW today to between 2 TW and 6 TW by 2050



Source: GWEC (2016)



Source: Bloomberg New Energy Finance (2017)

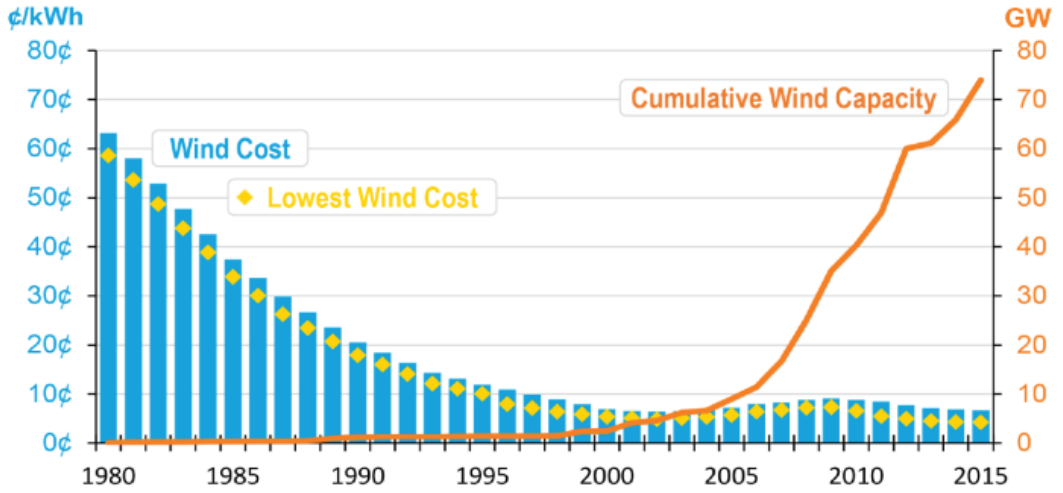
What will it take to achieve 50% or more of the global electricity supply?

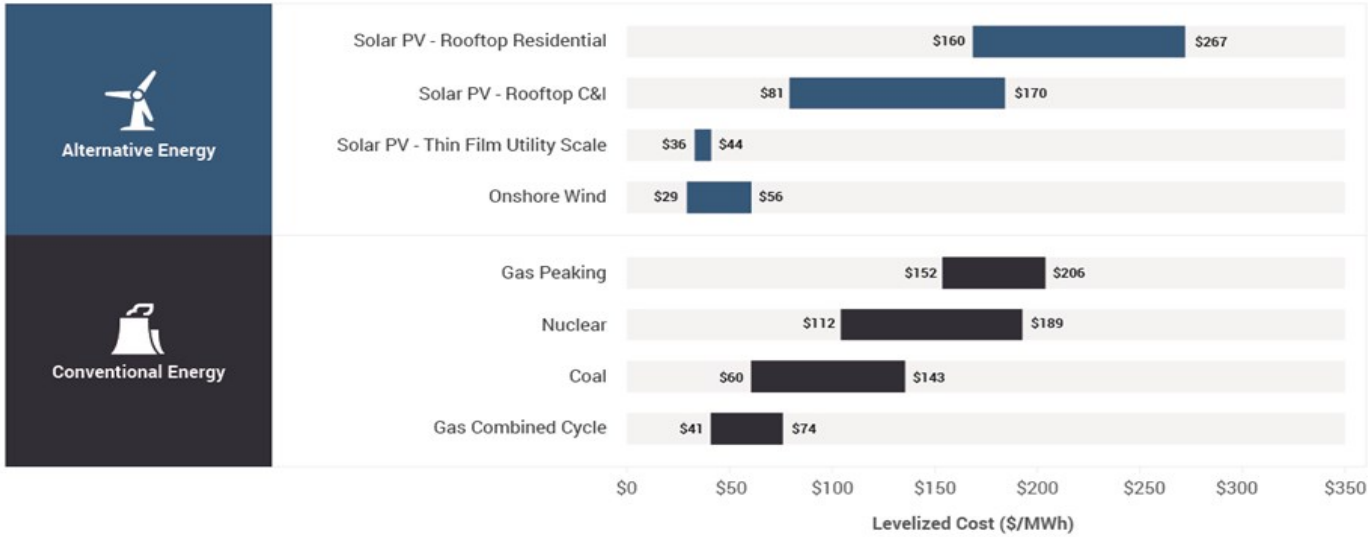
IEA Wind TCP Topical Experts Meeting #89: A Grand Vision for Wind Energy

- **Purpose:** Explore the question of how to enable a future in which wind energy achieves its full potential as global energy resource
- **Participants:** Over 70 experts representing 15 different countries
- **Outcomes:** *Grand Challenges of Wind Energy Science*

