

# Wind Turbine Technology Research at Sandia National Labs

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**Wind Energy Research Workshop  
University of Massachusetts Lowell**



Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.



**Sandia National Laboratories**

# Sandia National Laboratories

*“Exceptional Service in the National Interest”*

- National Security Laboratory
- Broad mission in developing science and technology applications to meet our rapidly changing, complex national security challenges



The graphic features a golden globe with a grid pattern. The word "Sandia" is written in a red cursive font, and "VISION" is in a large, bold, blue sans-serif font. A red banner curves around the bottom of the globe with the text "helping our nation secure a peaceful and free world through technology". To the left of the globe are five golden stars, each containing a value: Integrity, Excellence, Service to the Nation, Each Other, and Teamwork. The Sandia National Laboratories logo is in the top left corner.

**Our highest goal** is to become the laboratory that the U.S. turns to first for technology solutions to the most challenging problems that threaten peace and freedom for our nation and the globe.



# Energy and Climate Program Areas at Sandia

**Mission:** The [Energy Program Area](#) home to research programs in

- renewable energy systems
- nuclear energy systems
- energy for transportation
- energy efficiency.

Address the challenges of:

- ❖ reducing our dependence on foreign oil
- ❖ advancing energy storage technologies



Director, [Margie Tatro](#)

**Mission:** The [Climate Program Area](#) is home to research programs for

- sensing and monitoring
- carbon capture, sequestration
- water systems.

These programs will tackle the important challenges of:

- ❖ [providing the foundation to a global climate treaty](#)
- ❖ closing the carbon cycle through credible carbon management strategies
- ❖ assuring water safety, security, and sustainability



Director, [Rob Leland](#)





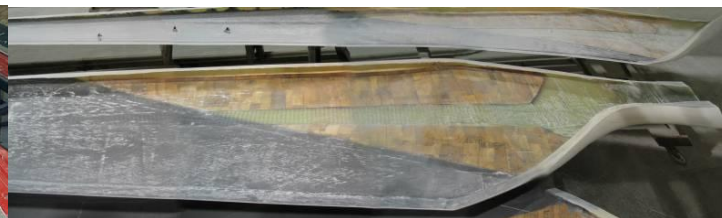
# Innovative Blade Developments

## Recent History

BMI 2000-02 **ERS-100**



Carbon-Hybrid Blade Developments  
2003-05 **CX-100, TX-100**



WindPACT (2001-05) **BSDS**



**STAR 27m Swept Blade (2005-09)**



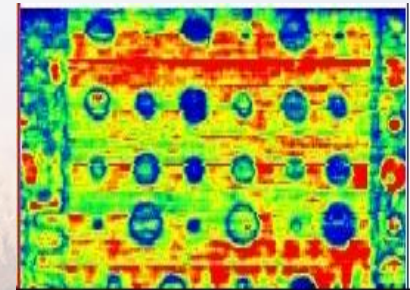
**Sensor Blade I/II (2008-10)**

**CX-100 with Flap for Active Control (2011-12)**



# Blade Reliability Collaborative

- **Goal:** Develop a collaborative framework to determine the causes of premature blade failure, the best inspection methods, and the adequacy of modeling tools and testing protocols
- **Methodology:**
  - **Blade Defect and Damage Database** – Aggregate data from blade manufacturers, service companies, and operators to determine largest sources of blade unreliability
  - **Inspection Validation** – Evaluate the ability of inspection techniques to accurately characterize blade defects and damage in manufacturing plants and in the field
  - **Effects of Defects**
  - **Analysis Validation**
  - **Certification Testing**
  - **Standards and Partnerships** – Identify pathways to implementing improved design, manufacture, and inspection with international standards committees and industrial partners
- **Partners:** SNL AANC, Montana State, NREL, EPRI, U-Mass. Lowell, GE, Vestas, Gamesa, TPI Composites, Rope Partners, EDPR, Dantec Dynamics



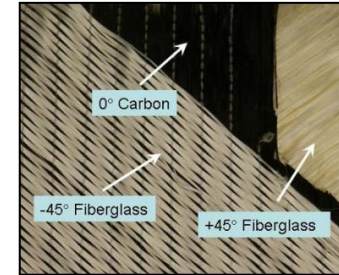
SNL Contact: Joshua Paquette



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# Materials Research

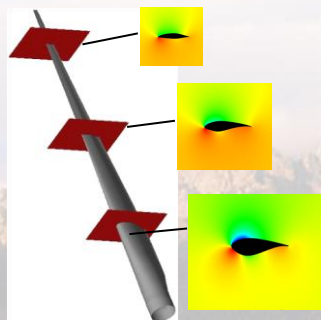
- **Goal:** Advance the state of composite materials for use in large-scale wind turbine blades.
- **Methodology:**
  - Determine composite fatigue & strength properties
    - ◆ New materials & forms
    - ◆ Ply drops, adhesives, core, alternate materials
  - Engineer materials to reduce weight & increase reliability of blades
  - Build up SNL/MSU Fatigue Database
    - Material properties (10000+ tests for 175 materials)
  - Develop design improvements
    - Structurally more efficient airfoils
    - Composite hybrids
- **Partners:** Montana State and multiple industry members; PPG, Owens-Corning, Reichold, Arkema, GE, Clipper, many others



