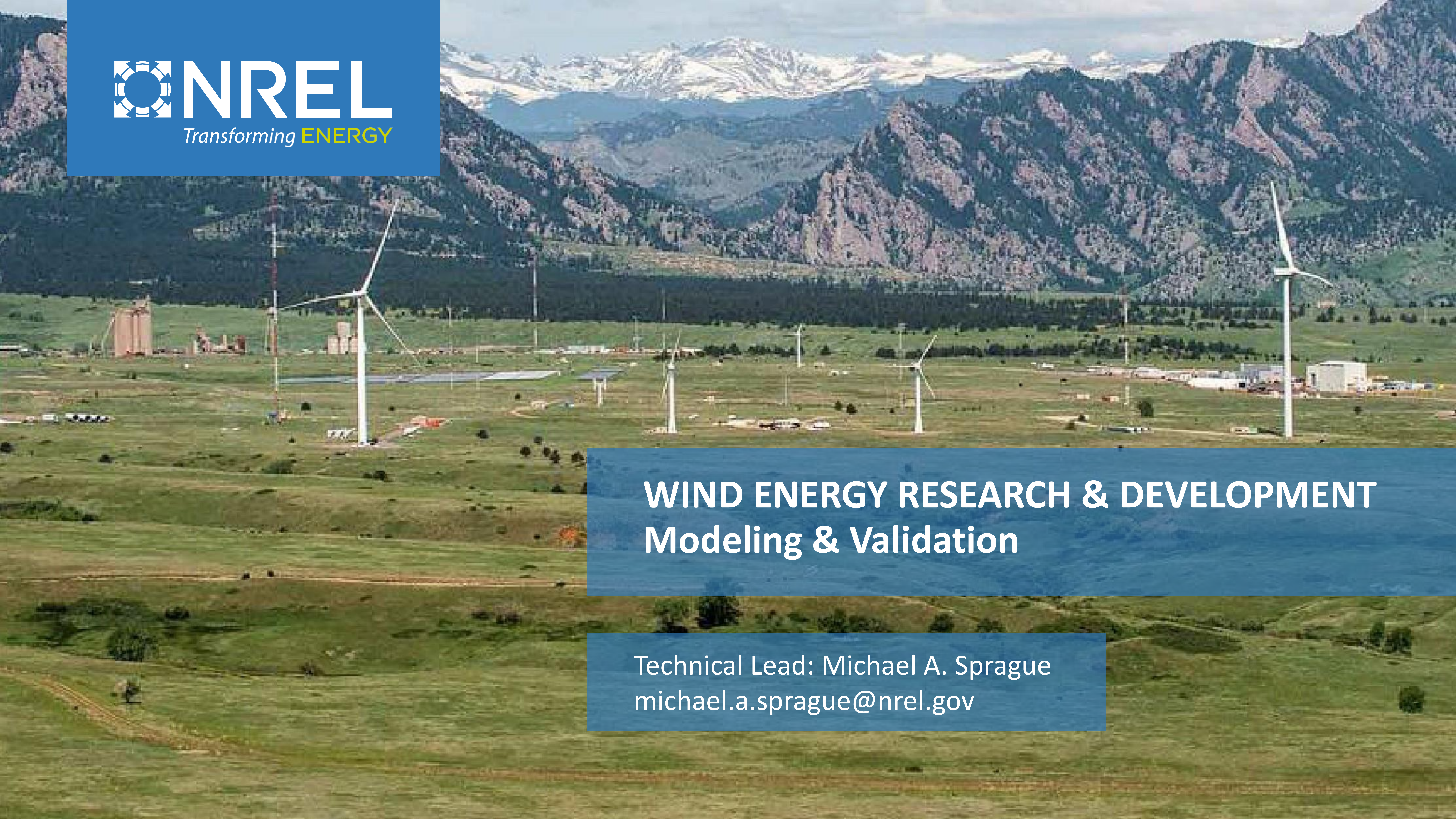

NREL
Transforming ENERGY

WIND ENERGY RESEARCH & DEVELOPMENT
Modeling & Validation

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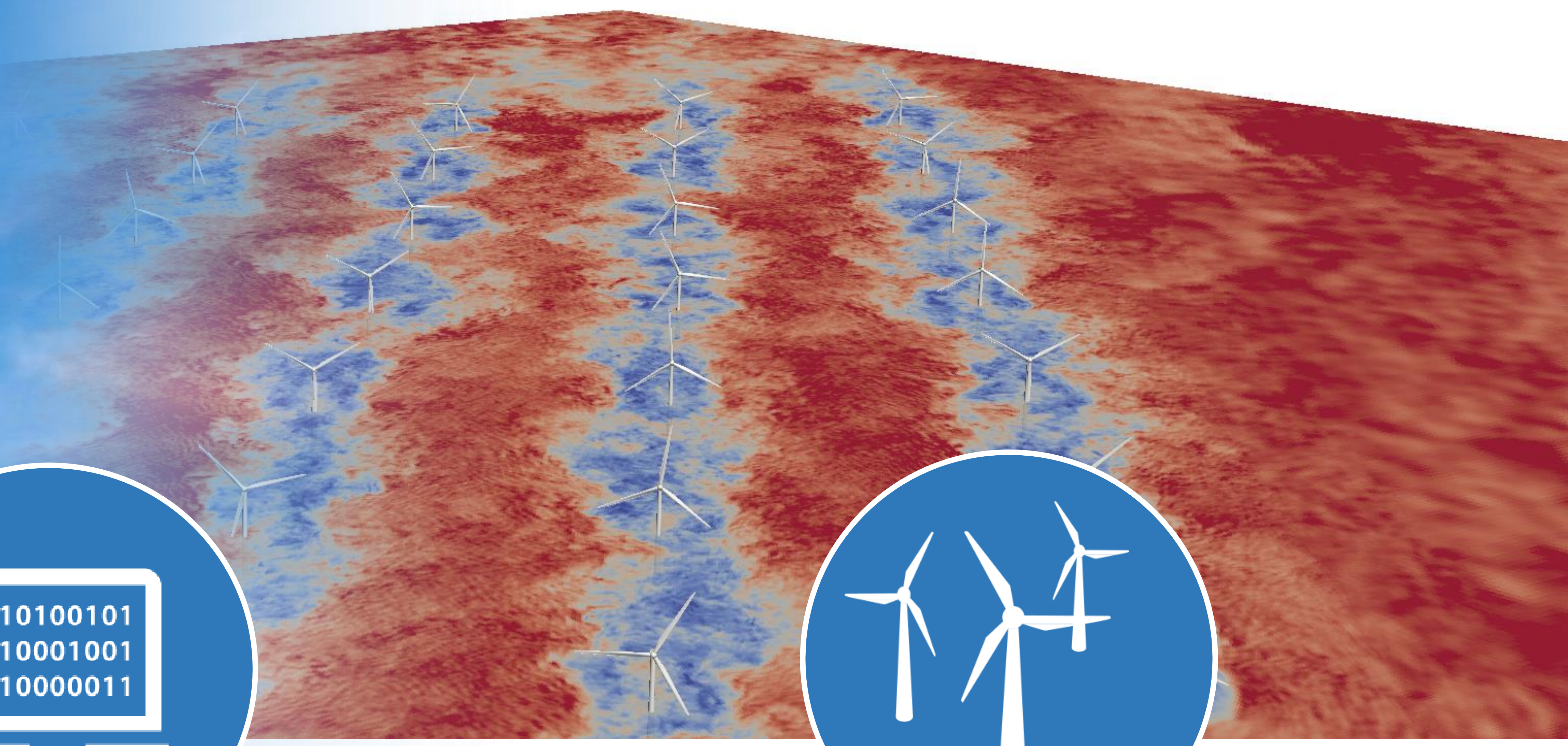
Modeling & Validation

Advancing wind plant technology development by creating open-source modeling tools and high-performance computing codes that simulate the behavior of wind power technologies in complex environments and create a deeper understanding of complex flow physics and turbine dynamics.



High-Fidelity Modeling and Validation

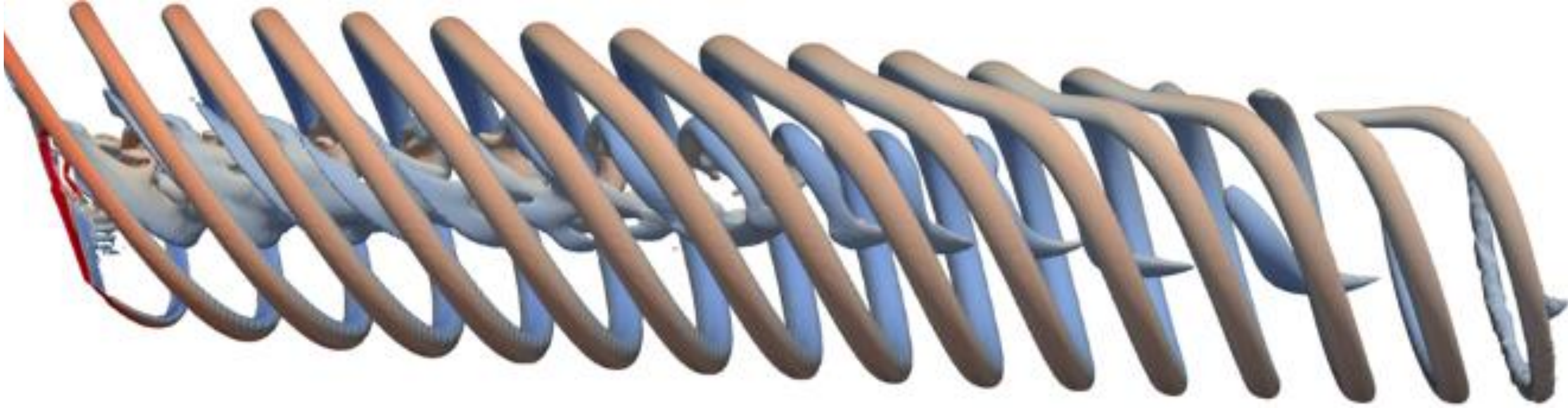
Creating a new suite of models and high-performance computing codes to predict and understand complex flow and turbine dynamics

Engineering Modeling and Validation

Improving, validating, and applying physics-based engineering models and design tools to advance wind plant technology

Systems Engineering Design and Optimization

Developing an analysis platform to leverage NREL's research capabilities toward integrating wind energy engineering and cost models across wind plants



Nalu-Wind simulation of the NREL Phase VI turbine under yawed conditions. Simulation performed on NREL's Eagle supercomputer.

