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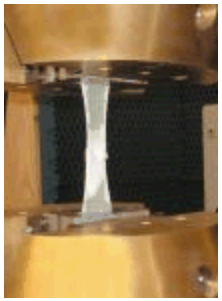

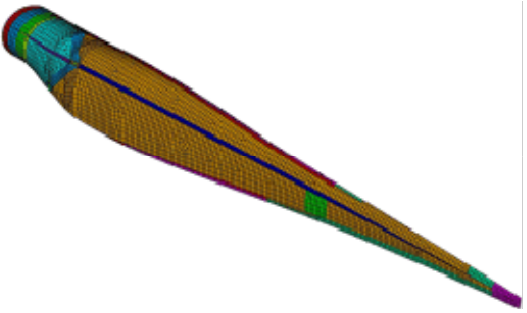

Materials Needs for Wind Turbine Rotor Technology

Brian Naughton

Sandia National Laboratories

Wind Energy Technology Department

BASF - November 19, 2013

Sandia National Laboratories

Exceptional service in the national interest

U.S. DEPARTMENT OF ENERGY

NNSA

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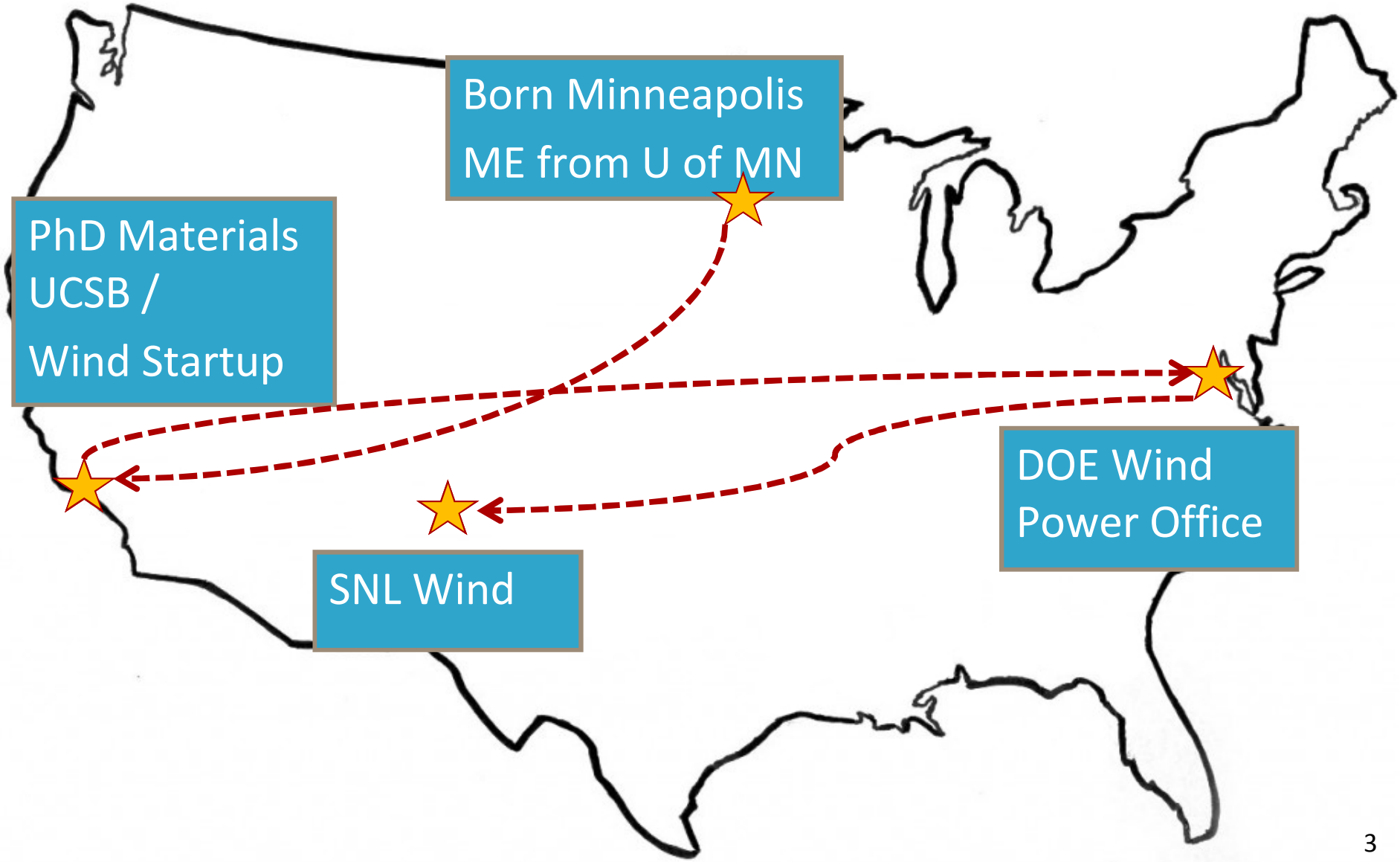
Outline

- Background: Personal & Sandia National Laboratories
- Wind Energy Technology Market Overview
- Blade Technology Overview
- Blade Technology R&D Opportunities
- Sandia Wind Research and Collaboration

Objective: Provide a framework for wind rotor technology to identify important research areas and facilitate collaboration.