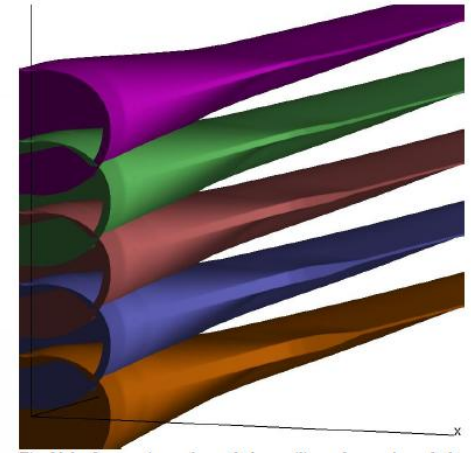
SNL Contact: Josh Paquette

# Aerodynamics & Aero-acoustics

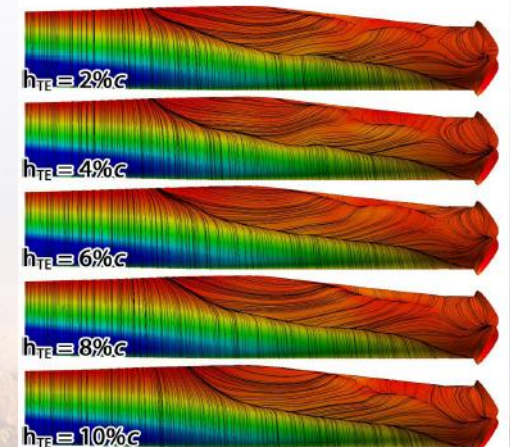
- **Goal:** Enable innovation in blade design through the use of advanced models for predicting blade loads and noise.
- **Recent Projects**
  - Computational Fluid Dynamics (CFD) analysis of MW-scale blades with innovative inboard design features (with UC-Davis)
  - Development of the TANDEM code for prediction of wind turbine blade trailing edge noise (with Penn State University)
  - Unsteady blade loading models for active aerodynamic load control devices (trailing edge flaps).



CFD models of blade section aerodynamics for input to a system aero-elastic model.



CFD simulations of the flow over the inboard region of a 5 MW turbine blade with blunt trailing edge airfoils of varying thickness.



SNL Contact: Matt Barone



# Structural and Mechanical Adaptive Rotor Technology (SMART Rotor)

- **Goal:** Investigate the blade fatigue load control potential of small, light-weight control devices and control systems with simulations and validate the simulation results with wind-tunnel and flight tests.

- **Program Focus:**

- ◆ **Field test** – 9-m active aerodynamic load control (SMART) blade set on Micon test turbine at Bushland, TX
- ◆ **Devices** – investigate conventional flaps, micro tabs, morphing trailing edges and micro flaps
- ◆ **Sensors** – investigate suitability/reliability for measurement of structural and aerodynamic states
- ◆ **Controls** – develop appropriate control algorithms
- ◆ **Wind tunnel** – test gust response of model with integrated devices and actuators
- ◆ **Simulation tools** – improve resolution and fidelity, validate

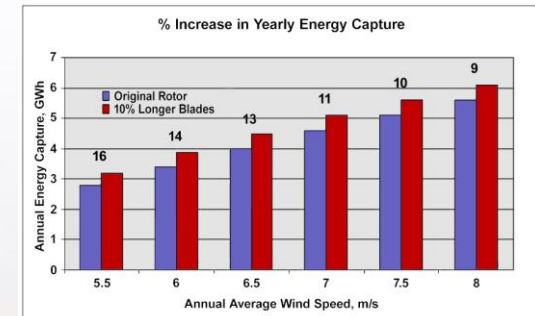
- **Industry Impact & Opportunities:**

- Improved blade fatigue load control, leading to rotor weight reductions or increased rotor area, and lower cost of energy

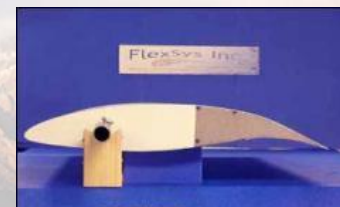
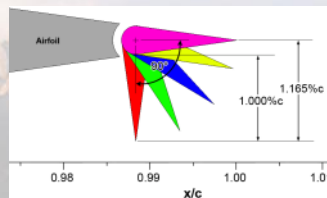


SMART Blade Set

1.5MW Turbine, 10% Blade Growth Simulation Results



SNL Contact: Dale Berg



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# CREW: Continuous Reliability Enhancement database for Wind

Create a *national reliability database* of wind plant operating data to enable reliability analysis

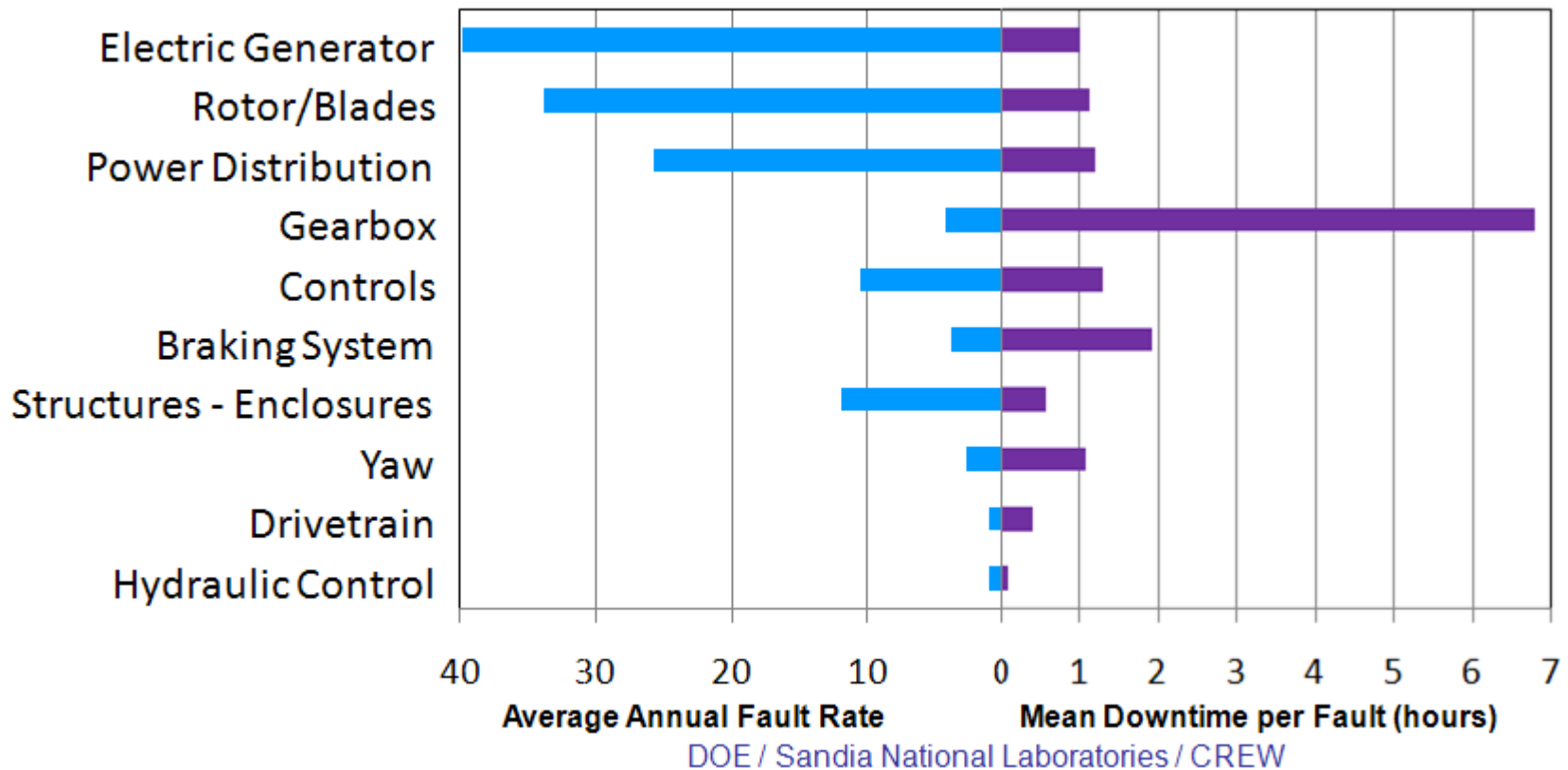
- Track operating performance at a system-to-component level
- Characterize issues and identify technology improvement opportunities
- Enable O&M cost reduction
- Benchmark reliability performance
- Protect proprietary information
- Increase confidence: financial sector and policy makers