High-Fidelity Modeling & Validation

- NREL develops open-source, high- and mid-fidelity predictive modeling and simulation capabilities for wind turbines.
- Using our high-performance-computing capabilities, NREL's simulations are designed to create a deeper understanding of complex flow physics and turbine dynamics.

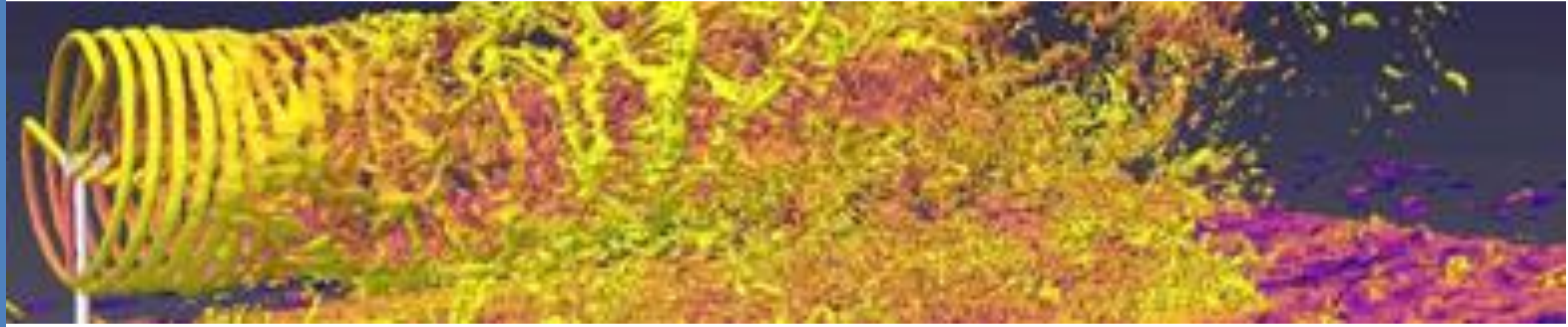
Areas of Expertise

- High- and mid-fidelity modeling of fluids and structures
- High-performance computing
- Validation, predictive modeling, and simulation
- Software engineering for open-source community codes.

Current Projects

High-Fidelity Modeling

HIGH-FIDELITY MODELING AND VALIDATION



CHALLENGE

Existing models cannot predict the complex fluid and turbine dynamics in modern wind power plants, which include floating platforms for offshore wind, complex terrain for land-based wind, and large flexible rotors.

APPROACH

In collaboration with the ExaWind project, NREL and its partners are creating a new suite of open-source, high-fidelity models that predict wind power plant dynamics and are backed by rigorous verification and validation.

IMPACT

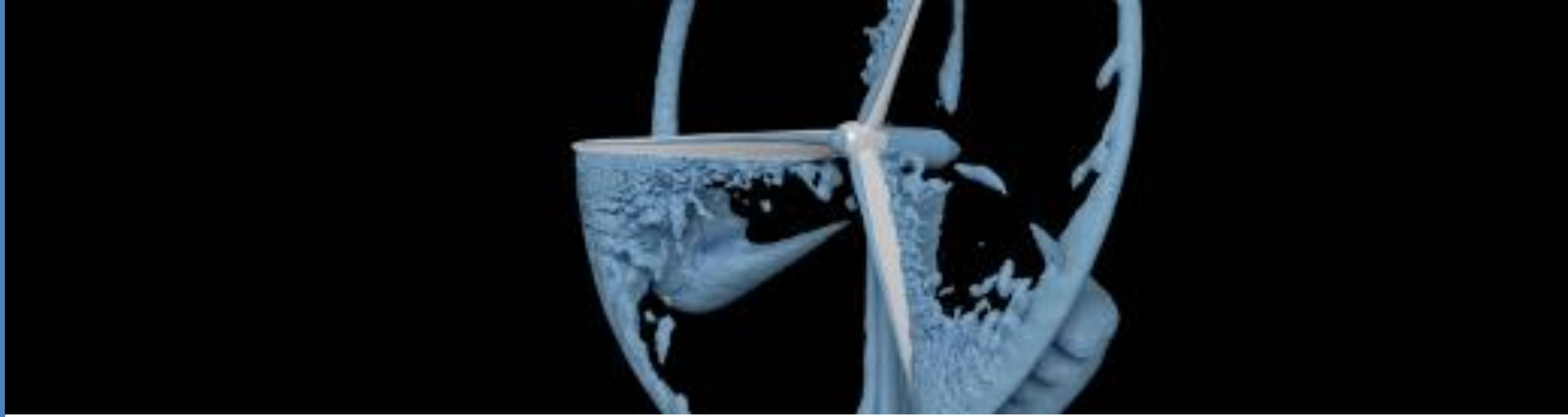
Predictive high-fidelity simulation enables the United States to make radical leaps in its ability to:

- Understand and resolve wind plant dynamics in atmospheric flow
- Explore disruptive technology innovations
- Perform final-design checks
- Calibrate, validate, and improve lower-fidelity models.