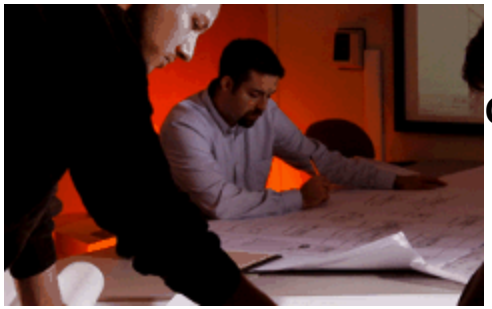
Personal Background



Sandia National Laboratories

Nuclear Weapons

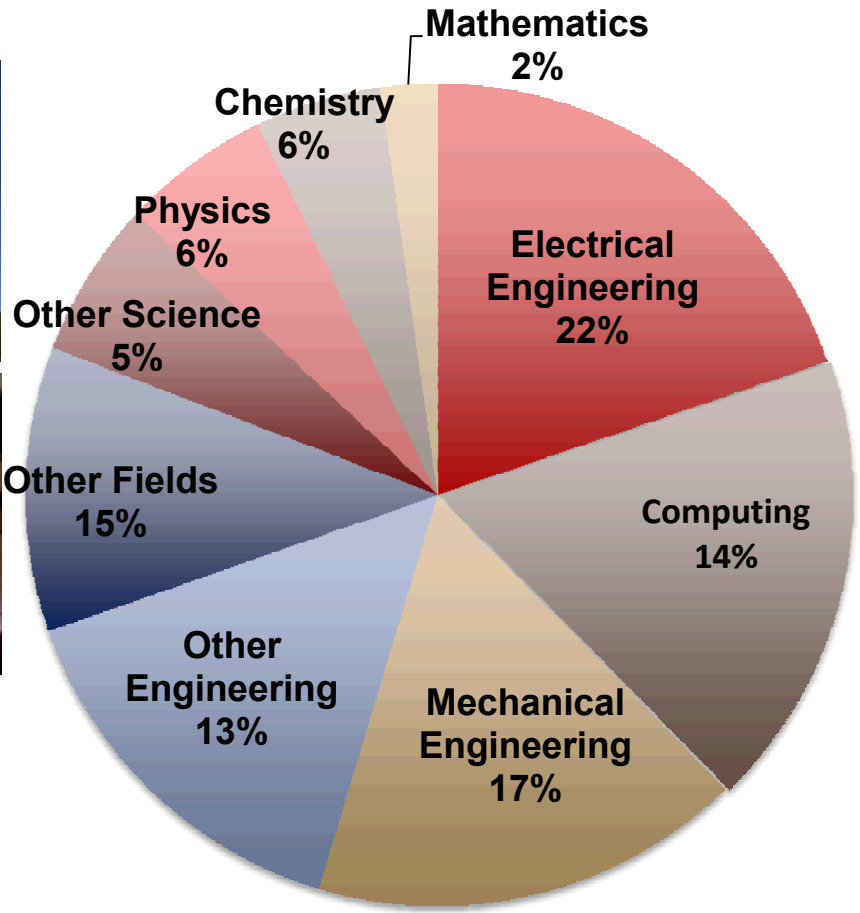
Defense Systems & Assessments



Energy, Climate, & Infrastructure Security

International, Homeland, & Nuclear Security

4800 R&D Staff

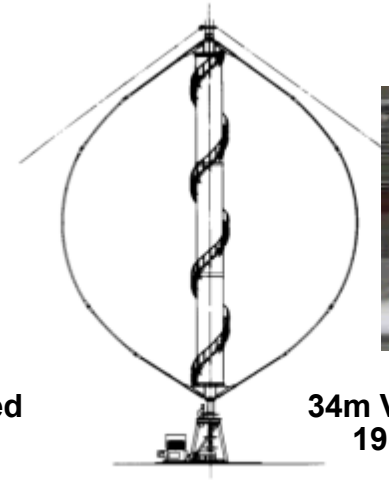


SNL Wind Program History

Sandia National Laboratories

28 Years of wind turbine rotor development

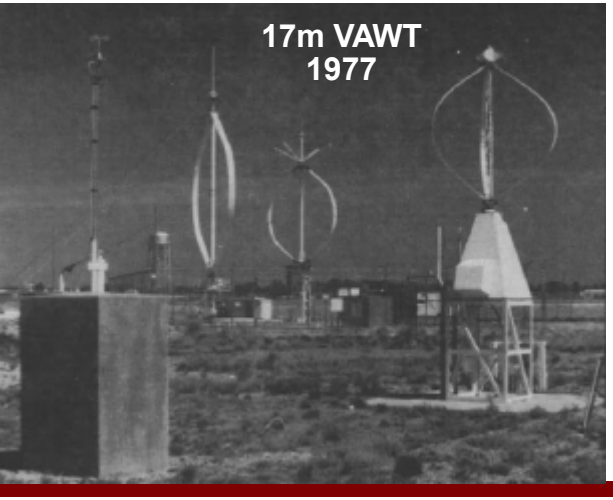
Wind Program Established 1975



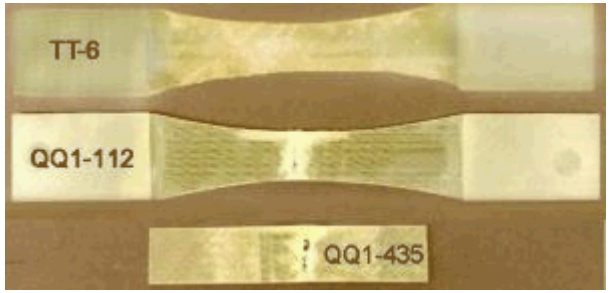
34m VAWT 1984

Blade Program 1994

SWiFT Facility 2013



Composite Materials Database 1988



Advanced Manufacturing Initiative 2008

Wind Energy Technology Market Overview

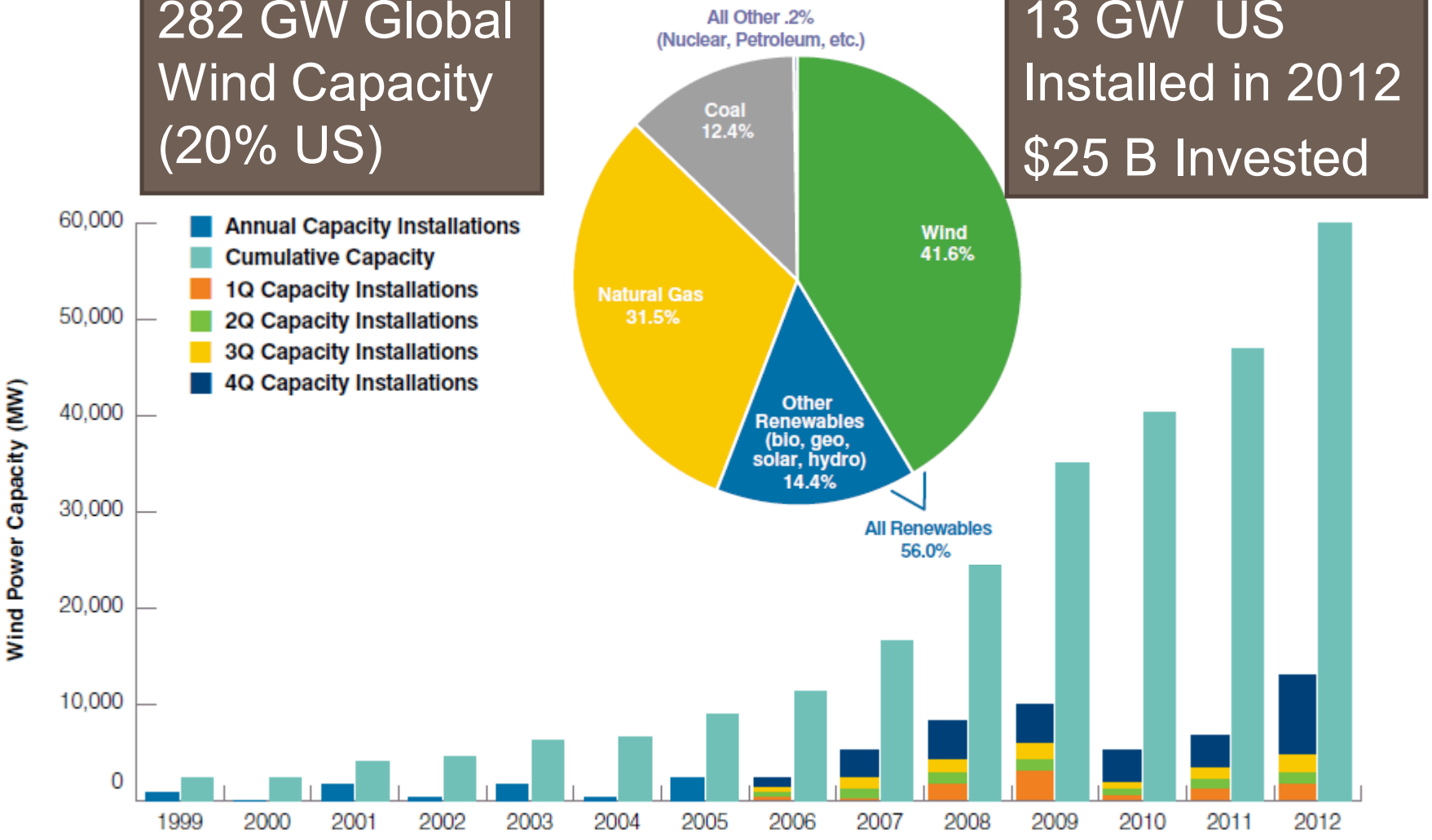
Wind Energy Market Overview

Sandia National Laboratories

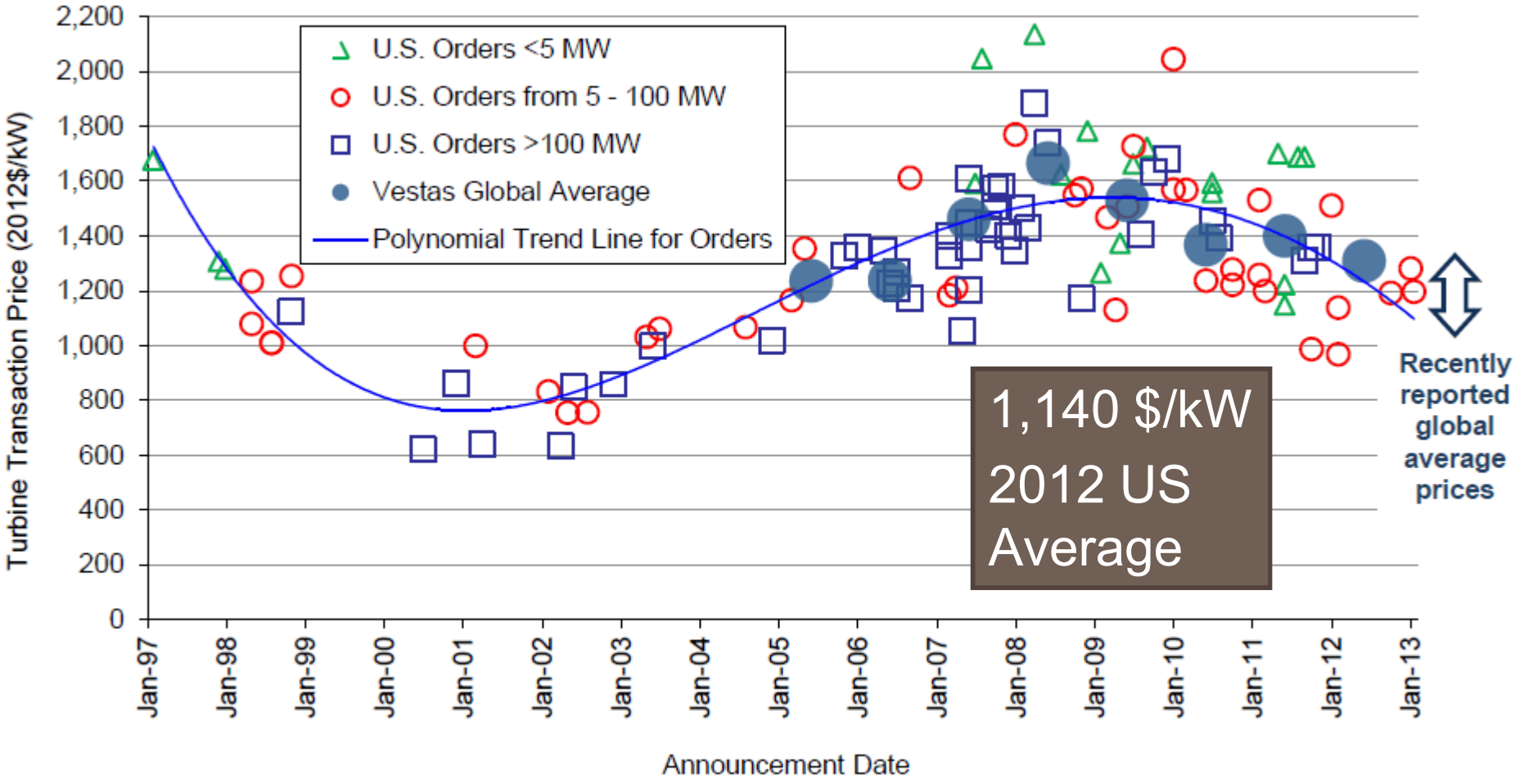
282 GW Global Wind Capacity (20% US)