SNL Contact: Alistair Ogilvie



# Fault Summary

- **Fault Rate & Fault Downtime, ordered by unavailability impact**
  - Average Annual Fault Rate = expected # faults per year per turbine
  - Mean Downtime per Fault = average duration of a single fault



# *Renewable Systems Integration*

## *Project Objectives*

- *Develop power system simulation models for wind power plants that regional transmission operators can utilize*
- *Improve on the first generation of wind power plant models to include emerging wind power plant functionality*
- *Validate models against field data to ensure proper behavior of model during system events*



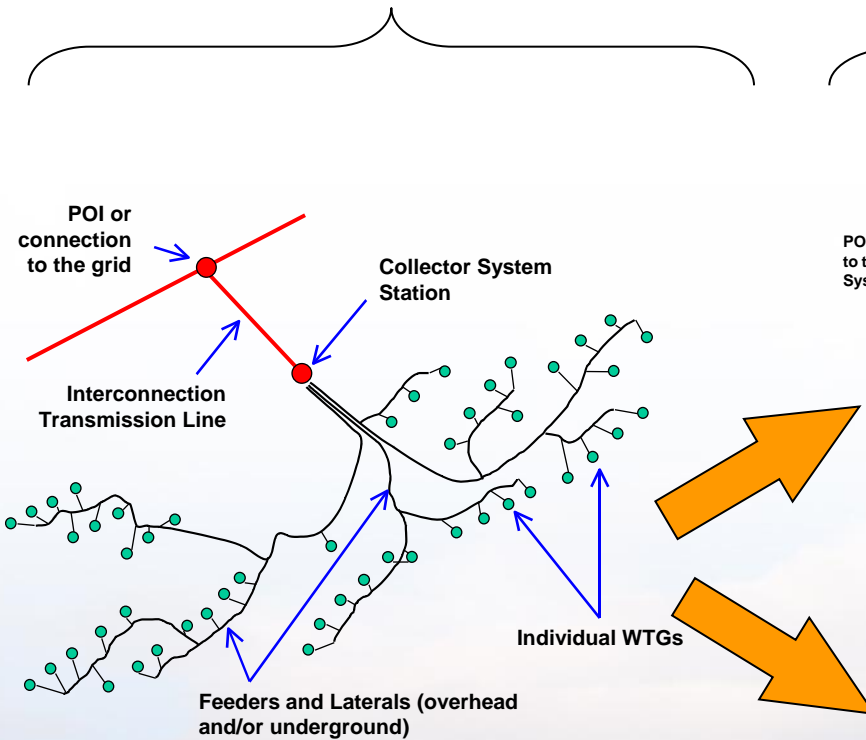
Contact: Ben Karlson - Benjamin.Karlson@sandia.gov



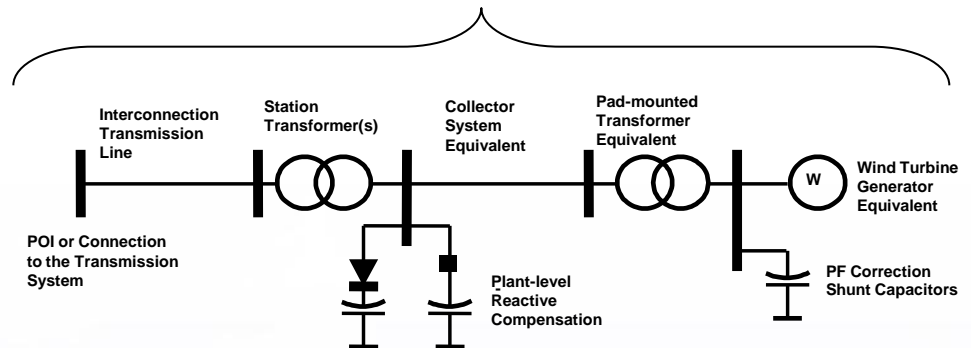
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# Generic Wind Power Plant Modeling