To Realize the Potential of the Resource, Costs Will Need to Continue to Fall

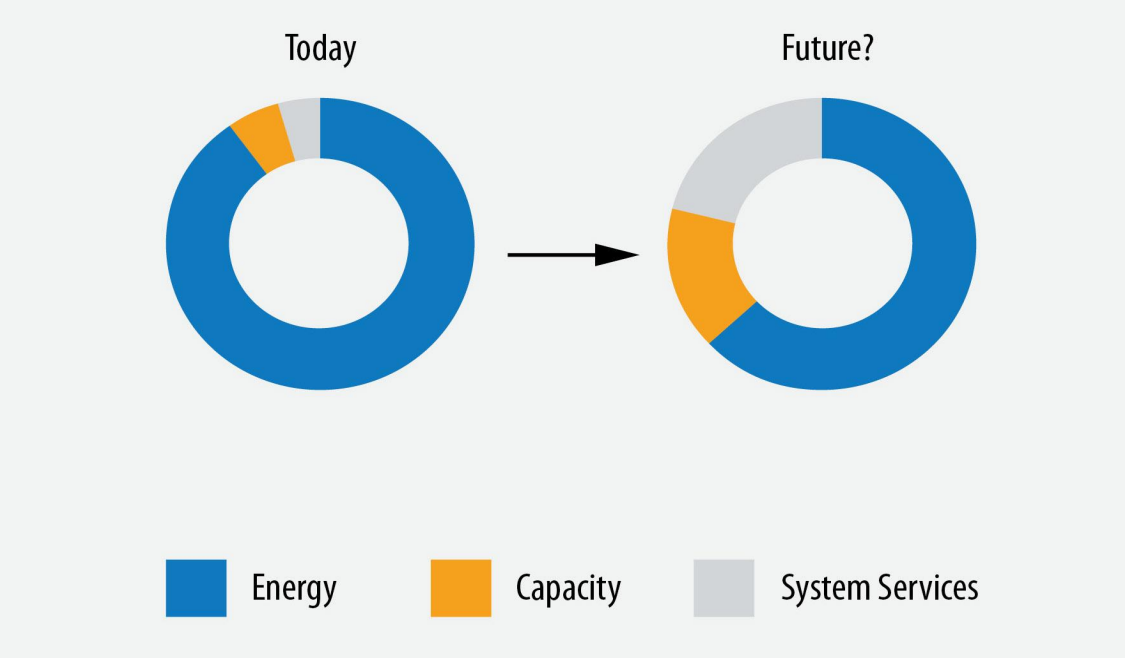
- Wind energy competitive in many places globally
- Costs of other technology (especially solar) also still falling





A Grand Vision for Renewables

- IEA Wind Grand Vision for Wind Energy explores a future scenario of 80% of the world electricity supply coming from renewables – a paradigm shift in system architecture, technologies and markets



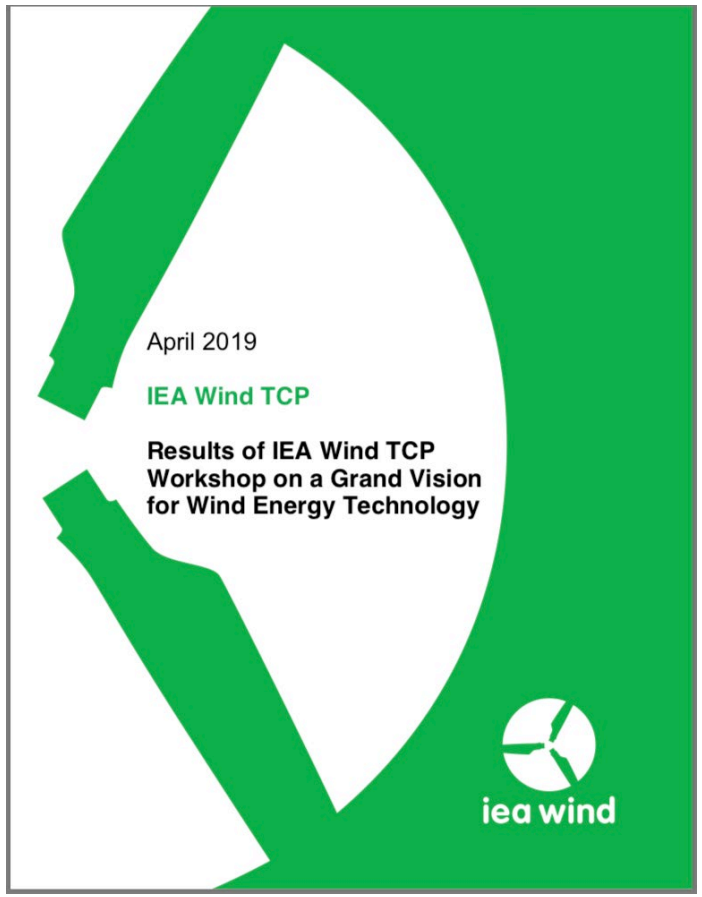
Future electricity system market structure (Source: Dykes et al 2019 based on Ahlstrom et al 2015)

Options for wind energy in a changing environment

- Success of wind energy in the future:
  - –If storage, power-to-x ubiquitous, highly elastic demand, then do nothing, focus on cheap electrons (**LCOE**)
  - –If dispatchability, capacity value dominate revenue, then rethink options and increase value of wind energy (**Beyond LCOE**)