13 GW US Installed in 2012

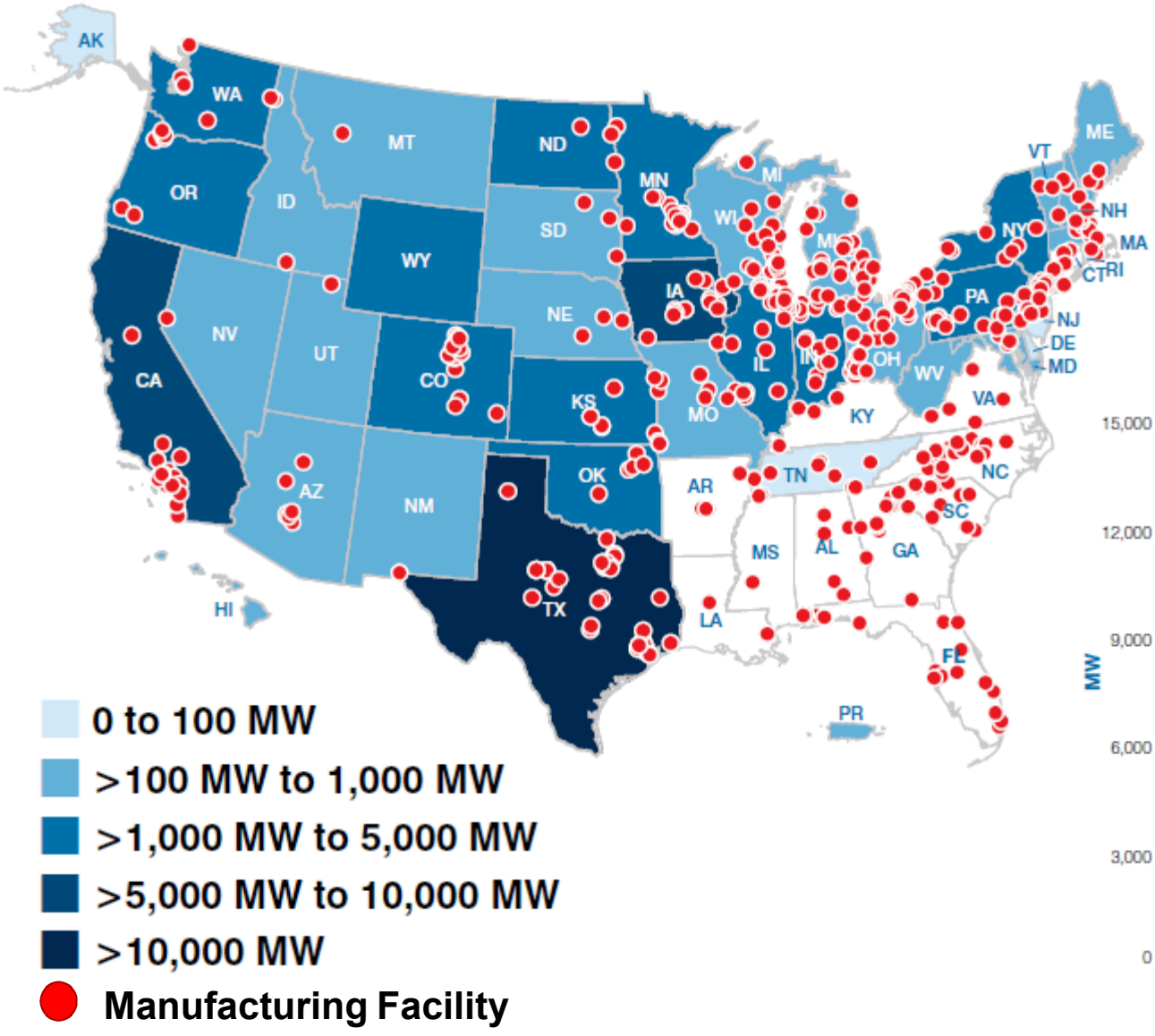
$25 B Invested

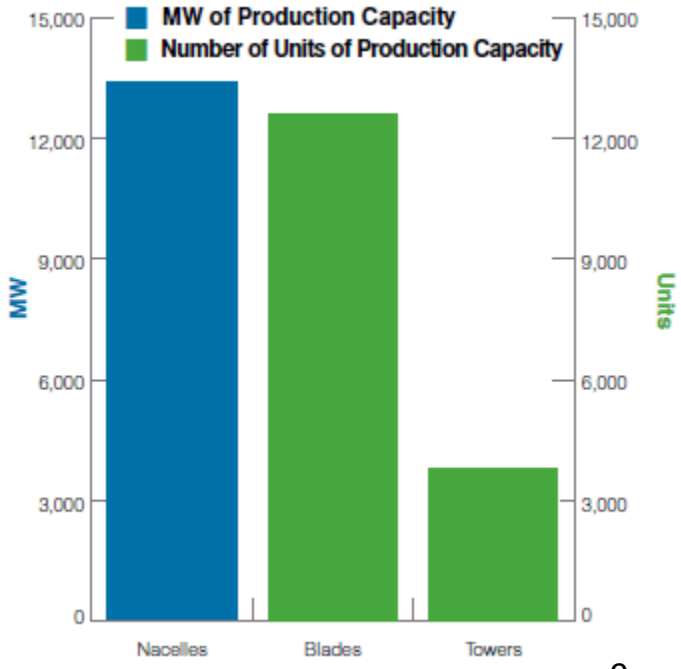


Capital Cost – US Market

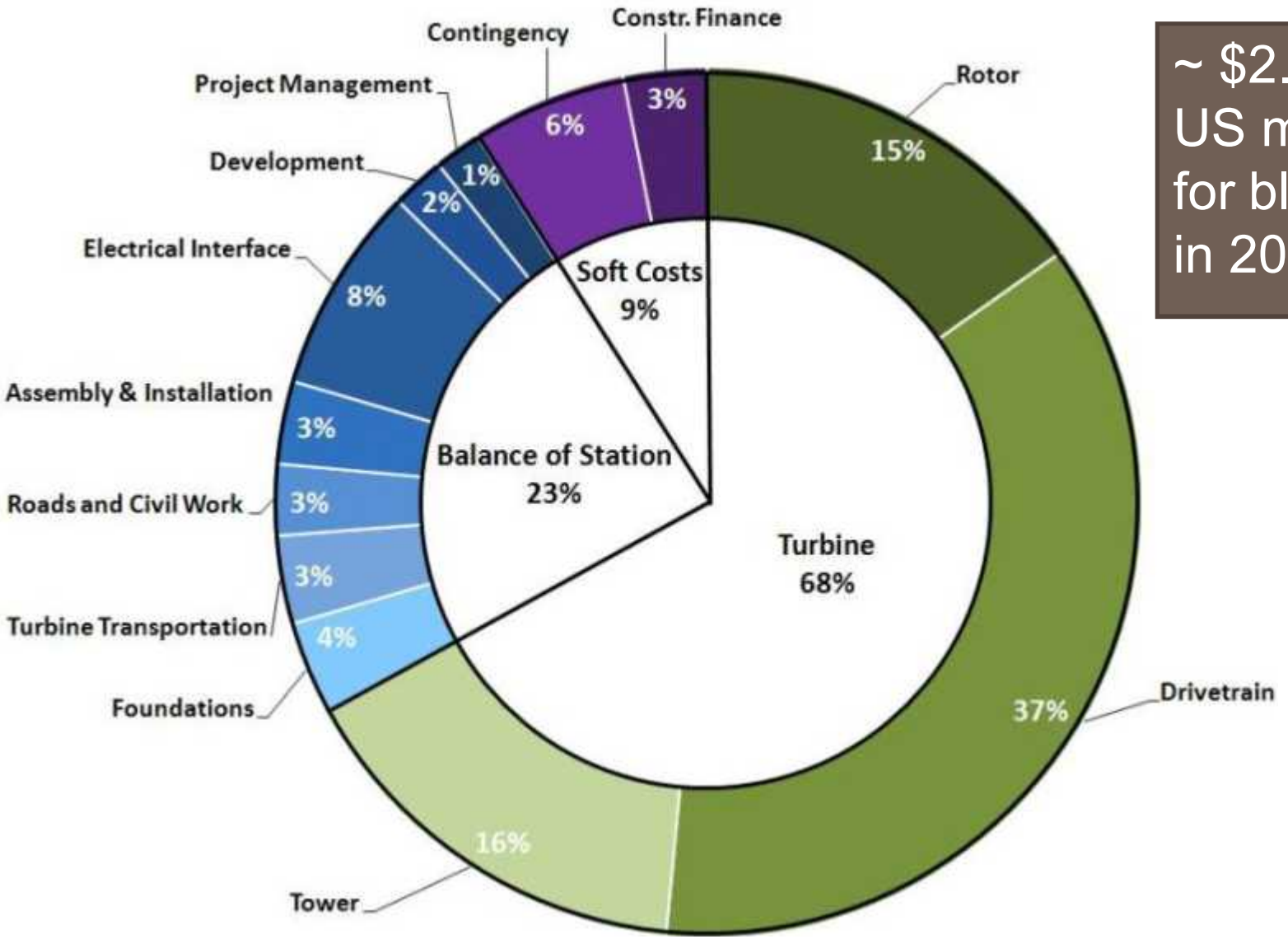


Domestic Manufacturing



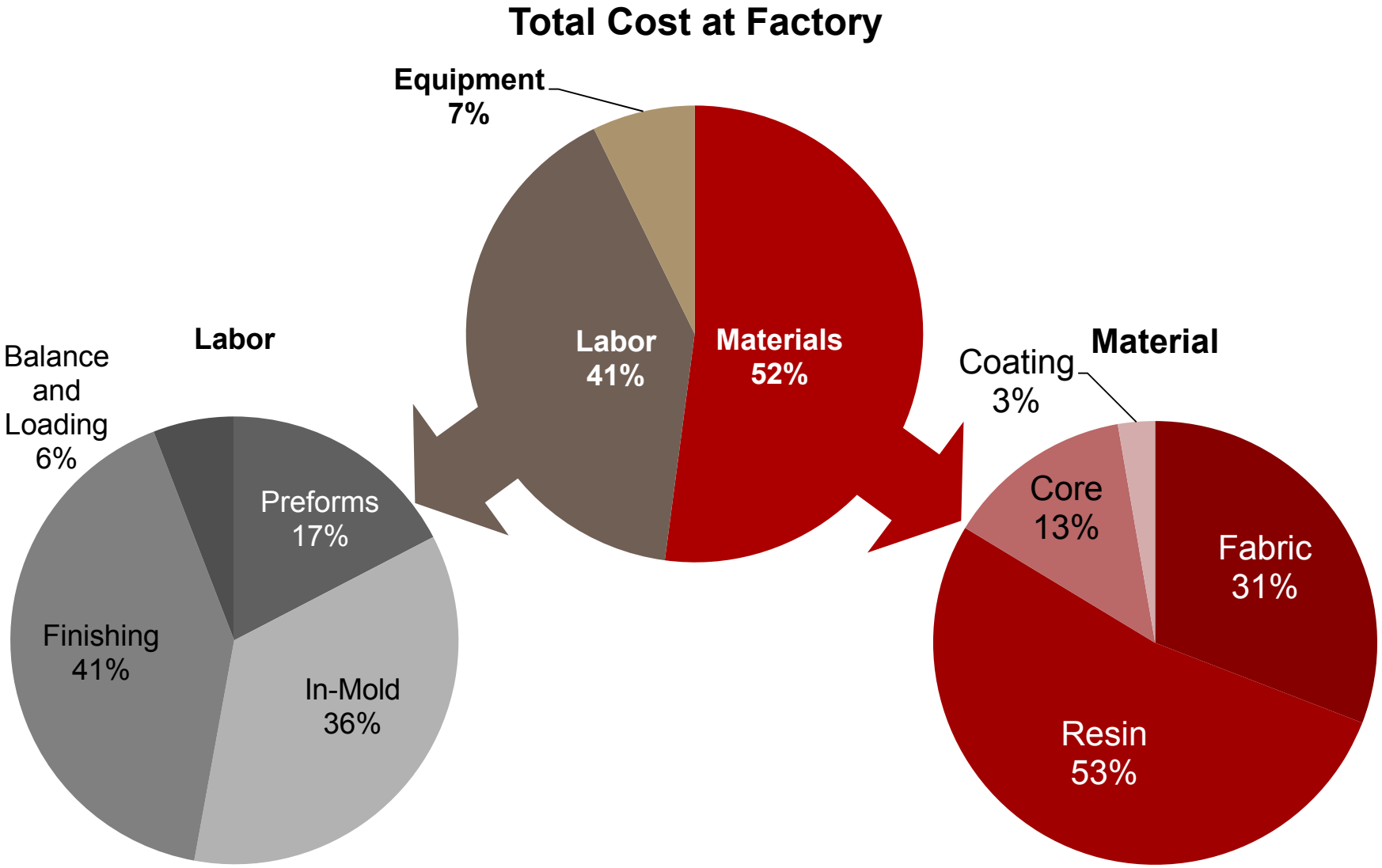


Capital Cost by Component

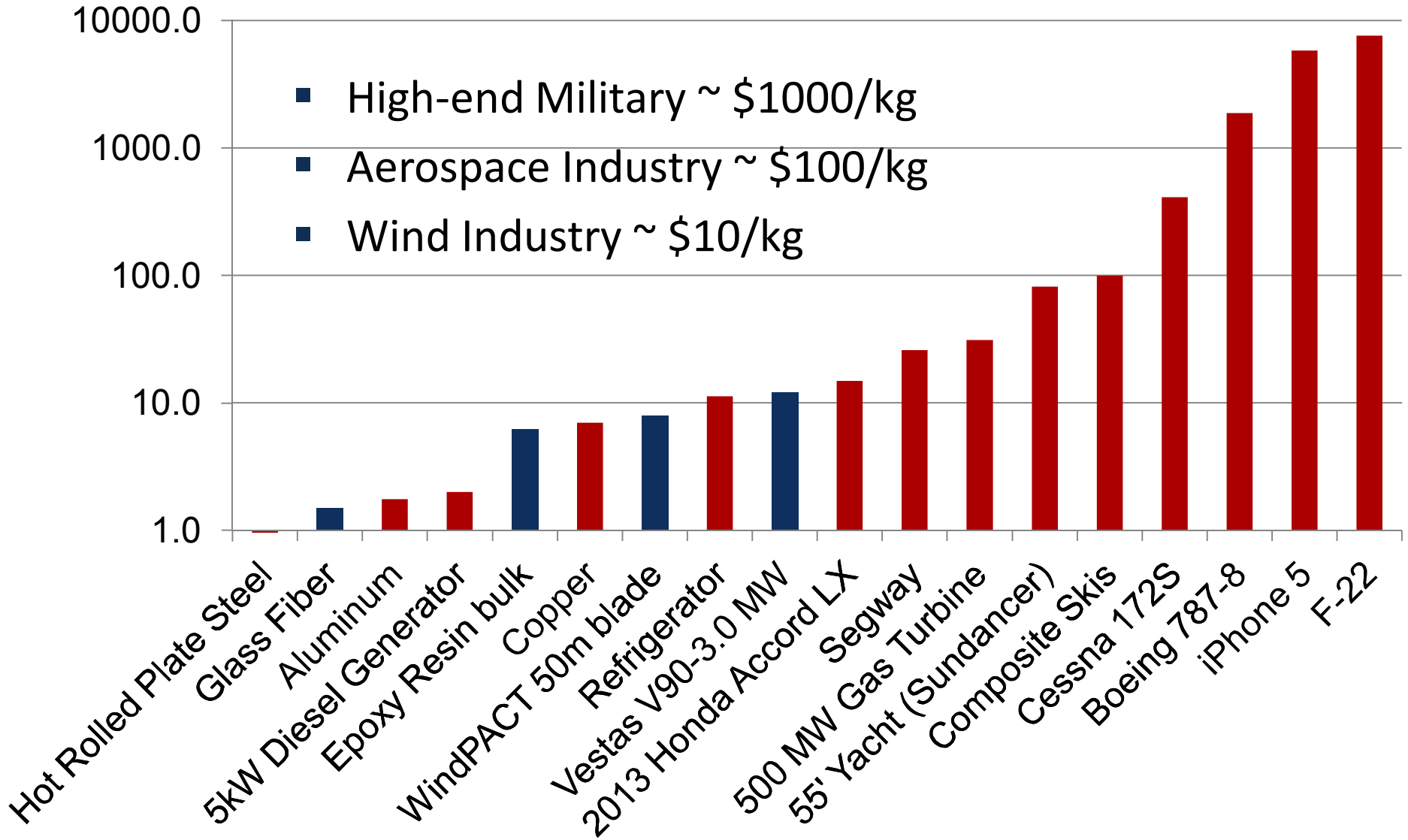


~ $2.5B US market for blades in 2012

Blade Cost – 40 m Blade



Materials Cost $/kg



US Wind Resource Quality Drop

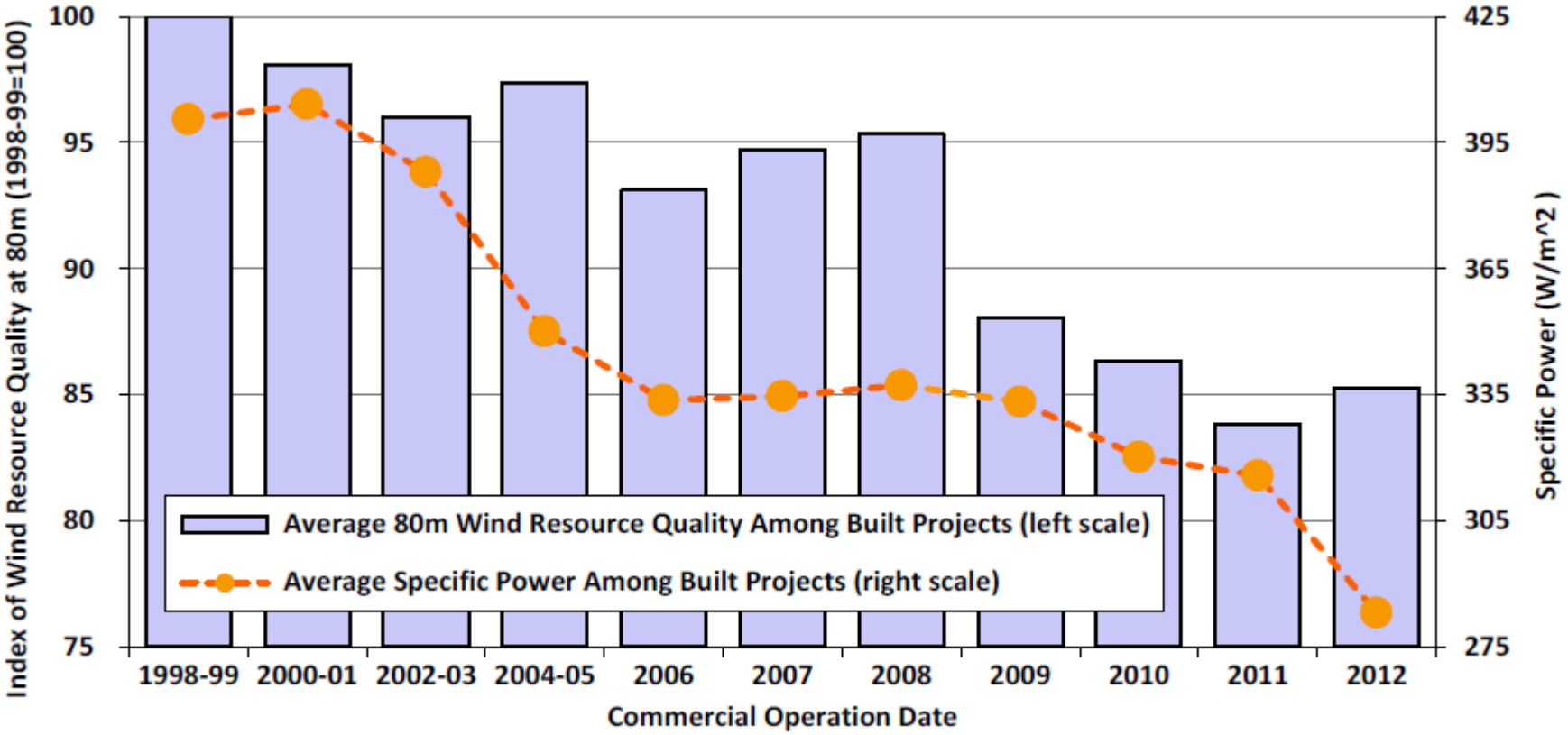
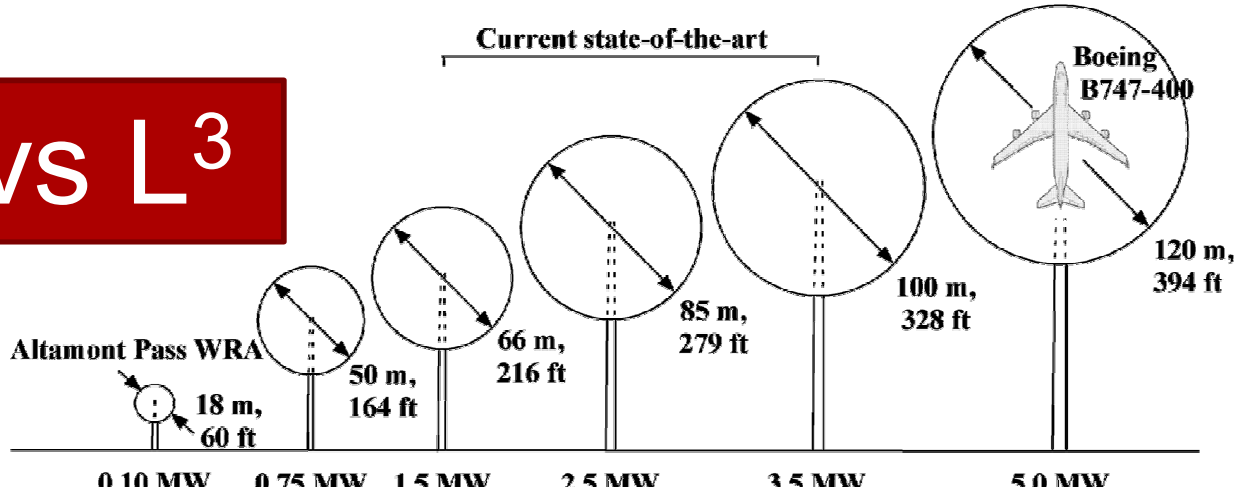
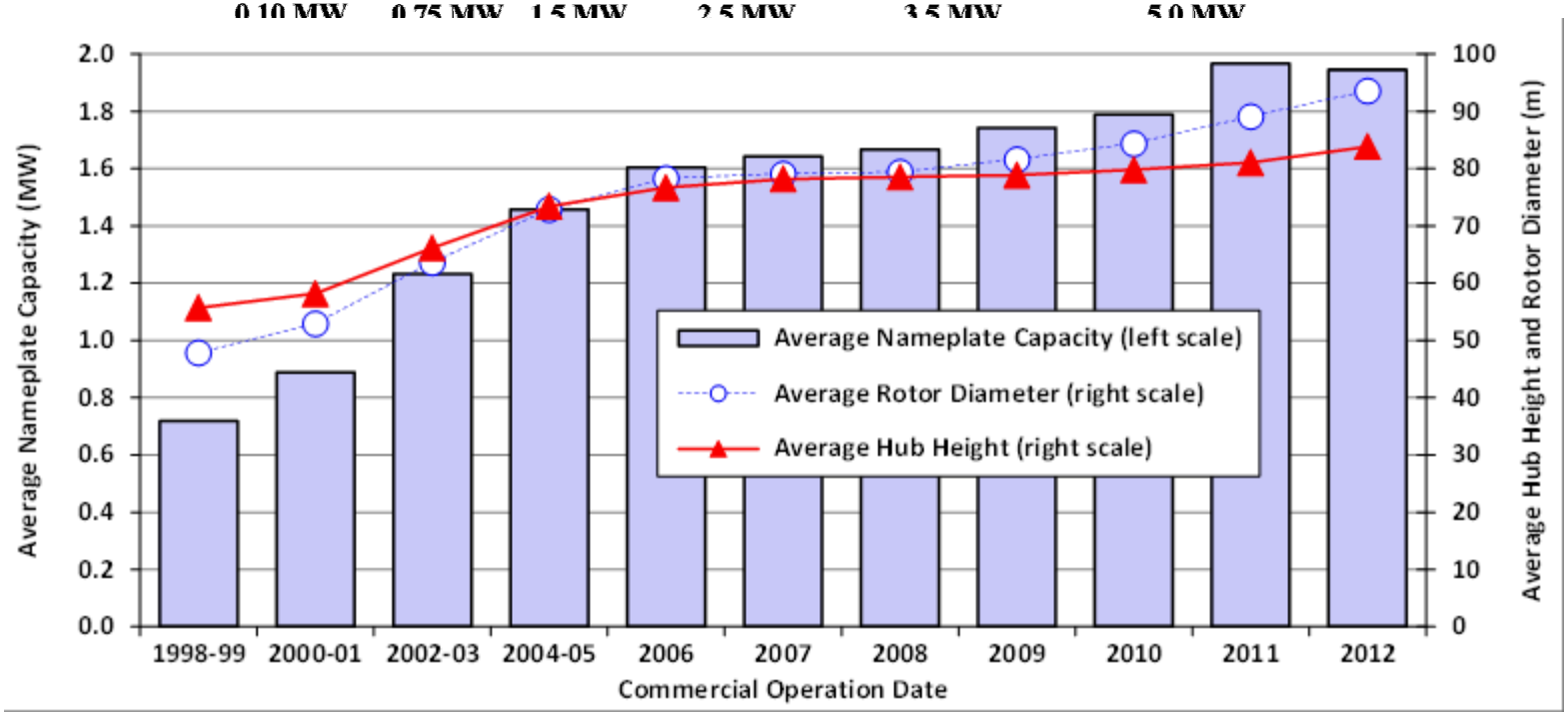


Figure 29. Index of Wind Resource Quality at 80 Meters vs. Specific Power

Turbines are Scaling Up

L^2 vs L^3





Transportation Challenges

- 10% or more of installed capital cost of blade is transportation
- Road-transport permits vary by state making logistics complex

Constraint	Road	Rail
Weight (ton)	75	>163
Length (m)	53	53
Width (m)	4.11	4.27
Height (m)	4.57	> 4.57

Market Summary

- Wind industry is global and industrialized
- Blade lengths are increasing for low-wind sites
- Material costs are a major portion of larger blade costs
- Transportation challenges increase for larger blades