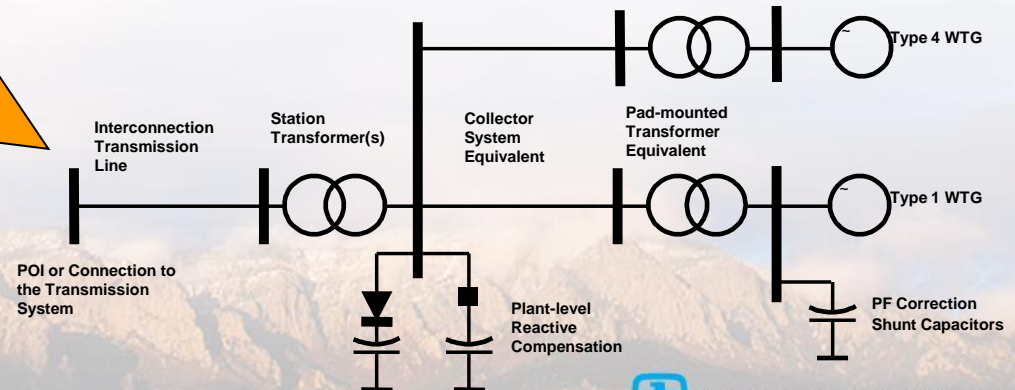
Actual Wind Power Plant Layout



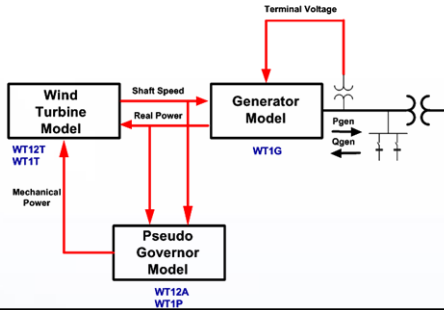
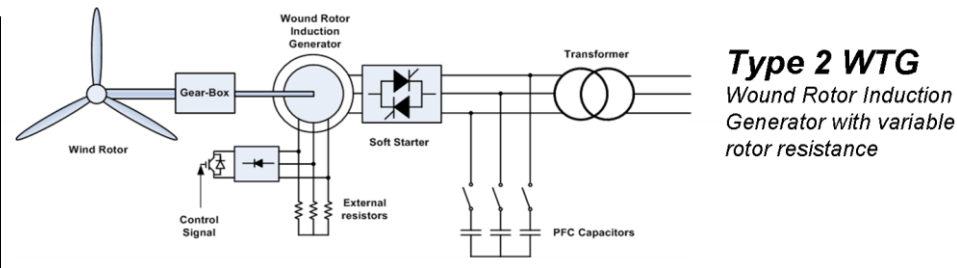
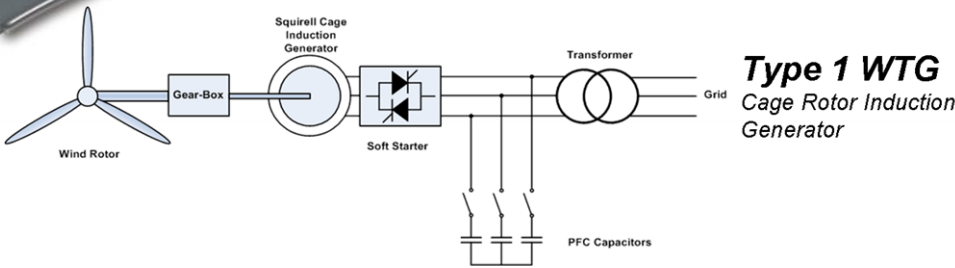
Equivalent Wind Power Plant Representation for Simulation



...or in special cases (e.g., heterogeneous feeders or WTGs of different types)...

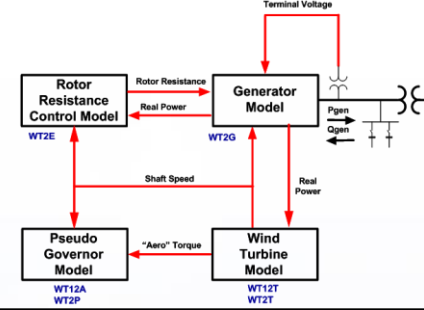


# Wind Turbine Generators & Models



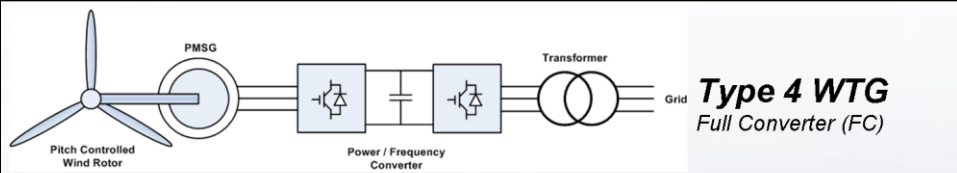
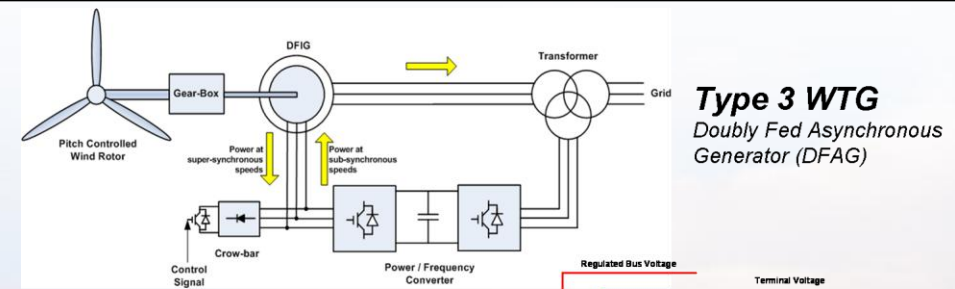
**WECC WT1**  
**Generic Model**