Current Projects

Exascale Computing Project: ExaWind

HIGH-FIDELITY MODELING AND VALIDATION



CHALLENGE

High-performance computing (HPC) is changing rapidly, with new supercomputers being centered on graphical processing units (GPUs) for speed. However, codes that run well on traditional CPU-based HPC need major overhauls in algorithms and software to utilize GPUs.

APPROACH

In collaboration with the High-Fidelity Modeling project, NREL and its partners are creating open-source codes with excellent computation-performance portability, with an emphasis on next-generation supercomputers accelerated by GPUs.

IMPACT

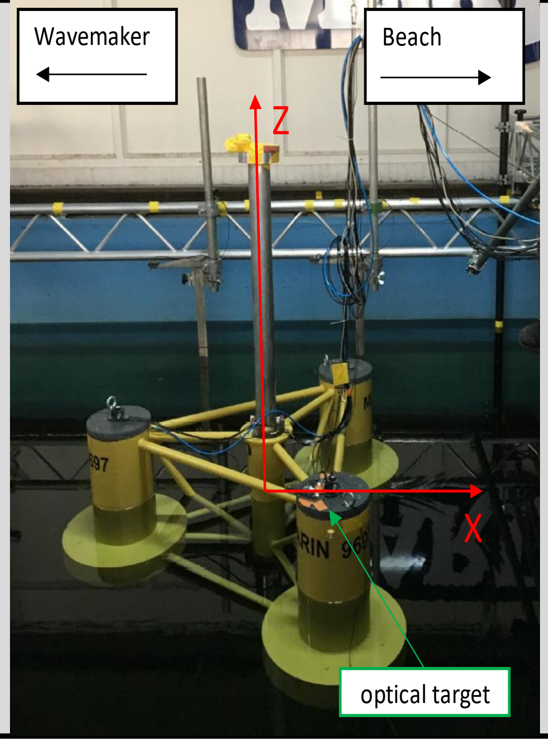
ExaWind ensures that needed wind simulations will be eligible to leverage modern supercomputers, especially DOE leadership-class supercomputers and the first exascale-class supercomputers.

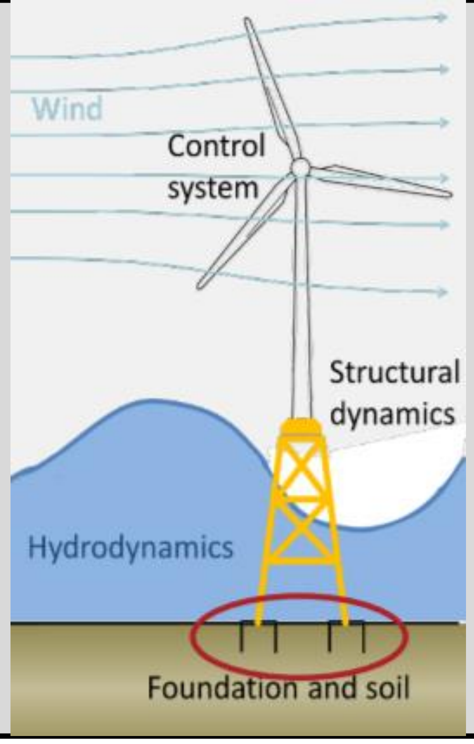
Engineering Modeling and Validation

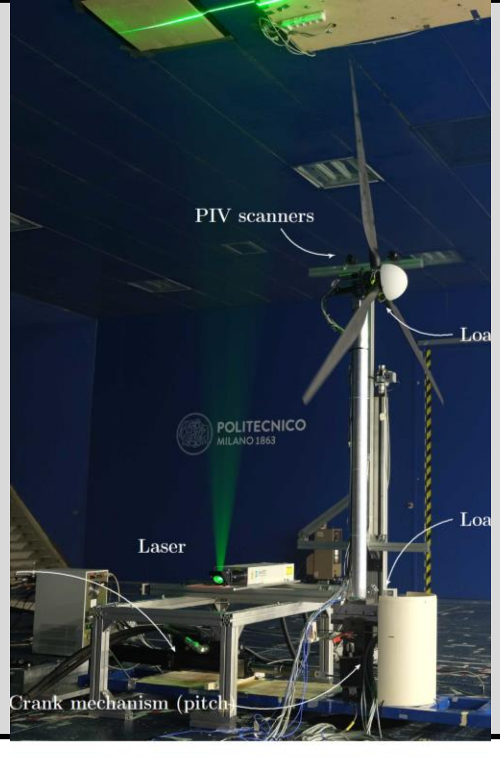
- NREL enables the development of advanced wind plant technologies by leveraging knowledge and data to improve physics-based engineering design competence and tools.
- NREL works collaboratively with the wind energy community to develop, validate, and apply engineering tools at the wind turbine, offshore support structure, and full wind plant levels.

Areas of Expertise

- Develop, verify, and validate physics-based engineering tools
- Loads analyses
- Identify design-driving conditions.







Current Projects

Offshore Code Comparison Collaboration, Continuation, with Correlation, and unCertainty (OC6) Project

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ENGINEERING MODELING AND VALIDATION

CHALLENGE

To ensure the reliability and cost-effectiveness of offshore wind systems, offshore design codes that consider the coupling between aerodynamic and hydrodynamic loading need to be validated for a variety of designs and conditions.