Blade Technology Overview

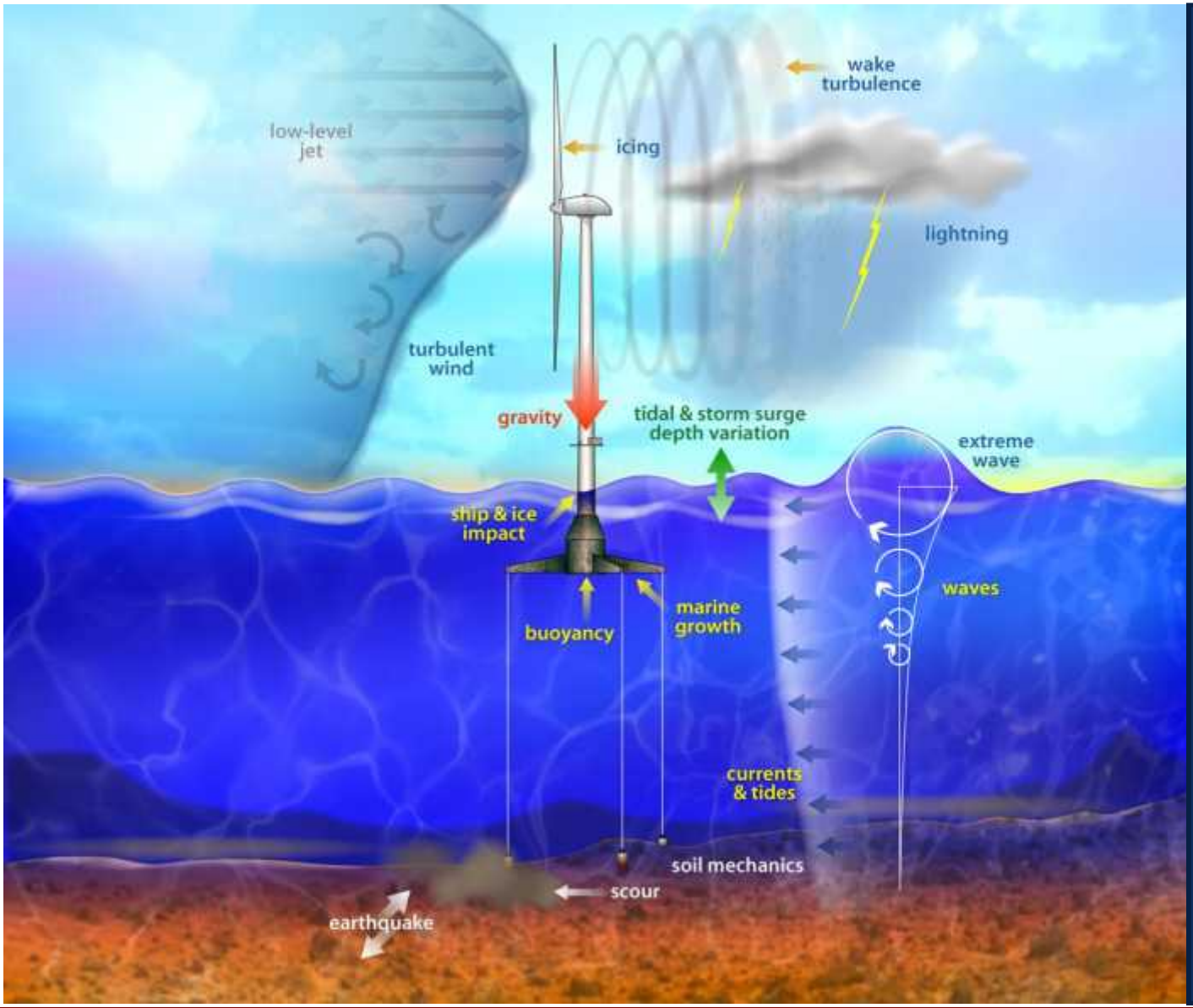
Basic Blade Design

Sandia National Laboratories

Identify Market → Aerodynamic Design → Structural Design → Manufacture → Test

Identify Market

Sandia National Laboratories



$$\frac{\$}{kWh}$$

Design Standards

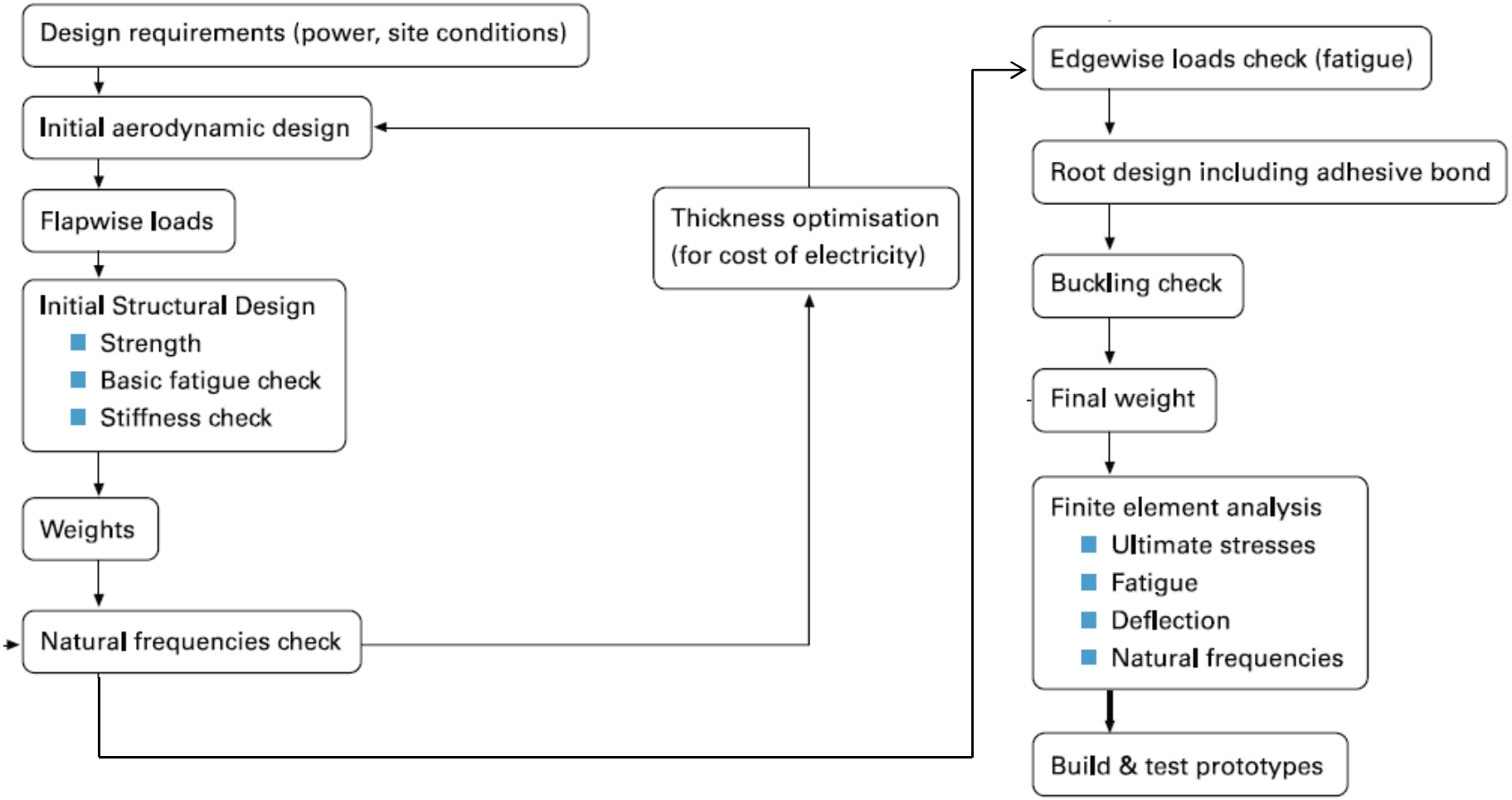
Sandia National Laboratories

International Electrotechnical Commission (IEC)

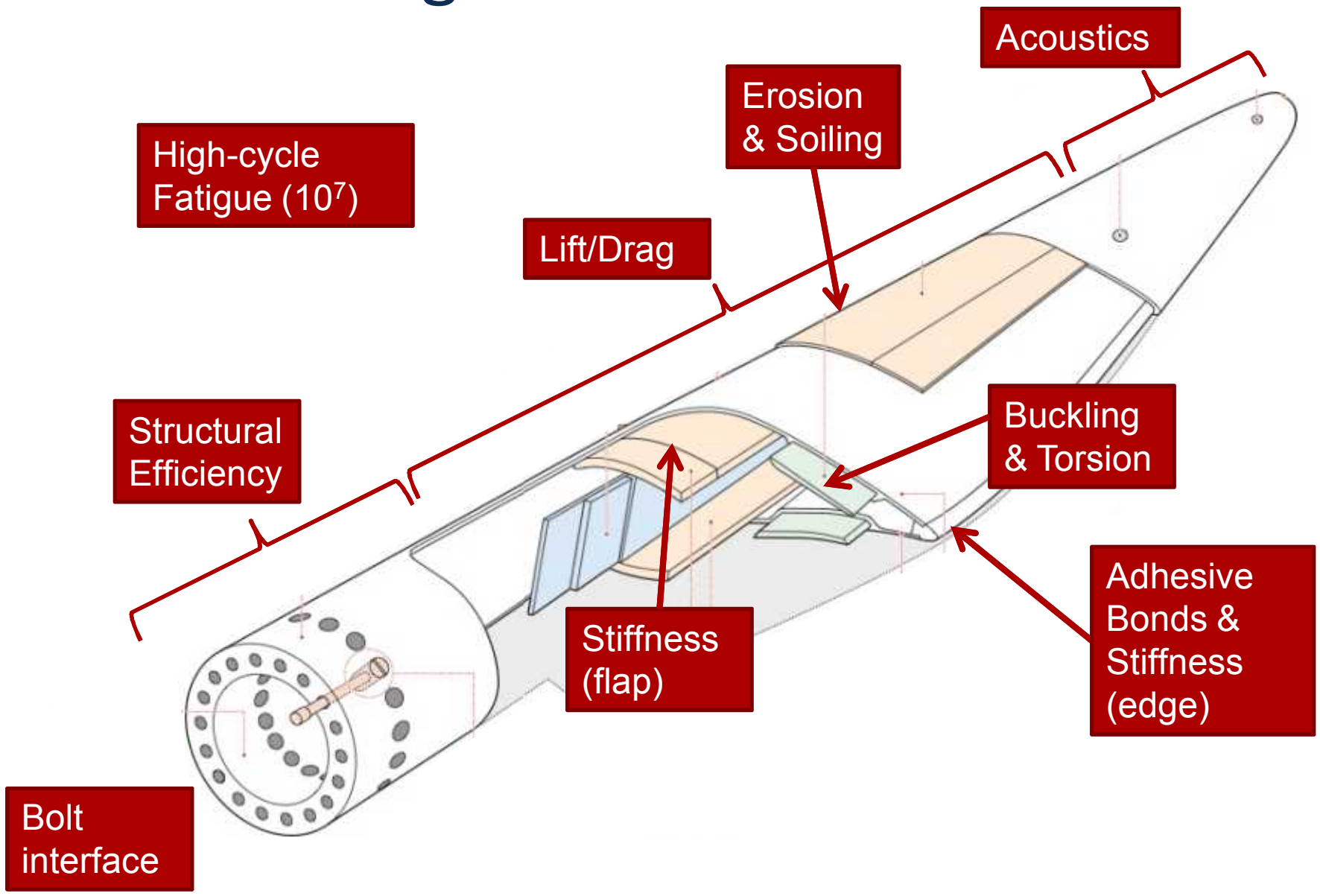
61400 series design standard + Germanischer Lloyd (GL) Blade standard set certification criteria

- Design load cases set loads depending on site characteristics, extreme weather events, normal and fault operations of a turbine.
- Partial safety factors applied to characteristic material properties based upon material and manufacturing parameters ~ 2-3 total safety factor
- 20+ year safe life design
- Can result in conservative (i.e. heavy) blade designs