Volt/frequency protection modeled separately



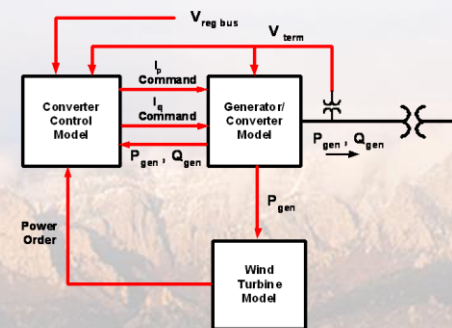
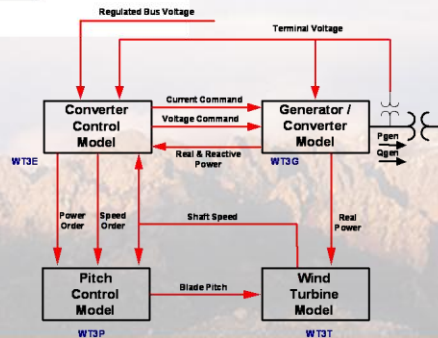
**WECC WT2**  
**Generic Model**

Volt/frequency protection modeled separately



**WECC WT3**  
**Generic Model**

Volt/frequency protection modeled separately








**WECC WT4**  
**Generic Model**

Volt/frequency protection modeled separately



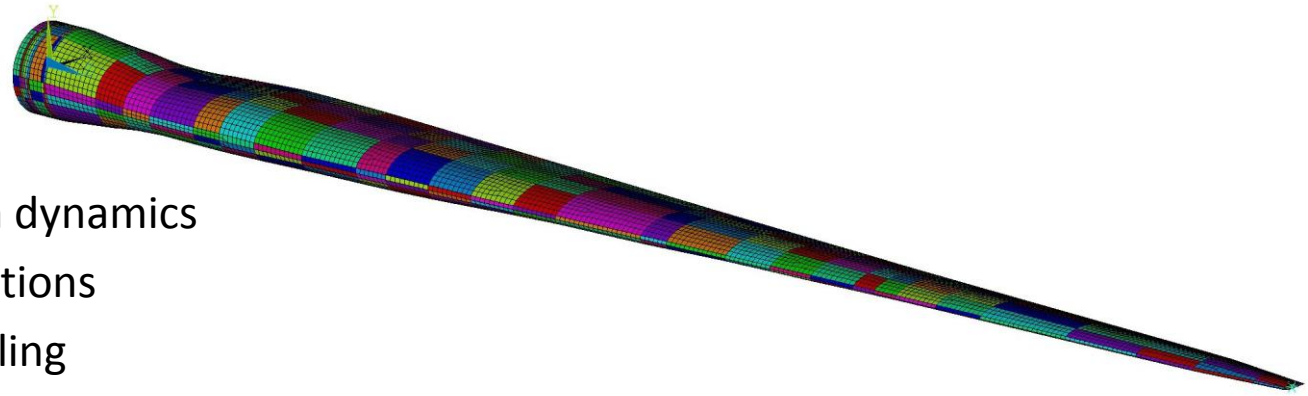
# Industry Involvement

Industry Effort	SNL's Role
<p><b>WECC</b> – Renewable Energy Modeling Task Force</p> <ul style="list-style-type: none"> <li>● Improve/expand model structure to cover a wider range of WTG controls and capabilities</li> <li>● Validation practices (including plant level, field data)</li> <li>● Improve availability of default model data for generic models</li> </ul>	<p><b>Task Force Chair</b></p> 
<p><b>IEEE</b> – Dynamic Performance of Wind Power Generation Working Group</p> <ul style="list-style-type: none"> <li>● Technical coordination</li> </ul>	<p><b>Former Chair – Participating Member</b></p> 
<p><b>IEC TC88 WG27</b> – Electrical Simulation Models for Wind Power Generation</p> <ul style="list-style-type: none"> <li>● Standard generic model specifications</li> </ul>	<p><b>Lead Delegate for the U.S.</b></p> 
<p><b>EnerNex/UWIG Project</b></p> <ul style="list-style-type: none"> <li>● Generic model refinement and documentation</li> </ul>	<p><b>Project Member</b></p> 
<p><b>EPRI/NREL/SNL Validation Project</b></p> <ul style="list-style-type: none"> <li>● Generic model validation and refinement</li> </ul>	<p><b>Project Member</b></p> 



# Design Tools

- **Goal:** Enable the creation and widespread use of more advanced, more accurate numerical models for simulation and evaluation of new wind energy technology

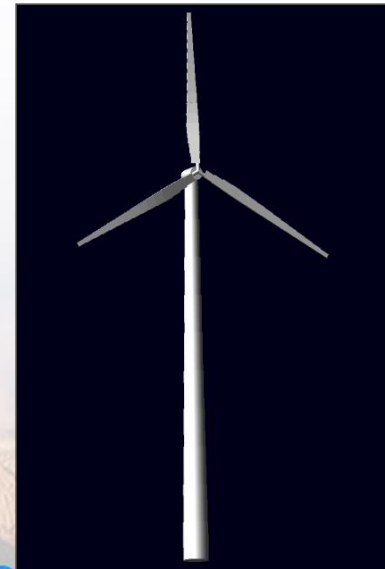
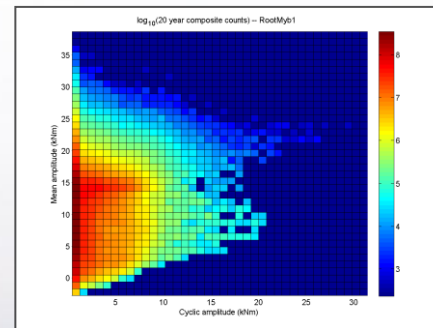


- **Program Focus:**

- Full aeroelastic system dynamics
- Fluid/structure interactions
- Blade structural modeling
- Leverage Sandia's high performance computing

- **Industry Impact & Opportunities:**

- Enable the shift from small system build/break/redesign to effective advanced simulations for large systems of the future
- Reduce risk and cost in new design evaluation and development