Realizing the future Grand Vision for Wind Energy

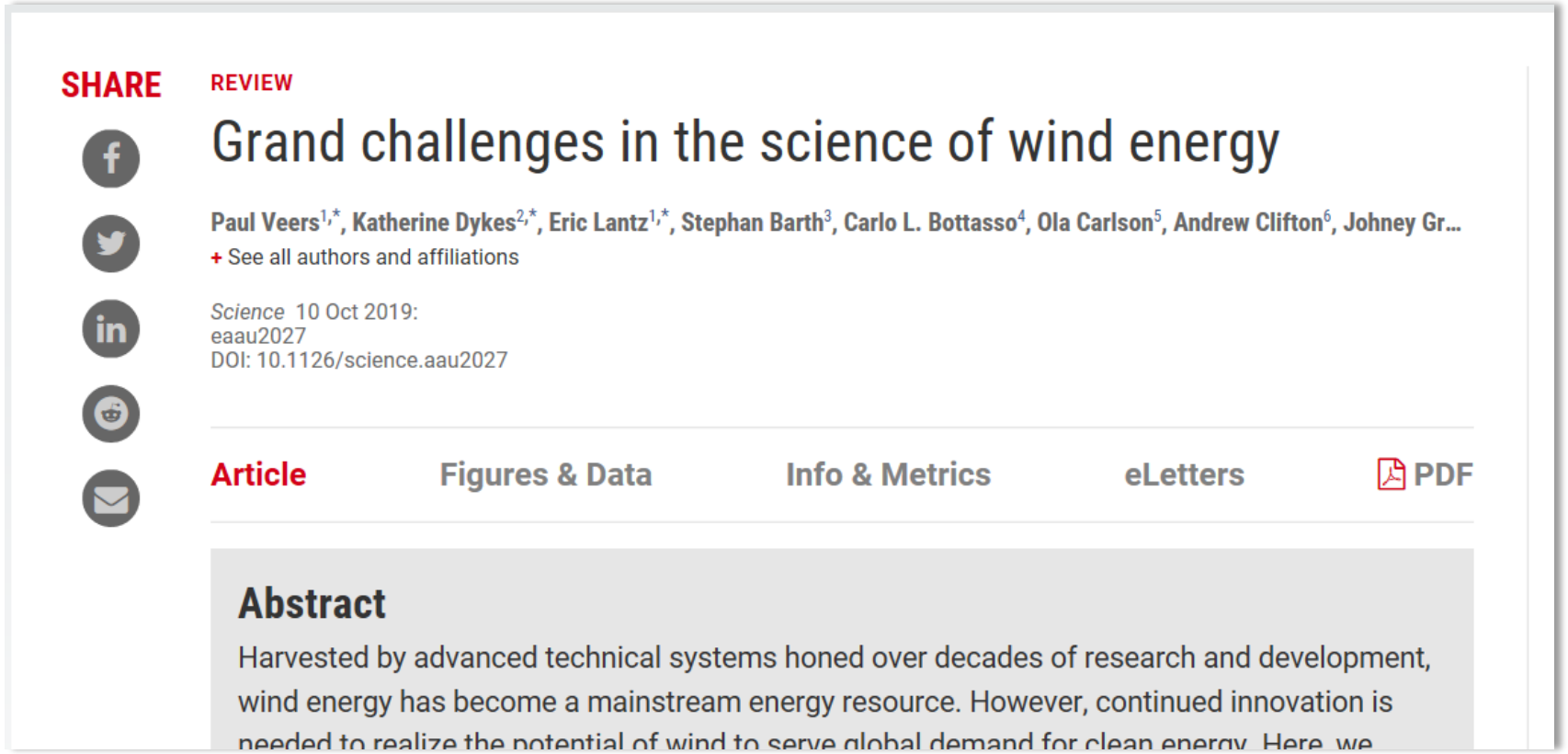
Research	Innovation	System Improvement
Research	Innovation	Reduce LCOE
Research	Innovation	Increase Value



The grand challenges in wind energy science and engineering to enable the wind-based future energy system

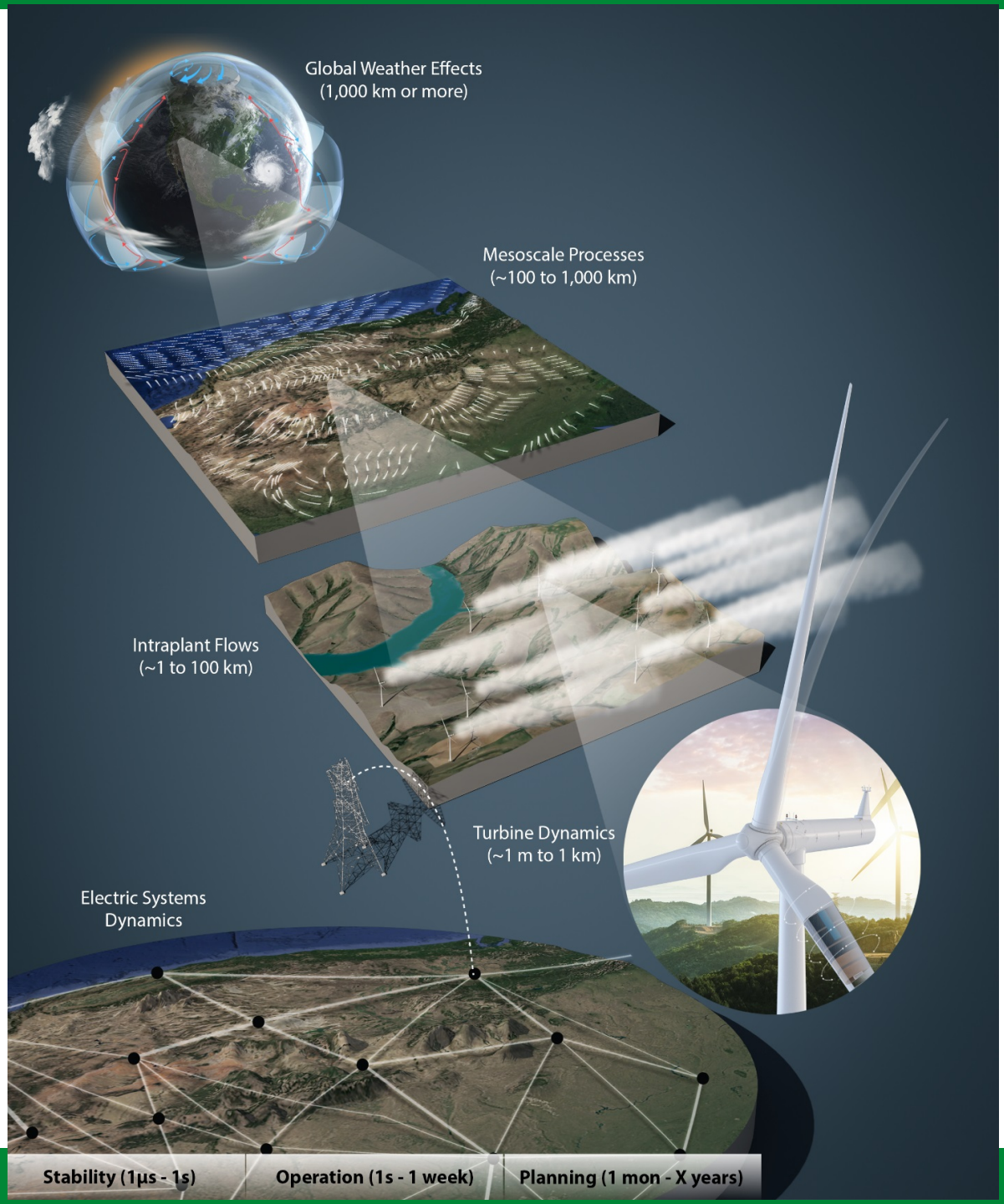
Realizing and Passing 6 TW Will Require New Fundamental Knowledge and Integration of Ideas across Several Domains