Design Process



Blade Design Drivers

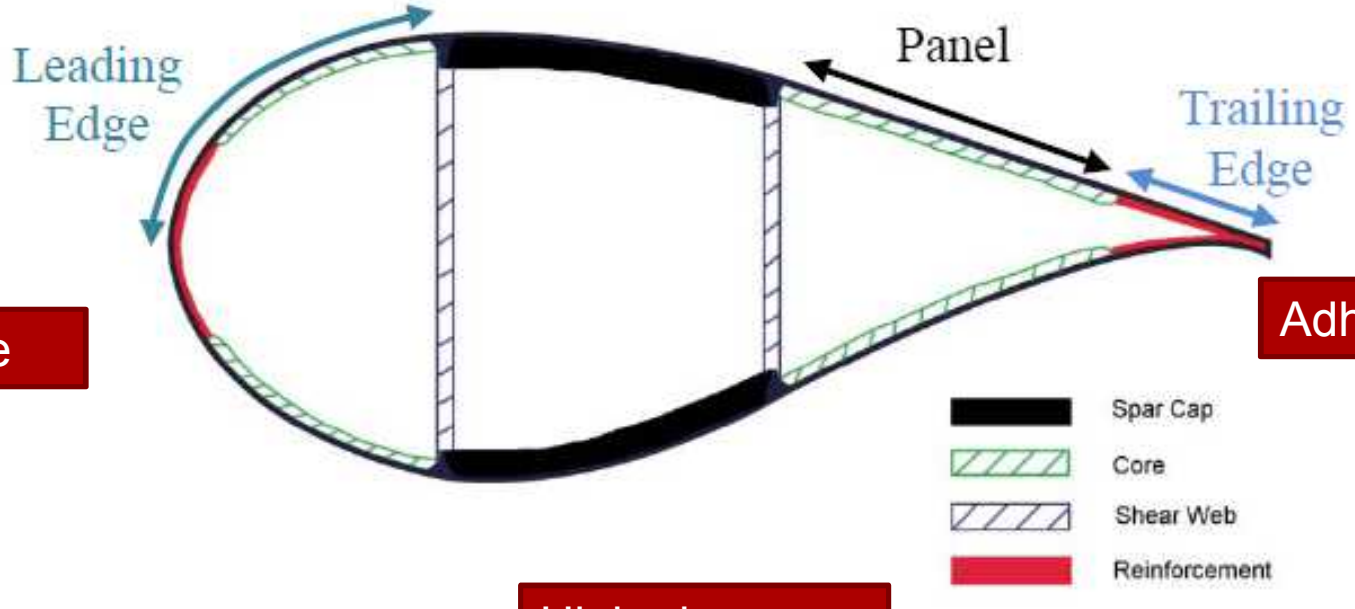


Material Selection

Sandia National Laboratories

Biaxial fabric - core sandwich

Uni-directional fiber



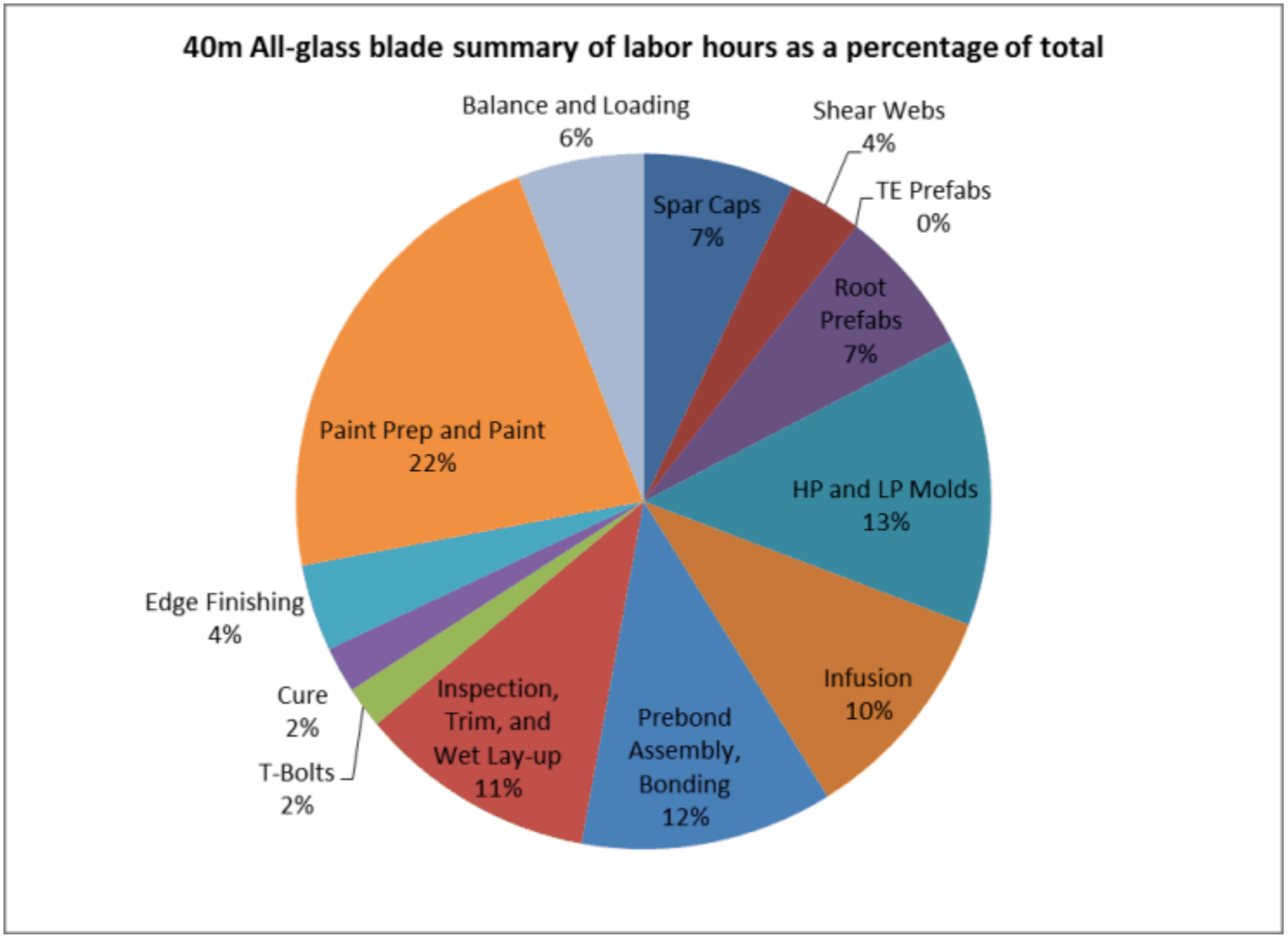
Adhesive

Adhesive

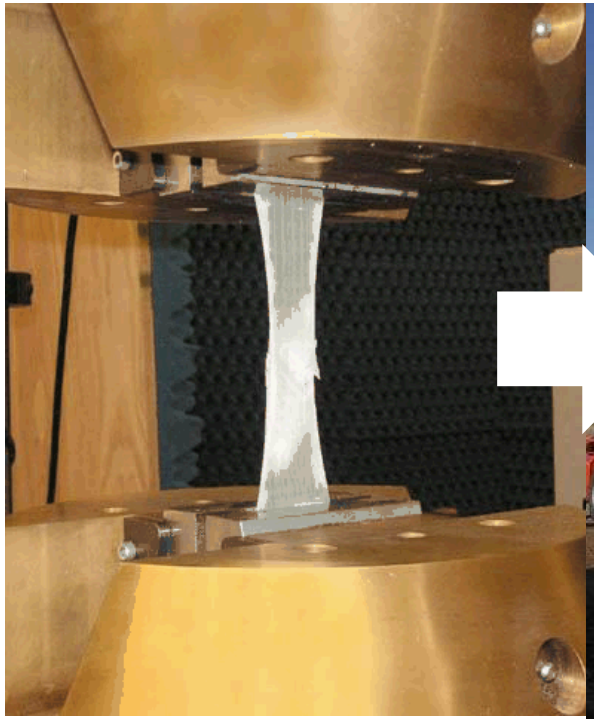
High-shear modulus core

Manufacturing Technology

Manufacturing Process



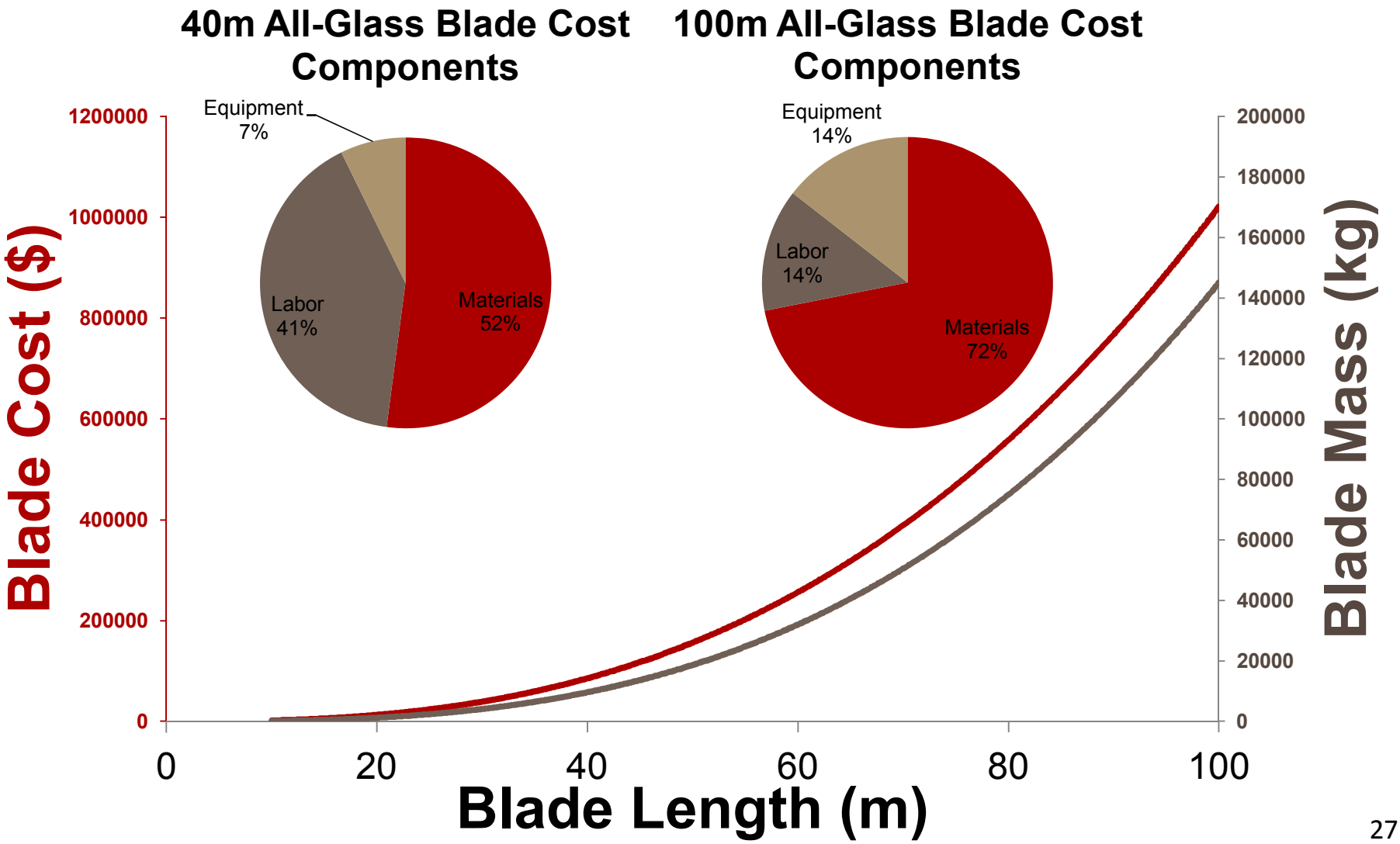
Current Testing



Coupon testing → characteristic value → partial factors→ design allowable

Tooling (molds) manufactured → 2 full-scale blades fabricated → 1 blade tested to ultimate loads → 1 blade tested for fatigue loads

Scaling Current Technology



Blade Technology R&D Opportunities

Design Philosophy

Sandia National Laboratories

Rotors are responsible for ALL of the energy capture and a MAJORITY of the loads into other components of a wind turbine.

Therefore..

MAXIMIZE energy capture (kWh)

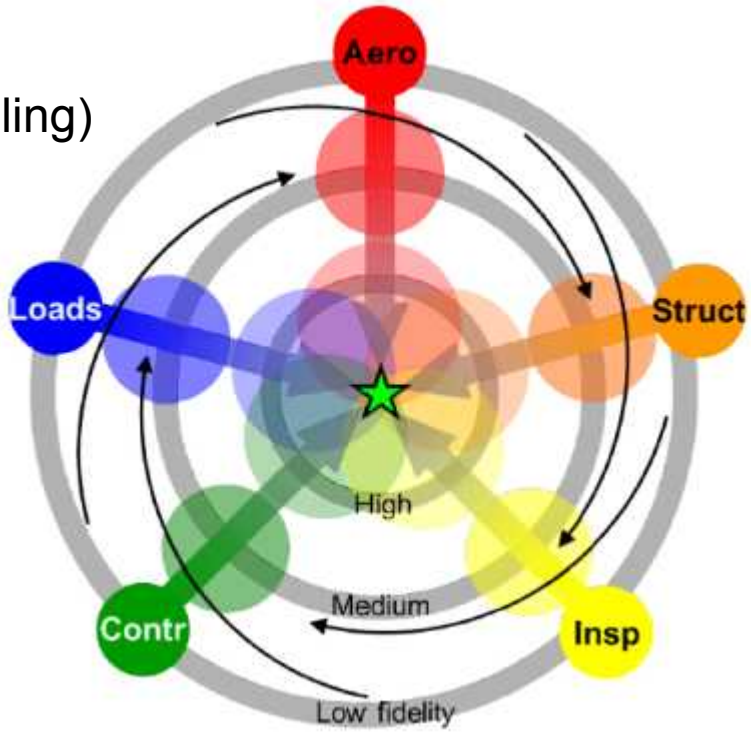
- Rotor length (area)
- Reliability (minimize downtime)
- Performance (reduced losses from soiling)

MINIMIZE cost ($)

- Materials
- Manufacturing productivity
- Non-torque loads into turbine (reduce cost of system)

REQUIRES

Multi-disciplinary team
Multi-scale optimization
Multi-fidelity tools



Fundamental Question

?

=

Damage Tolerant Design

Sandia National Laboratories

Residual Strength Analysis

+

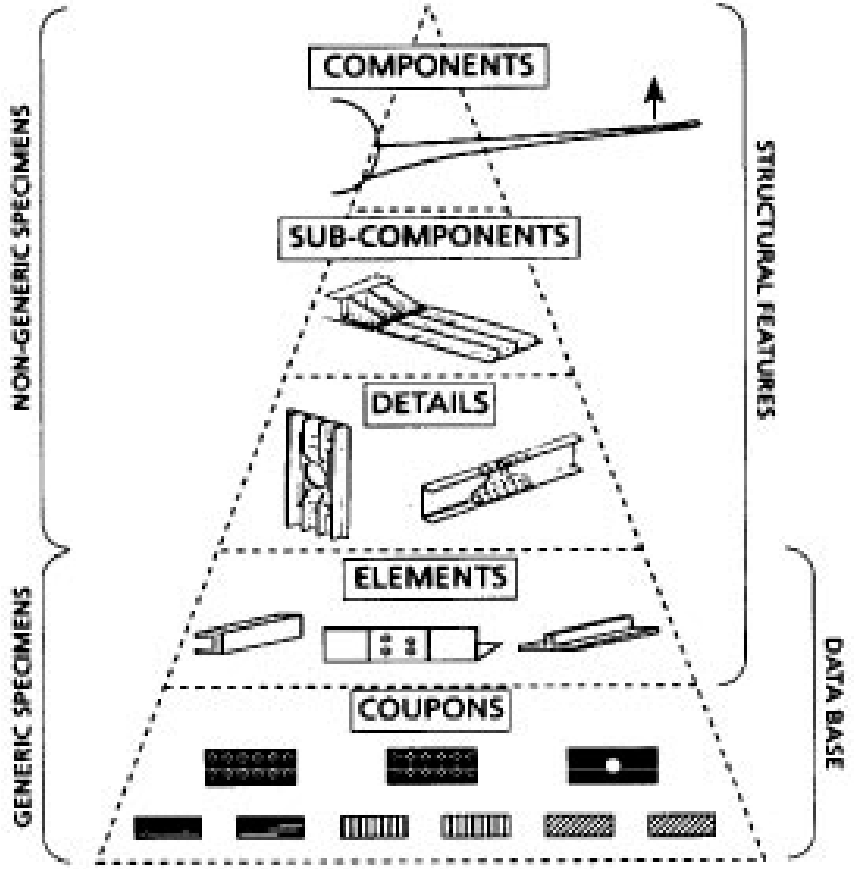
Progressive Damage Analysis (requires a damage growth model and accurate loads data)

+

Inspection Program

= **No in-service failures**

Testing Approach for Composites



Building Block Approach,

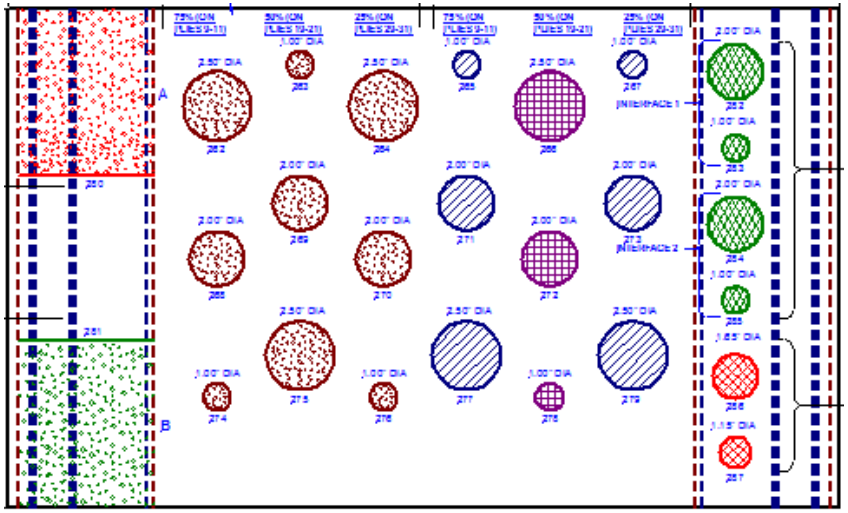
MIL HDBK 17

Statistical Variability for each level established

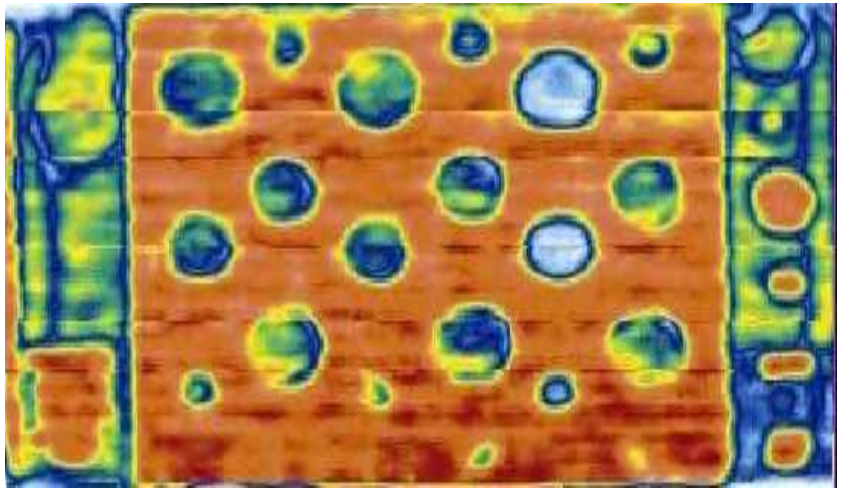
Inspection Technology

Inspection methods are need at the manufacturing plant and in the field to improve quality and reliability