SNL Contacts: Brian Resor



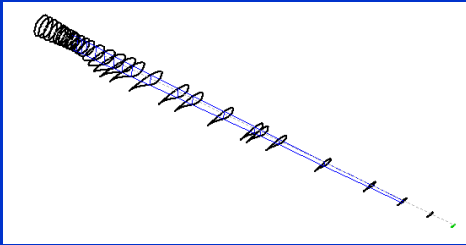
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# Blade Design with NuMAD

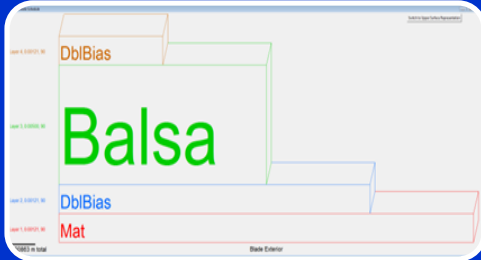
## NuMAD

NuMAD:  
Numerical Manufacturing  
And Design Tool

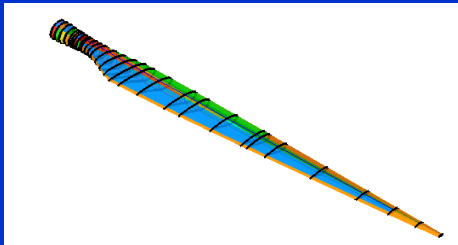
### Blade Geometry



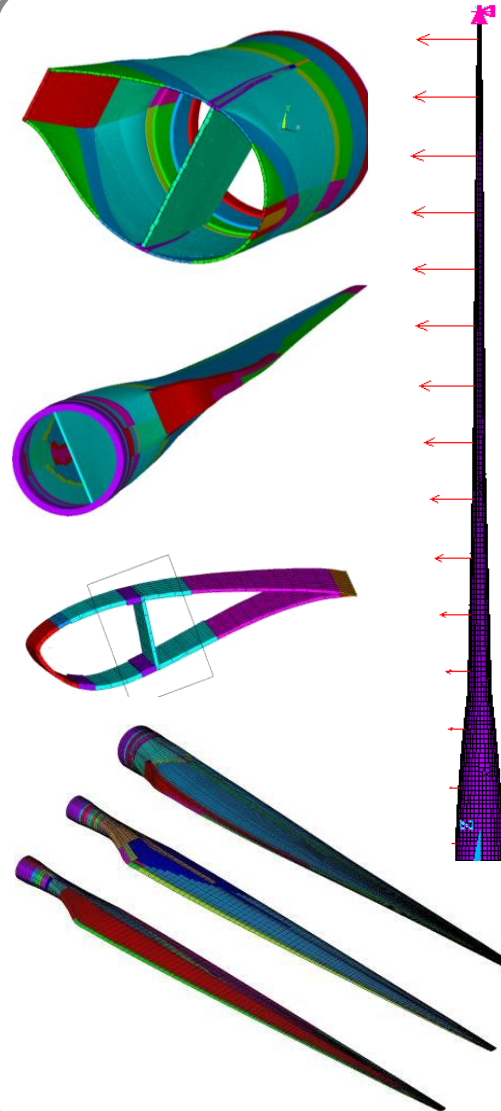
### Materials & Layups



### Stack Placement

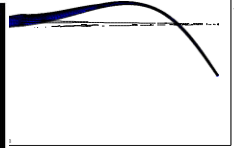
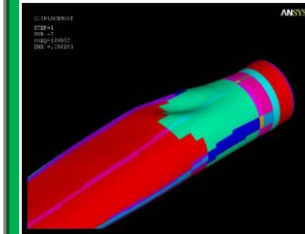


## ANSYS FE Model



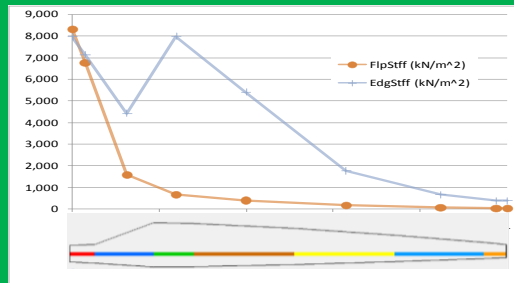
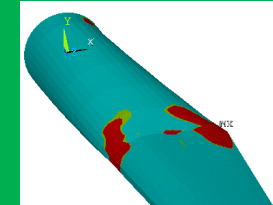
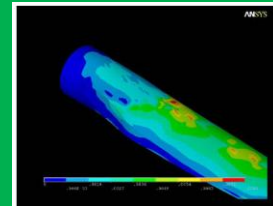
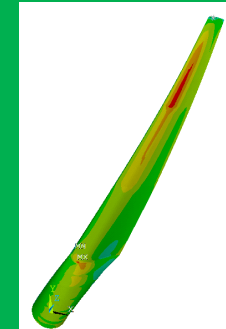
## ANSYS Analysis