- The Grand Challenges of Wind Energy Science include:
  - The **physics of atmospheric flow**, especially in the critical zone of wind power plant operation
  - The **system dynamics and materials** of the largest, most flexible machines that have yet to be built
  - **Optimization and control of fleets of wind plants** made up of hundreds of individual generators working **to support the electric grid**

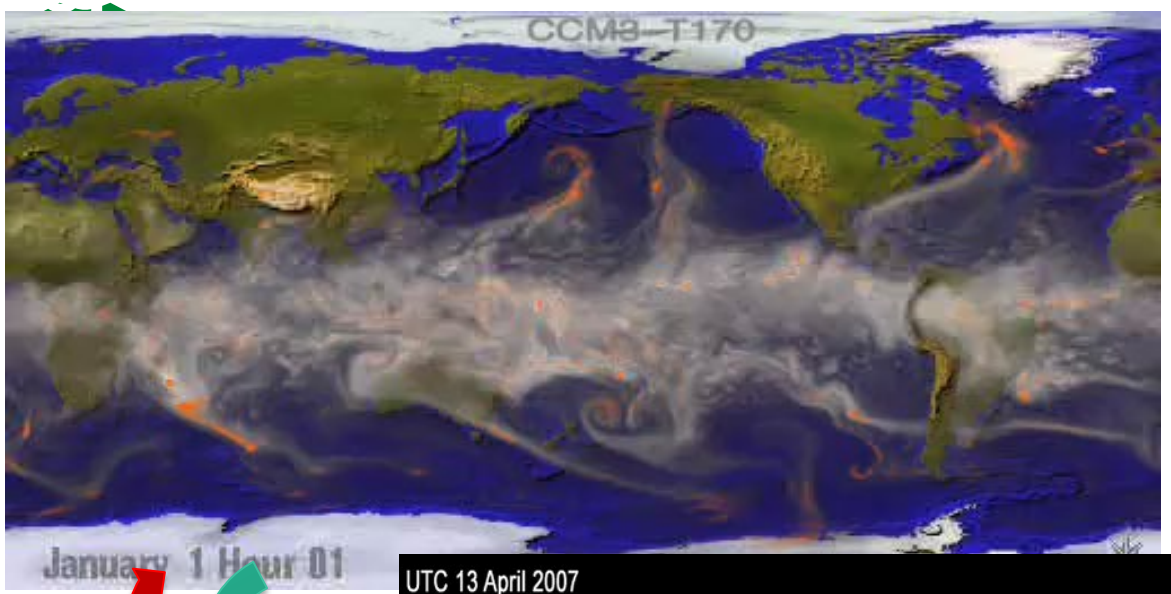


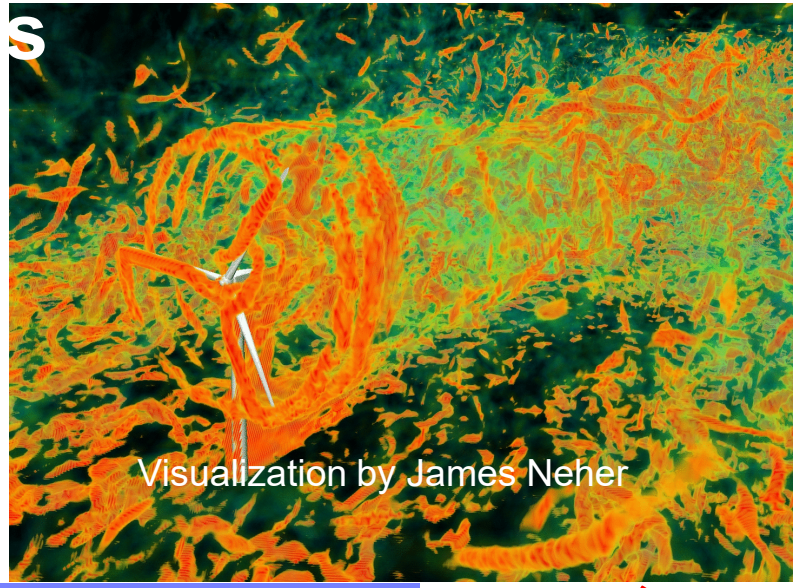
https://science.sciencemag.org/content/early/2019/10/09/science.aau2027