- Test specimens with different flaw types and sizes
- Evaluation of non destructive inspection (NDI) methods to determine probability of flaw detection
- Operationalize methods for manufacturers and inspectors



Test Specimen of Known Flaws



Ultrasonic Scan

Manufacturing Cost Reduction

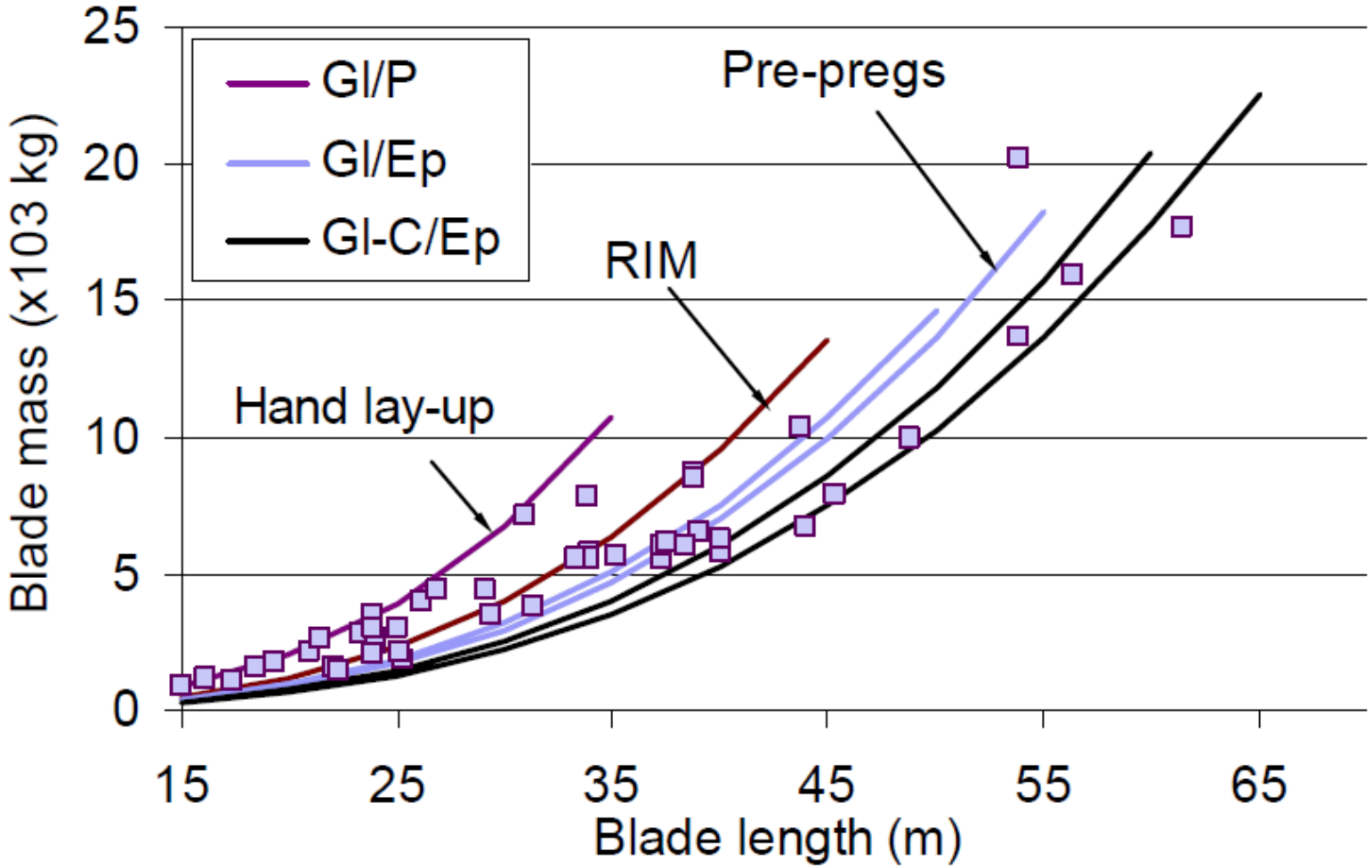


Figure 6 Blade mass trend with respect to technology

Materials Cost

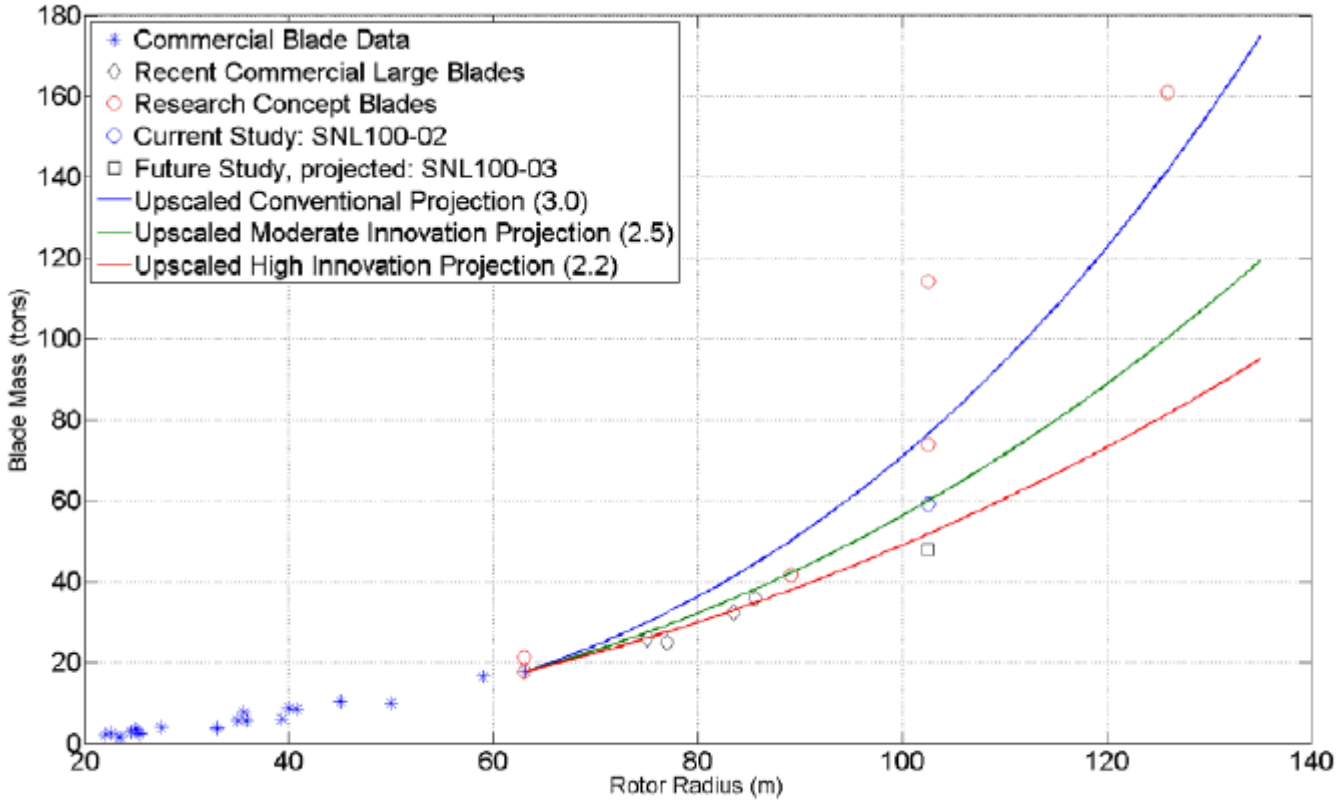


Figure 1. Blade Mass Survey and Projections Versus Rotor Radius

Carbon vs Glass Cost & Performance

Sandia National Laboratories

	Glass (PPG Hybon 2002 XM)	Carbon (Zoltek Panex 35)
Tensile Strength (MPa)	1200	4137
Tensile Modulus (GPa)	52	242
Density (kg/m^3)	2500	1810
Specific Strength Carbon/Glass	4.7x	
Specific Modulus Carbon/Glass	6.4x	
Cost Carbon/Glass	15-20x	