### Modal



### Buckling

### Stress & Strain

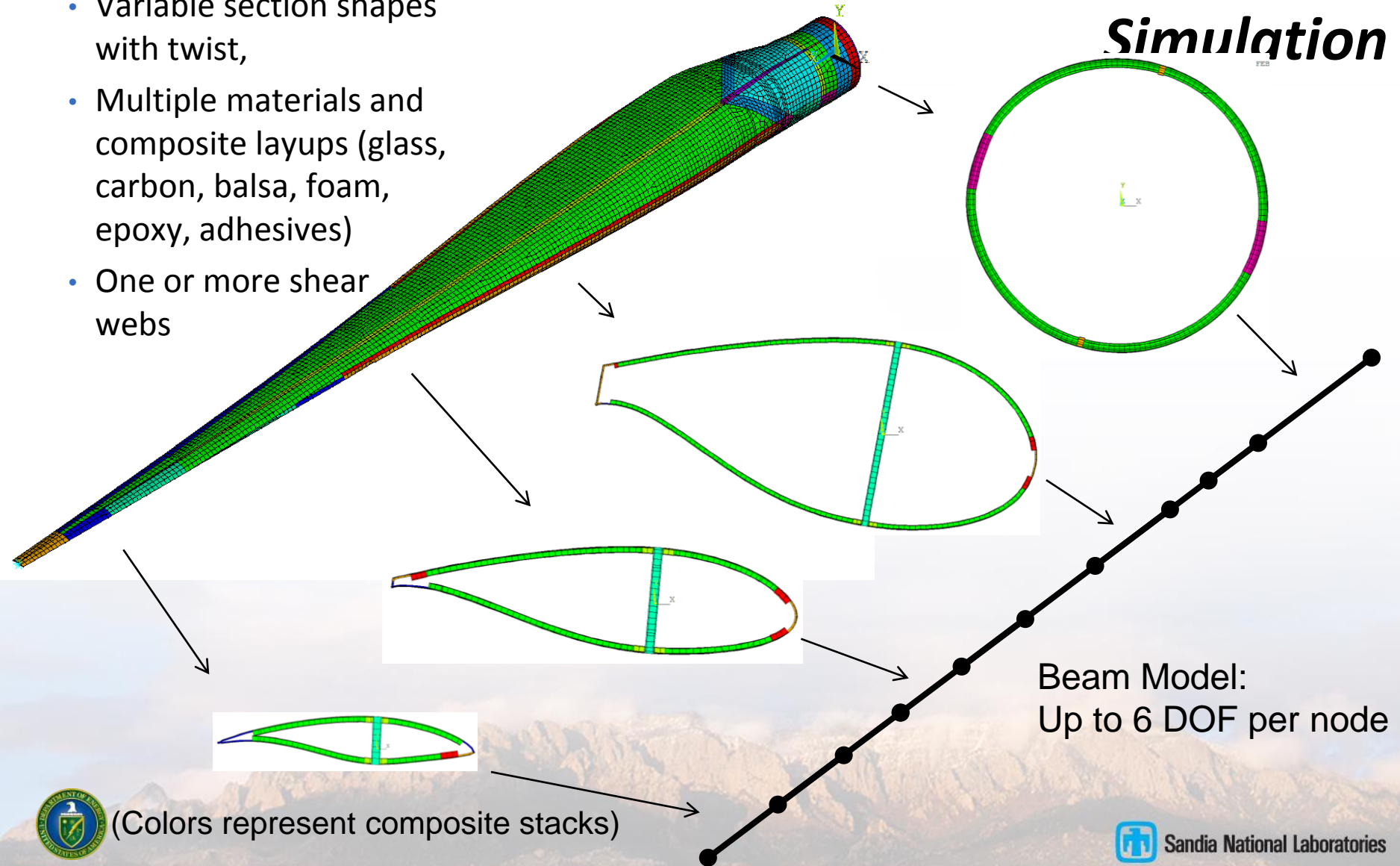


### Beam Properties

# Blade Structural Model Simplification for Aeroelastic Simulation

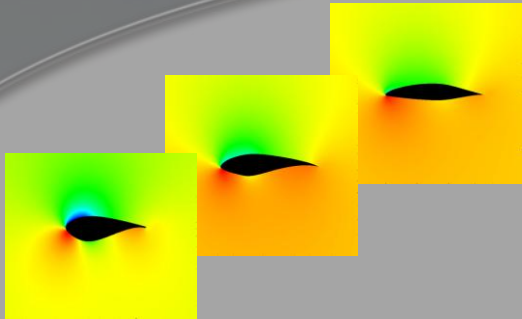
## ■ Wind turbine blades include

- Variable section shapes with twist,
- Multiple materials and composite layups (glass, carbon, balsa, foam, epoxy, adhesives)
- One or more shear webs