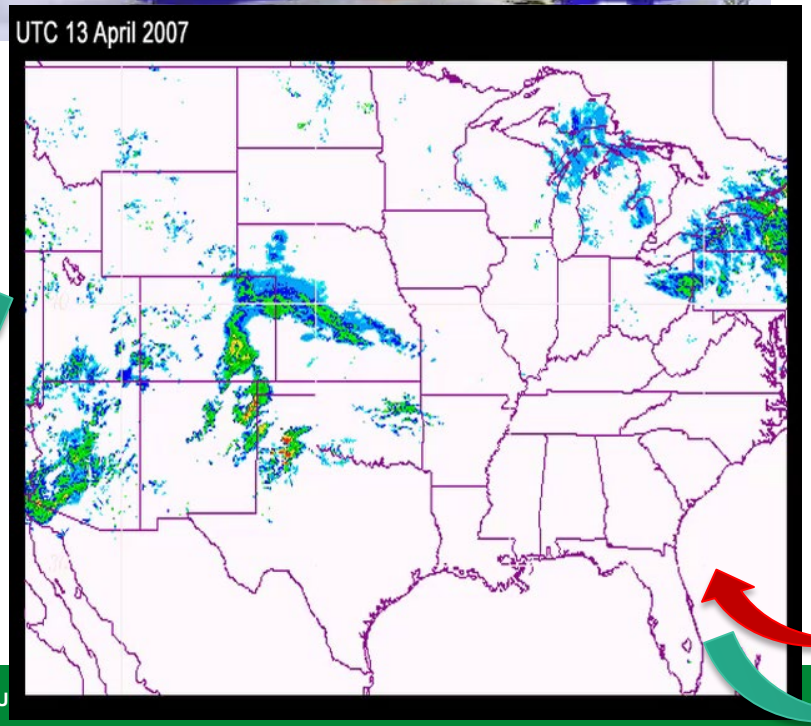
The Grand Challenges extend from the global weather system to the minutiae of materials science to sub-second power system stability