APPROACH

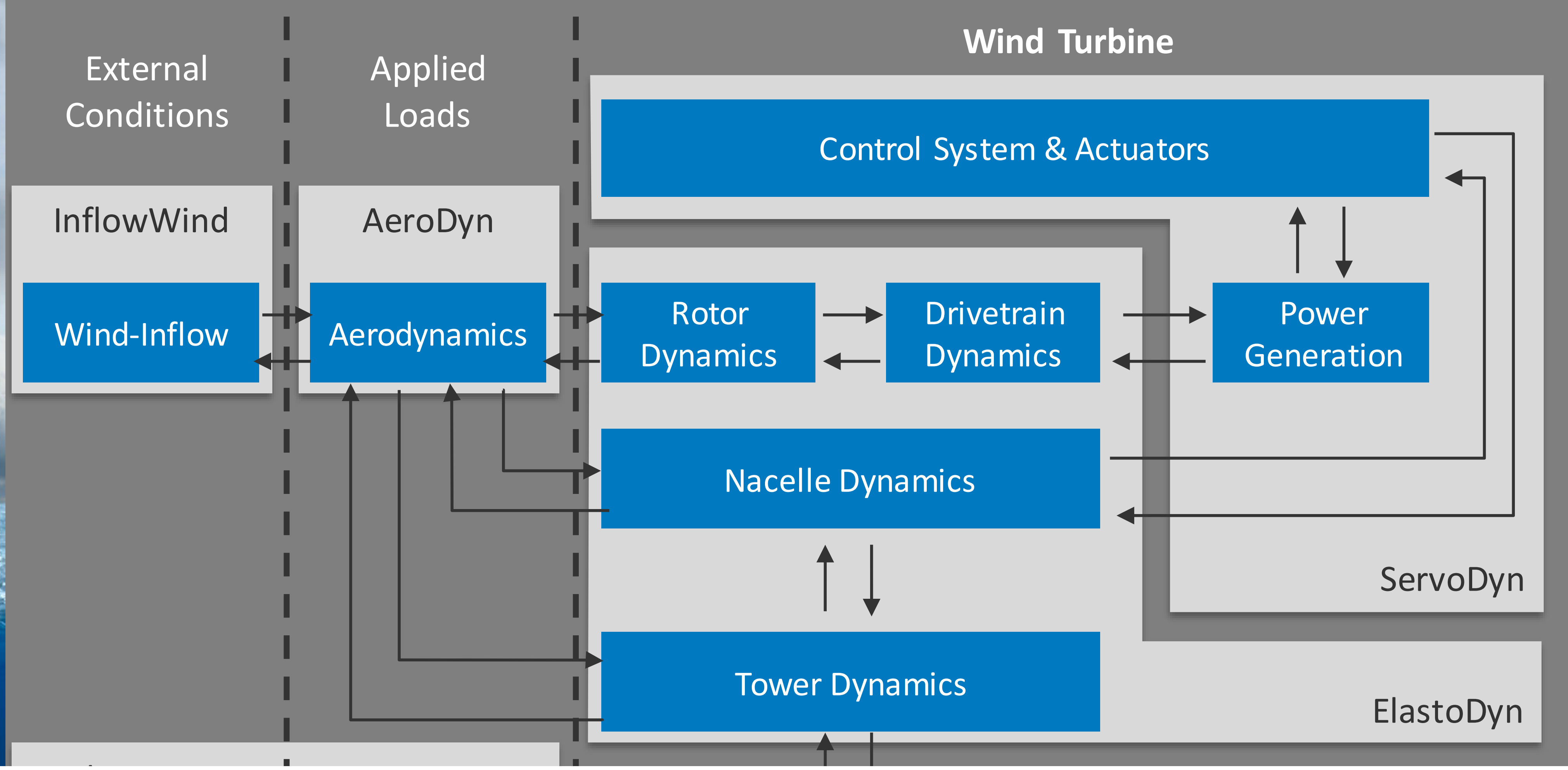
NREL is leading an international collaborative effort to validate the most critical phenomena in predicting offshore wind system loads. A three-way validation and verification process compares solutions from the new coupled engineering-level models to high-fidelity models and experimental data.

IMPACT

Validation will increase the level of trust and acceptance in offshore wind design tools, which directly affects the perceived risk in a project, impacting design methodology and bankability. Validated modeling tools can then be used to design next-generation offshore wind systems that will have lower costs.