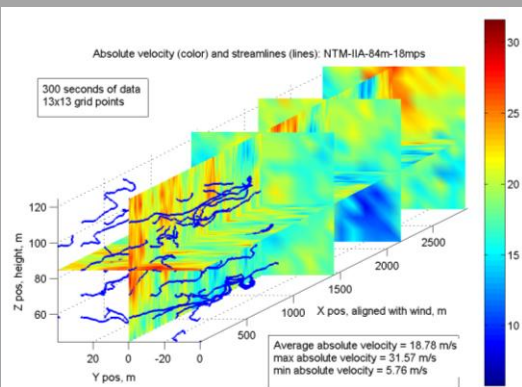


# System Analysis with Wind Turbine Aeroelastic Simulation

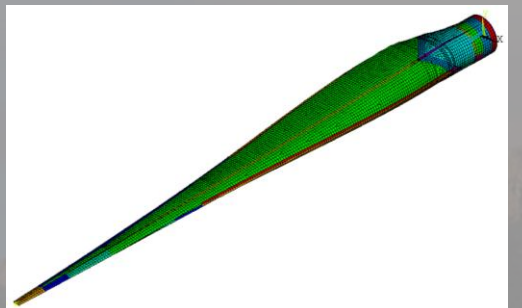
Aerodynamic Performance



Turbulent Wind Input



Structure and Materials

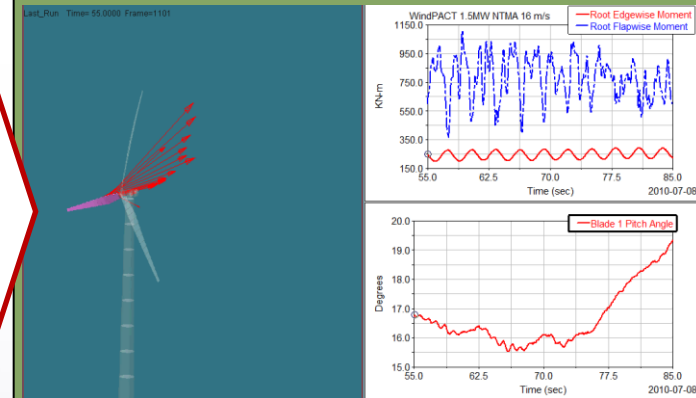


Aeroelastic System Dynamics Model



Includes Controls Implementation

System Response



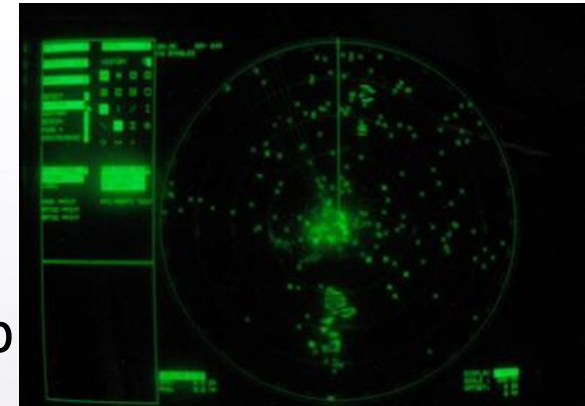
# Wind Radar Program

## Mitigation Strategy

- **Goal:** Develop mitigation options to reduce the reflectivity of wind turbine rotors .
  - Test COTS technologies to determine which are most effective are at reducing impact of turbines on radars.
  - Design a producible wind turbine blade with a significantly reduced radar cross section.

- **Approach:**

- Identify potential material combinations
- Demonstrate that these combinations can be p in small sections (18"x18")
- Test the RCS of these blade sections
- Produce a 9 or 13 meter blade with the new material combinations and test RCS in field



SNL Contact: Dave Minster



# *First Test of COTS Technologies to Mitigate Effects of Wind Turbines on Radars*



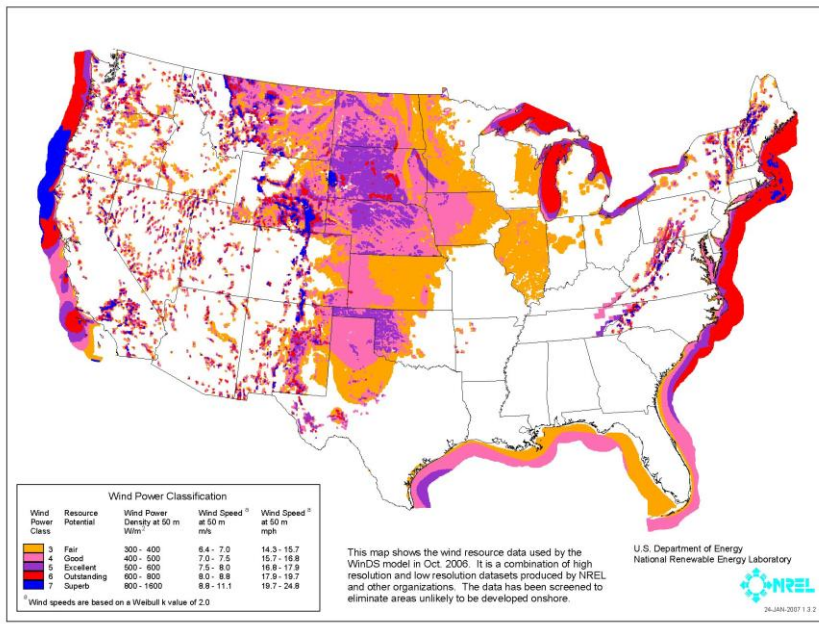
# Offshore Wind

- **Technical challenges, higher costs**
- **Close to load centers**
- **Limited shallow depths in U.S.**
- **Proposals in U.S.**
  - Cape Cod (Cape Wind)
  - Long Island (LIPA)
  - Texas gulf coast
- **1500 MW installed in Europe**



Belgium	30
Denmark	397.9
Ireland	25
The Netherlands	246.8
Sweden	133.3
UK	588
<b>Total capacity - World</b>	<b>1,421</b>

Source: BTM Consult ApS - March 2009



SNL Contact: Todd Griffith

# *Current Offshore Wind Research Activities*

## ■ **Offshore Structural Health and Prognostics Management\***

- Develop optimization functions that balance the performance, rate of growth of damage and the associated cost of repair / replacement

## ■ **Offshore Innovative Concepts and Approaches**

- Concept studies on the co-location of offshore wind and MHK energy devices
- Evaluate feasibility for VAWT technology and leverage longstanding history and knowledgebase

## ■ **Large Off-Shore Rotor Development**

- Design studies for very large rotors to identify and assess enabling technologies
- Phase II reference model inclusive of rotor innovations

## ■ **Sediment Transport, Scour and Foundation Impact Analysis\*\***

- Predict flow and scour around foundations, anchors, and moorings of offshore wind power devices, arrays of devices, and their inner-array cable installations
- Develop specifications for required flow measurements, measuring flow fields, and collecting representative erosion rate data as a function of shear stress to estimate scour

## ■ **Interaction of Wind and Wave Loading Simulations**

\* Leverage existing landbased program

\*\* Leverage existing water power program




# Large Blade Innovations

## 100-m Sandia Blade Design

**Goal:** Provide technology research to produce innovations and advanced design concepts to develop very large utility-grade blade and rotor designs for offshore and onshore (where possible).



 6' human scale

### ■ Methodology:

- Develop and apply scaling laws to scale-up of 5 MW turbine system.
- Create 13.2 MW Sandia Baseline (100 m long blade) with detailed composite laminates
- Apply innovative concepts to baseline to reduce weight, and improve performance & cost effectiveness

### ■ Partners: European UpWind Program

### FY10 Offshore Accomplishments:

- Completion of baseline 100-meter blade for offshore applications
- Visualization Study for 1/3 scale floating wind turbine platform for the DeepCWind Consortium



**SANDIA REPORT**  
SAND2010-7910  
UNCLASSIFIED  
November 2010


**Evaluation of Feeder-Connected Utility-Scale Wind Power Plants Using Positive-Sequence Simulation**

Abraham Ellis, Benjamin Karlson, Joseph Williams

**Prepared by:**  
Sandia National Laboratories  
Sandia National Laboratories, 3745 and Livermore, California 94550  
MS-1308

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***Thank You***