Source: NREL



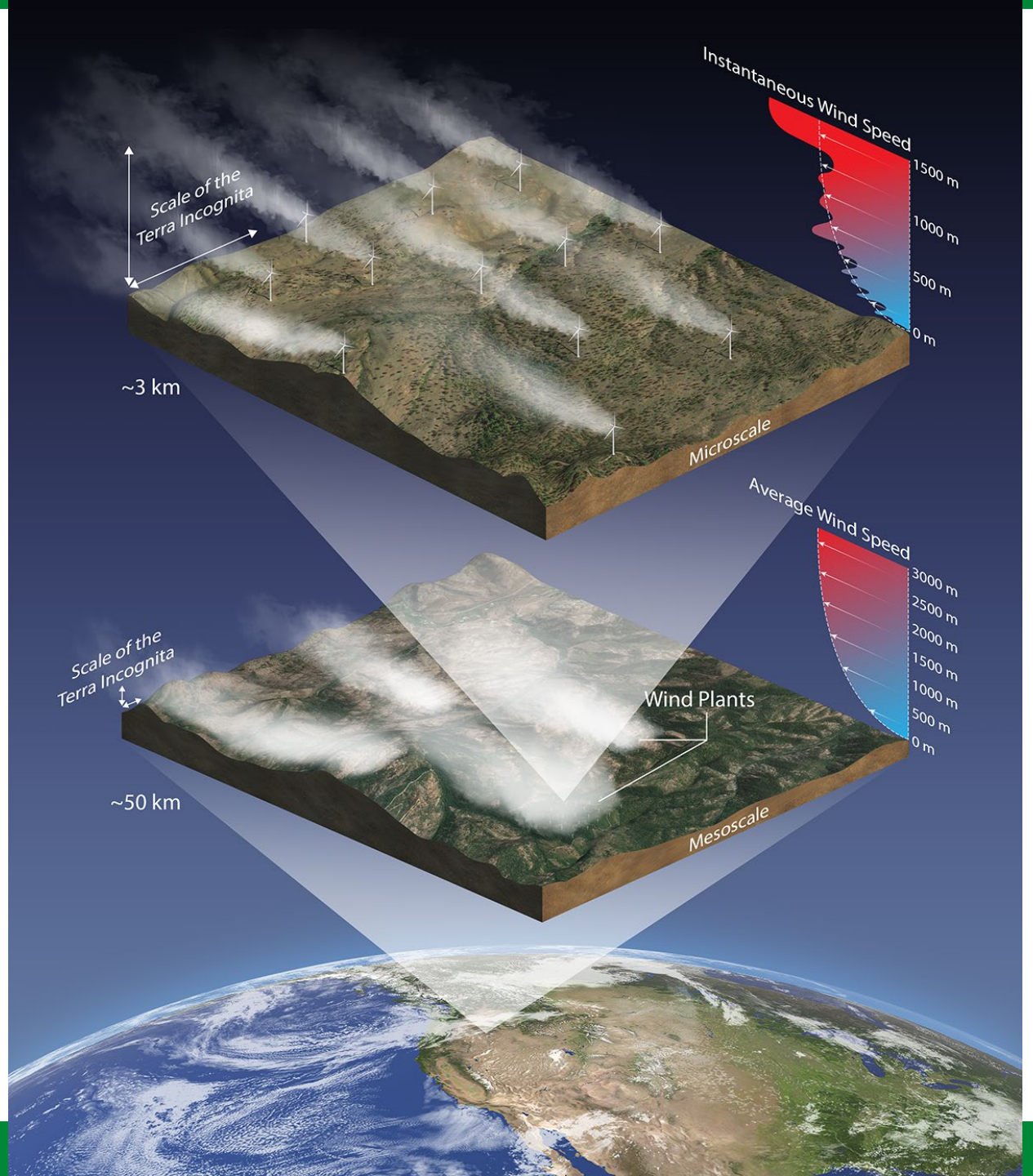




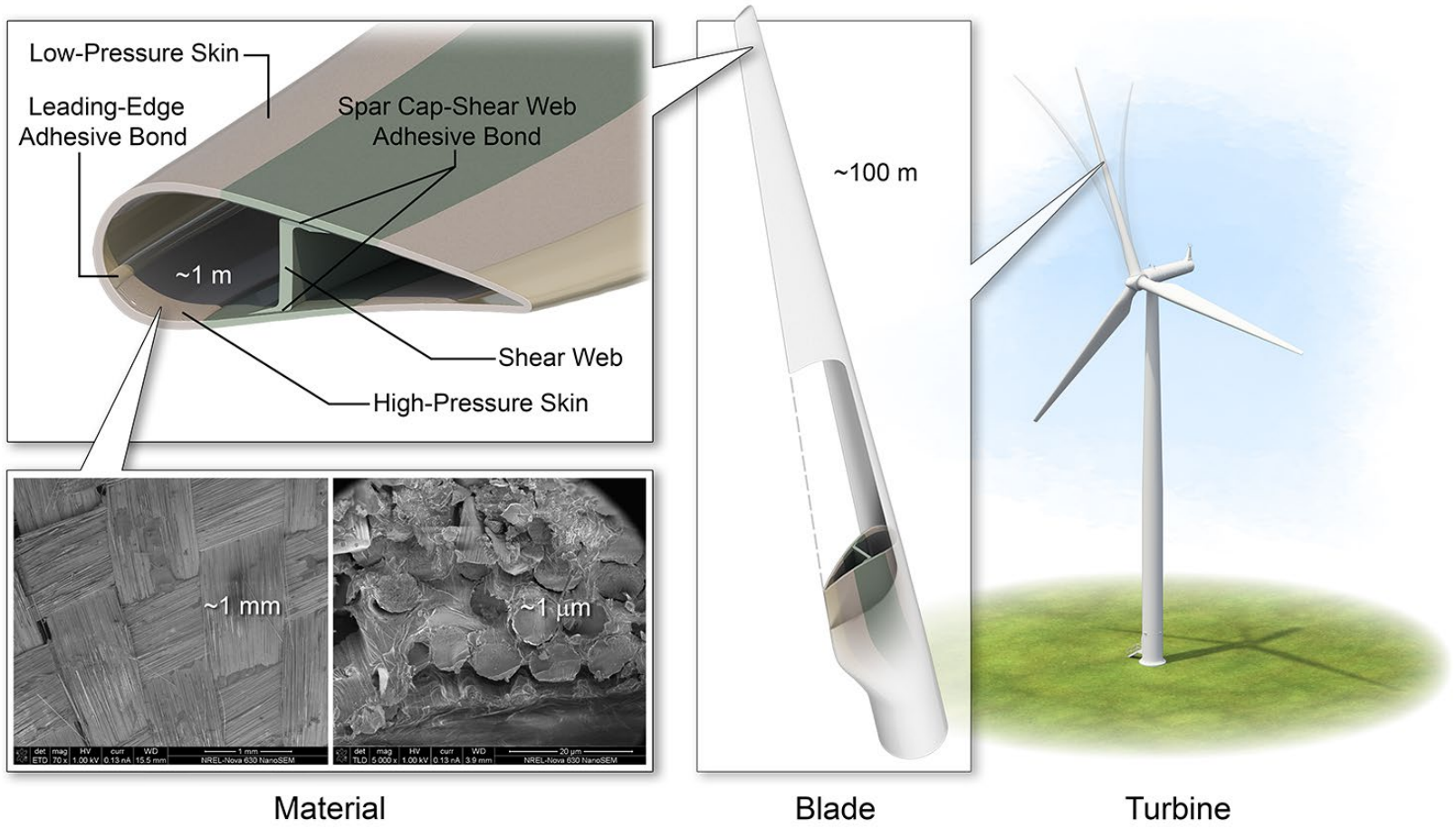
Courtesy Sue Haupt of NCAR and colleagues