Current Projects

Modeling To Enable Next-Generation of Floating Offshore Wind Turbines



ENGINEERING MODELING AND VALIDATION

CHALLENGE

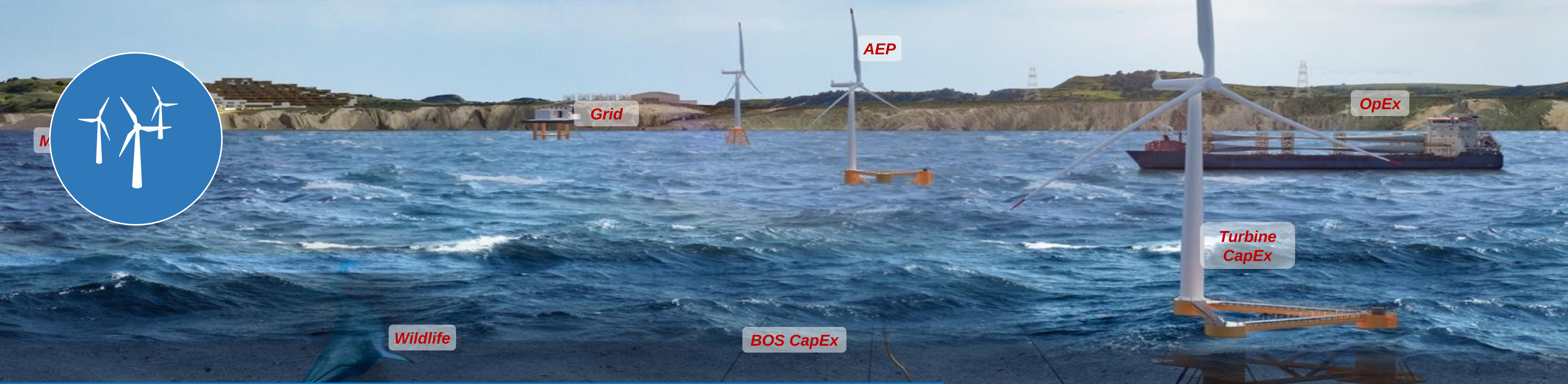
Historically, the substructure of floating offshore wind turbines has been modeled rigidly, which is an impediment to their design—especially newer designs that are streamlined, flexible, and cost effective.

APPROACH

NREL is upgrading OpenFAST to compute substructure flexibility and member-level loads. In collaboration with Stiesdal, we are validating the new capabilities through model-to-model comparisons and comparisons with experimental data generated in wave-tank testing using the TetraSpar design.

IMPACT

The upgraded OpenFAST tool will enable the design and optimization of the next-generation floating wind systems that show promise for making floating offshore wind cost competitive with other energy technologies.



Systems Engineering and Optimization

- Integrate wind plant engineering performance and cost software modeling to enable full system analysis.
- Apply a variety of advanced analysis methods in multidisciplinary design analysis and optimization, and related fields, to the study of wind plant system performance and cost.
- Develop a common platform and toolset to promote collaborative research and analysis among national laboratories, industry, and academia.

Areas of Expertise

- Modeling wind turbines and plants together, multidisciplinary analyses, and overall cost of energy
- Assessing system engineering and cost impacts of technology or logistic innovations.

Current Projects

Wind Energy with Integrated Servo-Control (WEIS)

SYSTEMS ENGINEERING AND OPTIMIZATION

CHALLENGE

To reliably produce power and reduce motion and loads, floating offshore platforms tend to be extremely large and stiff, which also means they are quite expensive. System-level complexity has hindered next-generation designs.

APPROACH

Build on existing design optimization and cost estimation capabilities in NREL's WISDEM tool, the floating offshore wind analysis capability in OpenFAST, and advanced control theory to create a multifidelity tool capable of controls codesign for floating offshore wind turbines.

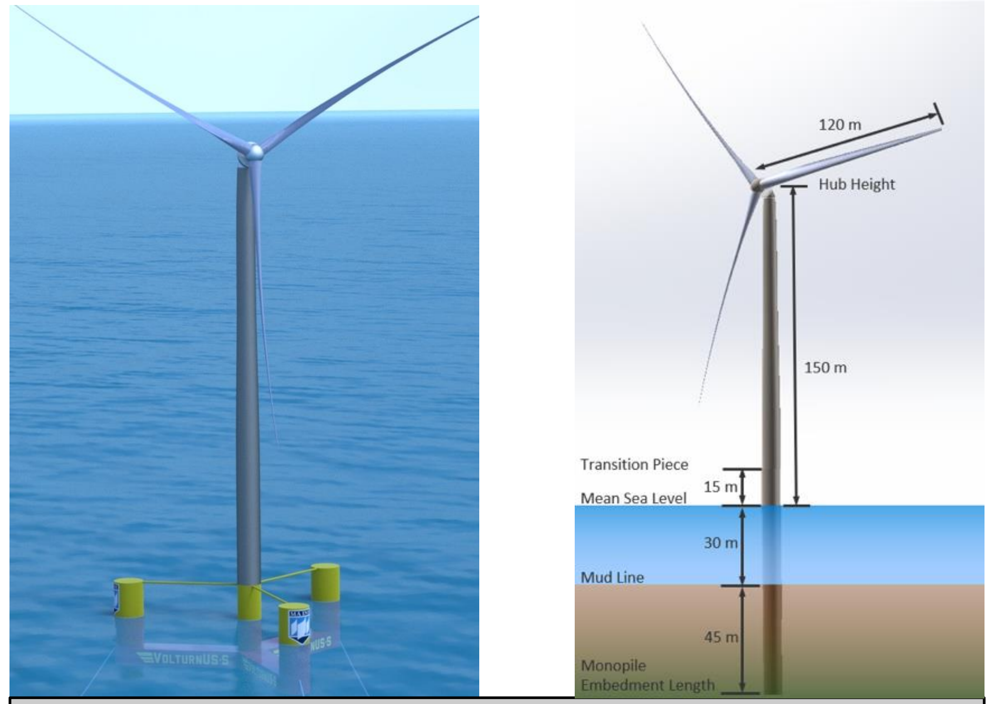
IMPACT

Cost-competitive floating offshore platforms and turbines designed *a priori* with customized control actuators to achieve the lowest capital cost while maximizing power output and operational lifetimes.

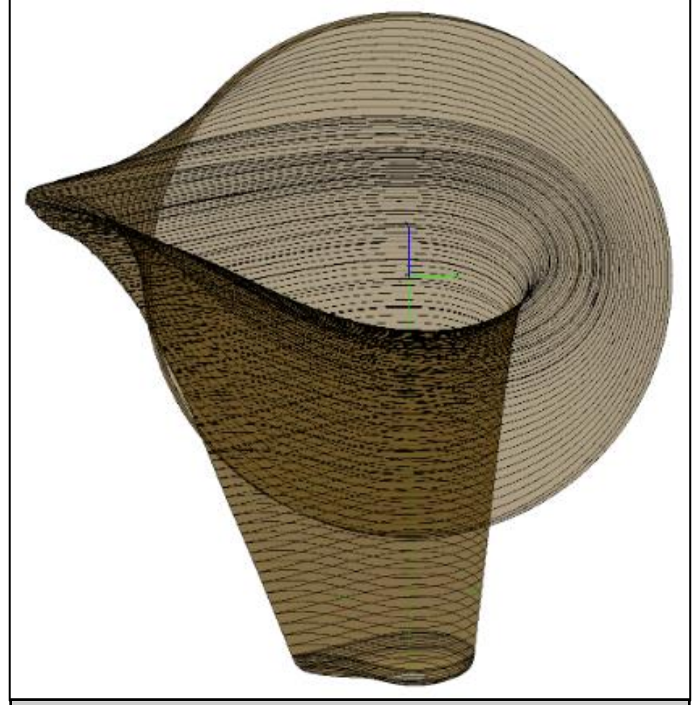
Current Projects

International Energy Agency (IEA) Wind 15-MW Reference Wind Turbine

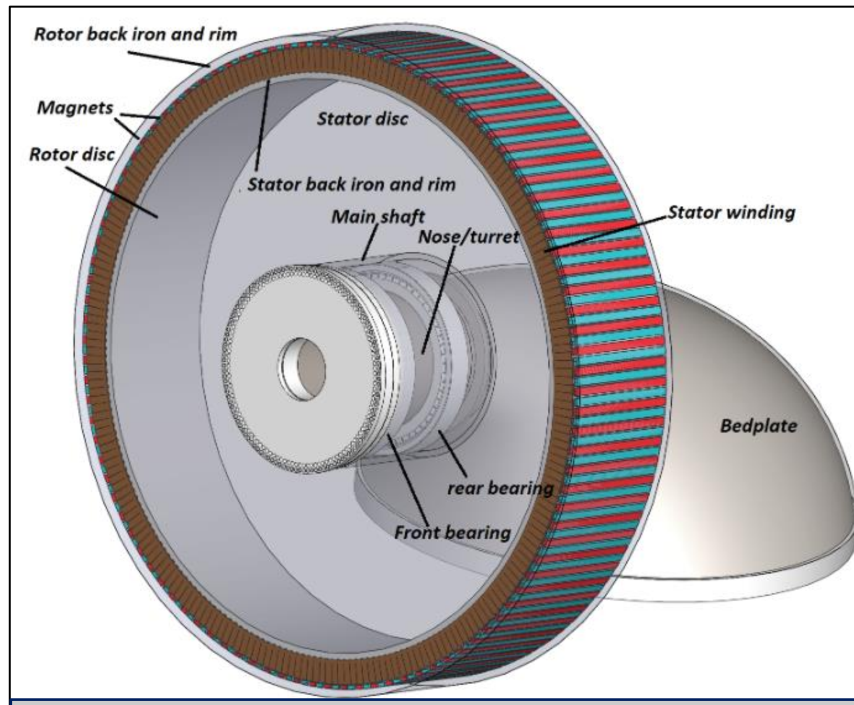
SYSTEMS ENGINEERING AND OPTIMIZATION



Monopile and Semisubmersible Support Structures



Detailed Blade Design



PMDD Generator Design

CHALLENGE

Wind energy researchers and engineers need openly defined reference wind turbines (RWTs) as the platforms on which to publicly demonstrate and share advances in modeling and design. The existing slate of RWTs has not kept pace with the power-rating growth of commercial wind turbines.

APPROACH

Under coordination of IEA Wind Task 37, NREL led the design effort of a new, modern, 15-MW RWT featuring both fixed-bottom and floating-support structures; the RWT is completely open and documented.

IMPACT

Enables collaboration with industry without sharing intellectual property, provides a common baseline model for which research teams around the world can demonstrate research advances, and establishes an education resource for understanding the fundamentals of wind turbine design.

Current Projects

Wind-Plant Integrated System Design & Engineering Model (WISDEM)

SYSTEMS ENGINEERING AND OPTIMIZATION

CHALLENGE

New technologies or component innovations often come with a price premium and system impacts, but it can be difficult to do levelized cost of energy roll-up.