Courtesy Jeff Mirocha, LLNL

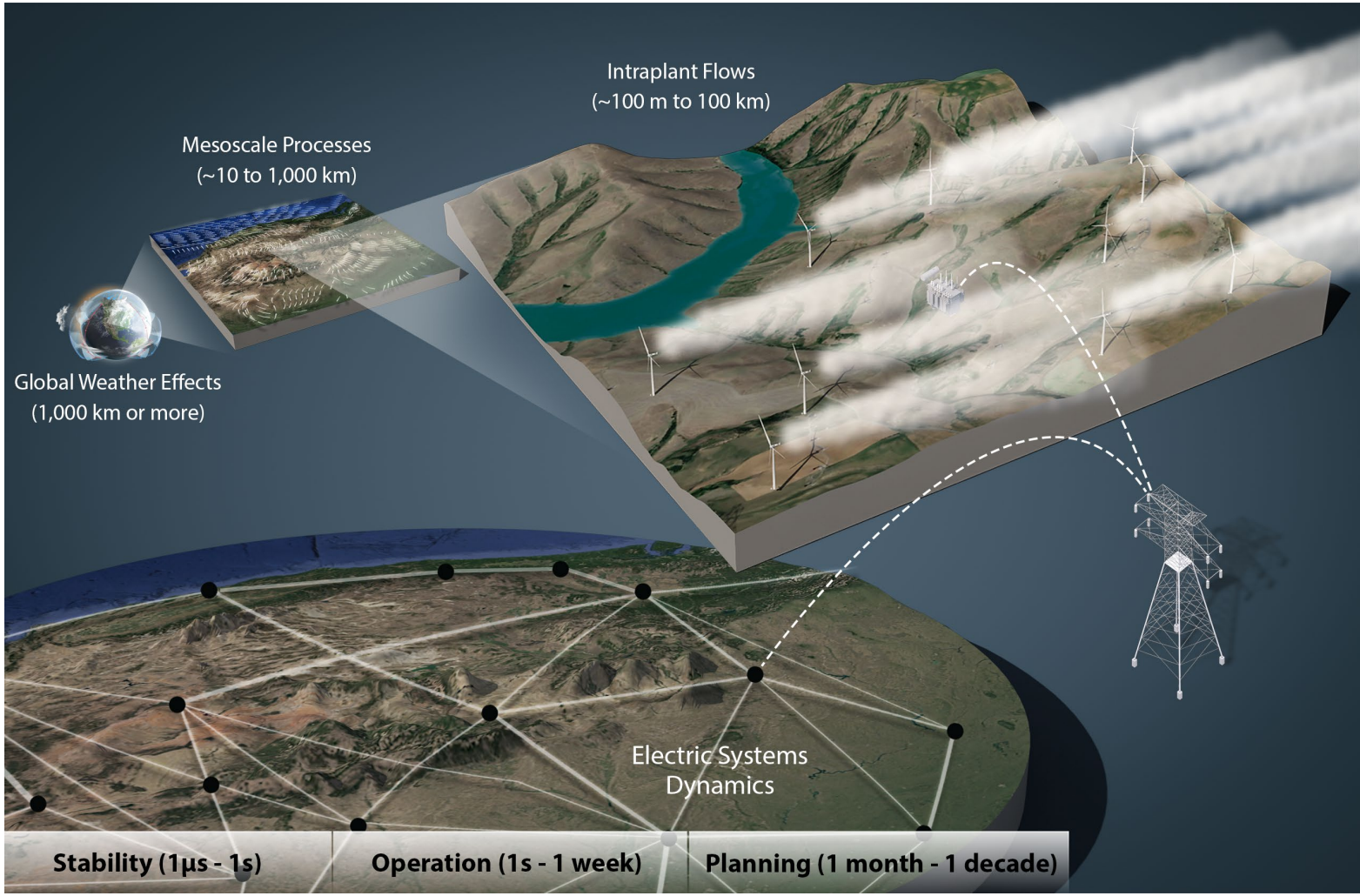
Grand Challenge #1: Mastering the physics of resource from the atmosphere to the intra-plant flows



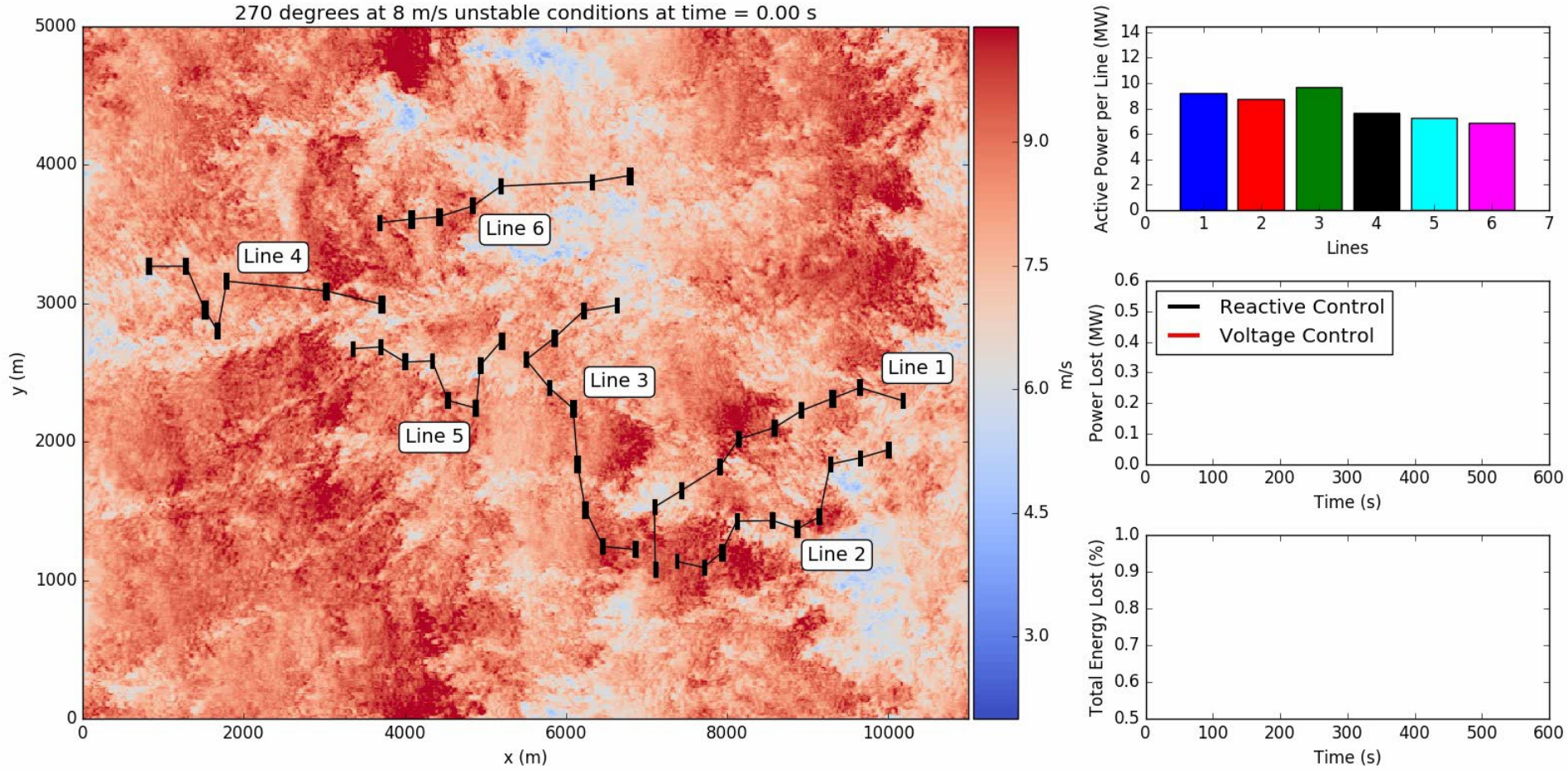
Grand Challenge #2:
Characterizing the structural, aero and hydrodynamics of some of the largest standing structures ever built coupled with access to the most advanced material properties at commodity prices