APPROACH

NREL researchers integrated cost and engineering models into a single, multidisciplinary framework, WISDEM.

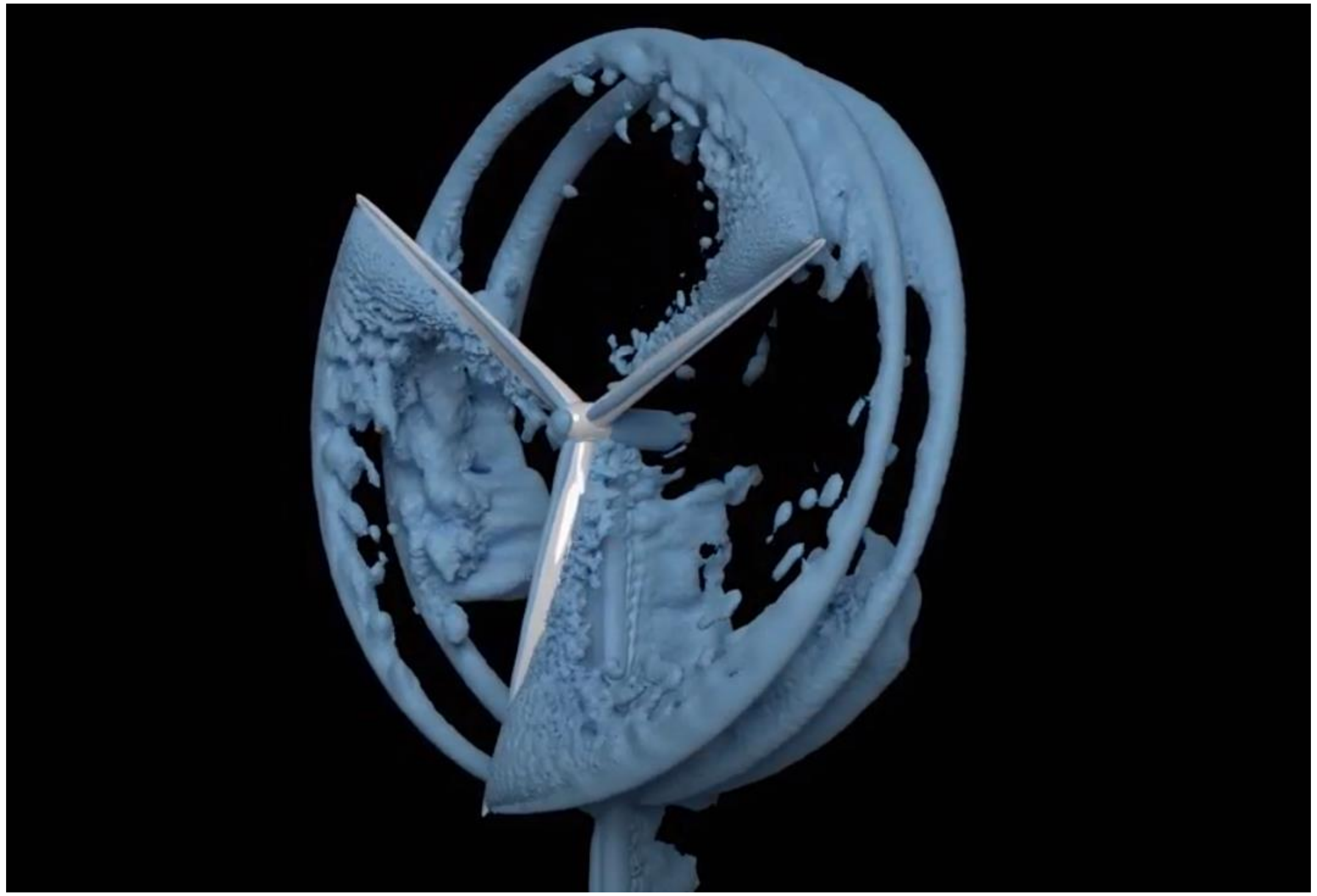
IMPACT

Rapid design optimization, sensitivity and trade-off studies, and system impact assessment.

Accomplishments & Impacts

NREL researchers have unique simulation capabilities that include high-fidelity and engineering modeling and validation—as well as systems engineering design and optimization. These capabilities are supported by the lab's high-performance supercomputers and are exemplified by:

- The DOE Exascale Computing Project, which established the open-source ExaWind modeling and simulation environment: https://github.com/exawind/
- NREL researchers who will lead in expanding the ExaWind code for floating offshore wind turbines. By collaborating with the DOE Exascale Computing Project, the team will run some of the highest-fidelity wind power plant simulations on the first exascale-class supercomputers that are scheduled to go online in 2022.



The github animation shows the velocity isosurface at 5.5 m/s from 2.7 s to 8.6 s of a geometry-resolved large-eddy simulation of the NREL 5-MW wind turbine. The simulation was performed on the NERSC Cori system with Nalu-Wind, which is an unstructured-grid, low-Mach-Number computational fluid dynamics code. The code development and simulations are being performed as part of the U.S. Department of Energy ExaWind Exascale Computing Project and the DOE EERE Wind Energy Technologies Office High-Fidelity Modeling project.