Grand Challenge #3: Systems science and control of wind power plants to orchestrate wind turbine, plant, and grid formation operations to provide low cost energy, stability, resiliency, reliability and affordability in the future power system



Wind Plant Hardware in the Loop



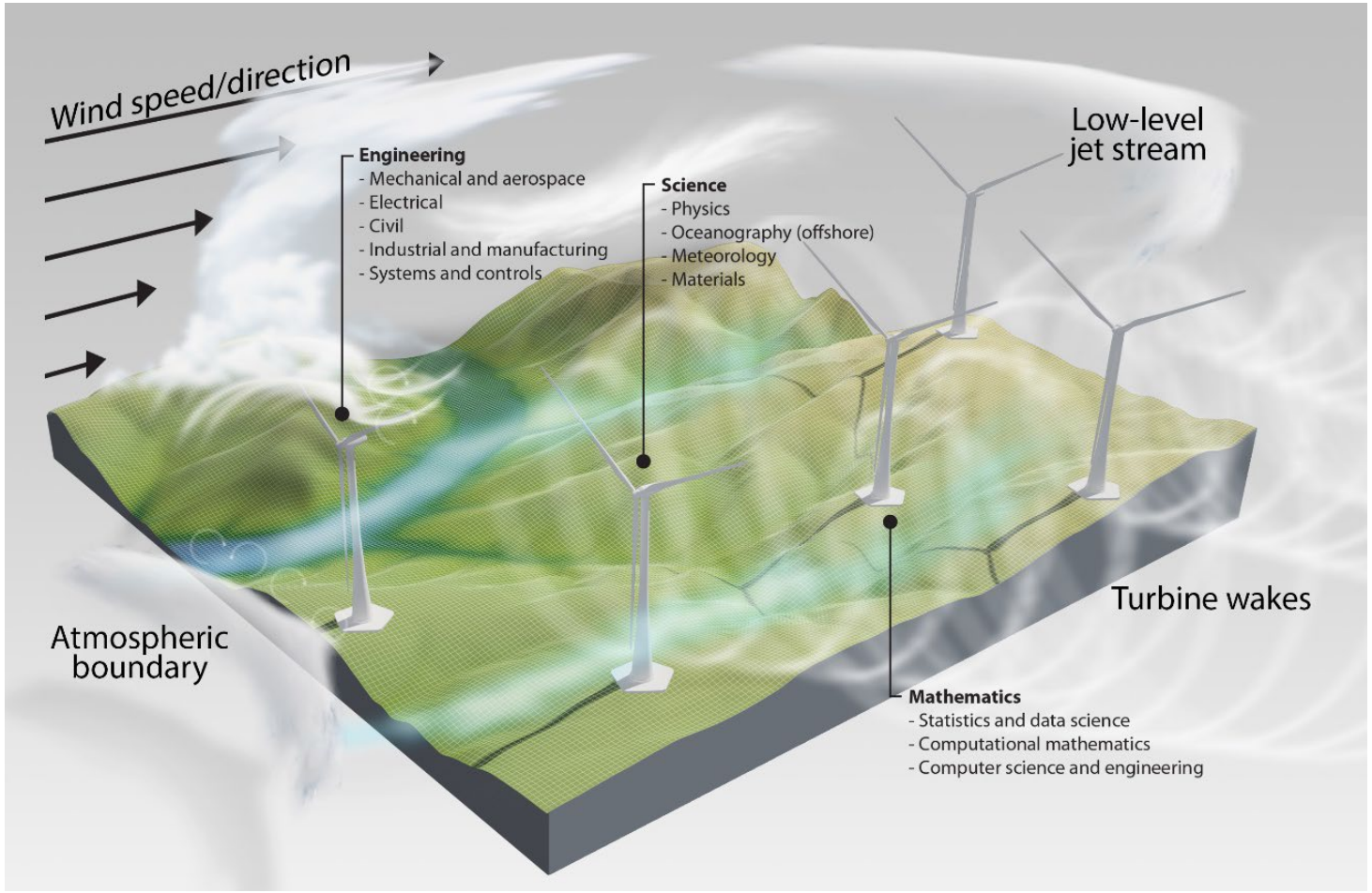
Courtesy Patrick Moriarty, NREL

Optimal electrical control depends on atmospheric conditions and grid

The wind energy research and technology pathway forward

Closing

- There remains a **great deal of work to drive Wind Power** to its full potential
- Much of the need is in **fundamental knowledge that can catalyze subsequent innovations** in the public and private sectors
- Both **industry and the research community need talented minds** to apply themselves to the problems of wind power
- **Inter-disciplinary training and groups as well as concentrated discipline focused expertise are expected to be essential** to future success



Thank You