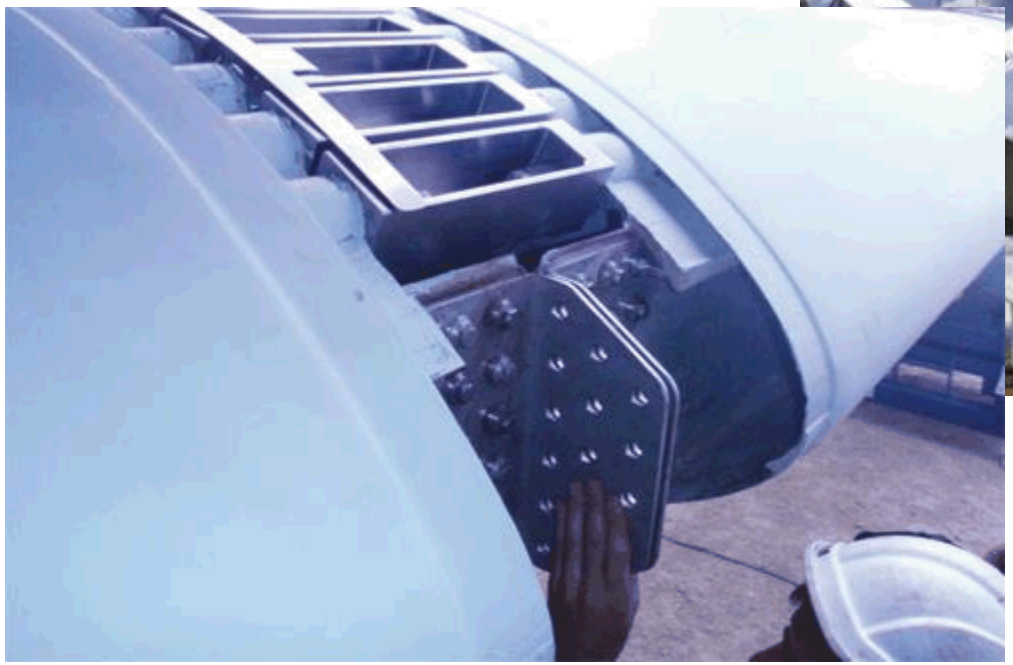
Transportation

Sandia National Laboratories

Transportation costs will continue to increase for large blades on land

New Transportation Modes

Segmented Blades

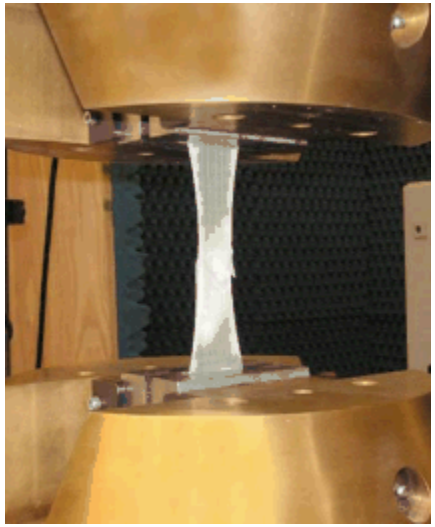


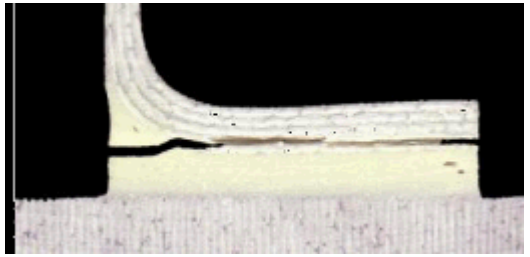
Sandia Wind Research and Collaboration

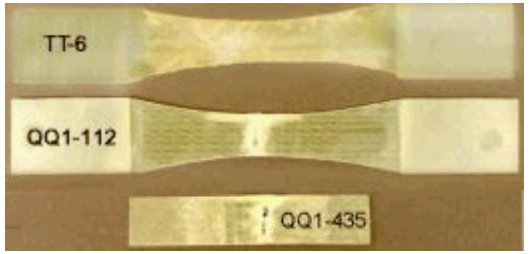
Materials Research

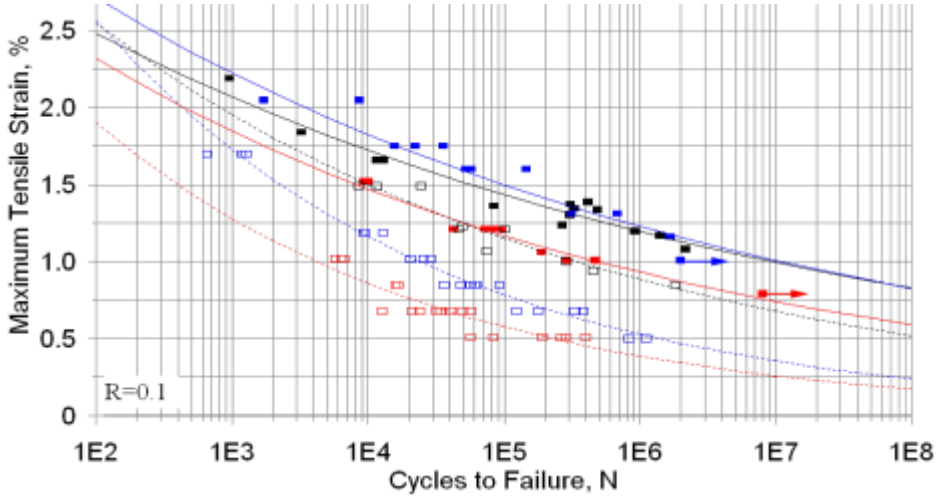
Characterize static and fatigue properties of blade materials from suppliers (resins, fabrics, adhesives, cores), and laminates and structural details from blade manufacturers.

Results published in Composite Materials Database since 1989









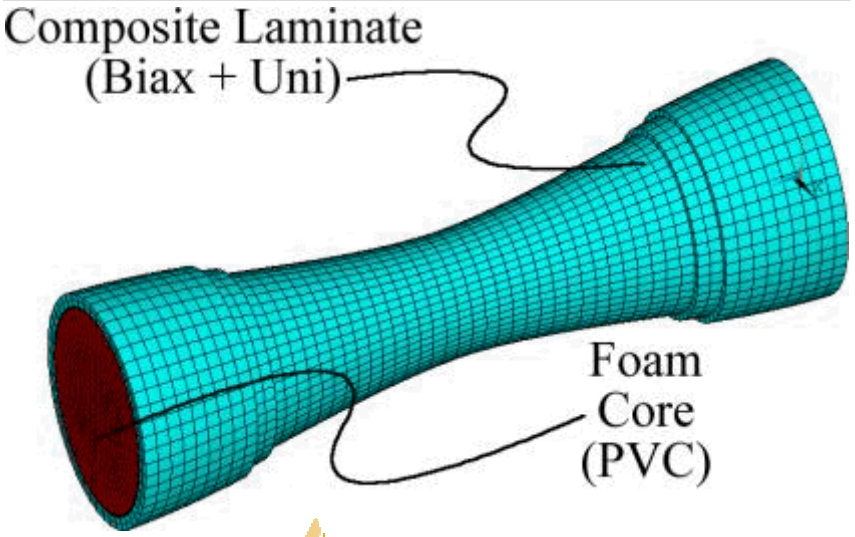
MONTANA STATE UNIVERSITY

Substructure Testing

Sandia National Laboratories

Building Block Approach

- Complex loads
- Structural Details



MONTANA STATE UNIVERSITY

SWIFT Test Site

Sandia National Laboratories

Scaled Wind Farm Test (SWiFT) Facility

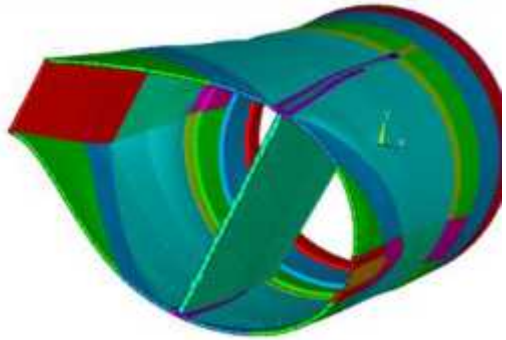
Cost-effective wind plant testing facility to transition basic research to commercialization

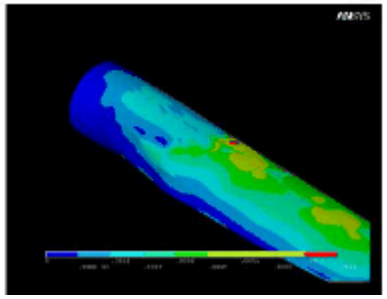
- Lubbock, Texas
- 3 x 225 kW Turbines
- ~14 m blades
- Highly instrumented site and turbines
- Modern technology

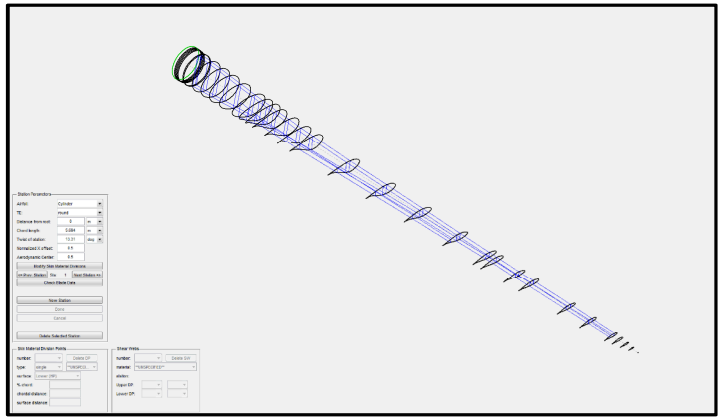
TEXAS TECH UNIVERSITY

Blade Design Tools & System Modeling

- Design codes to analyze:
  - Structures
  - Aerodynamics
  - Control
  - Aero-servo-elastic stability
  - Manufacturing costs
- Tools:
  - NuMAD
  - Public blade models (100m)
  - Blade manufacturing cost model

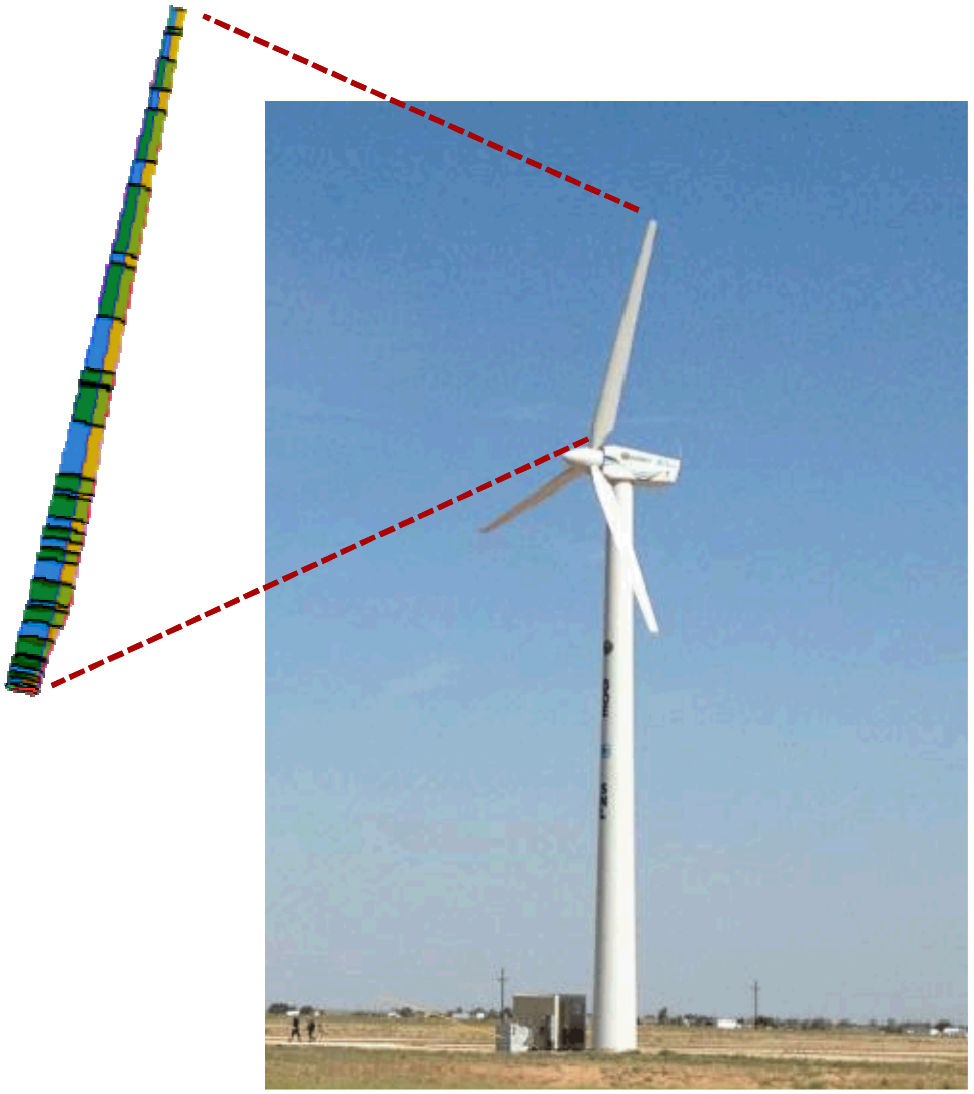






National Rotor Testbed

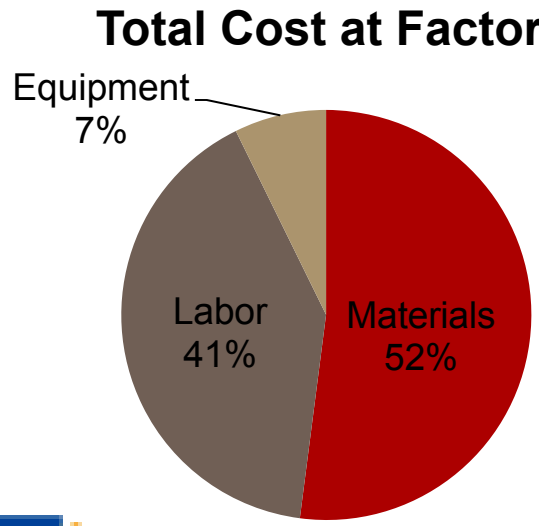
- Design and manufacture sub-scale rotors for the SWiFT turbines to emulate a modern, megawatt scale rotor.
- Enables low-cost field testing of new rotor technologies.
- Public rotor design



Advanced Manufacturing Initiative

Sandia National Laboratories

Goal: Increase labor productivity by 35% and reduce cycle time by 35% while maintaining or improving part quality.



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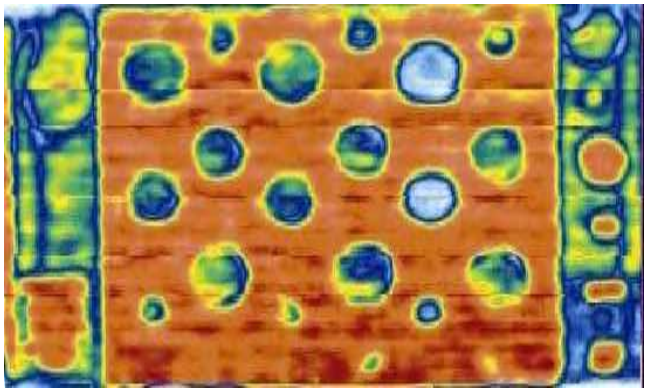
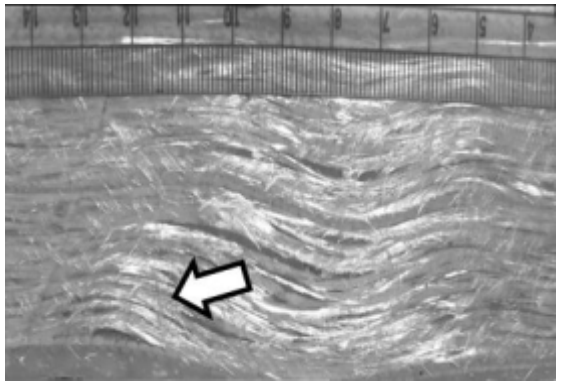
IOWA STATE UNIVERSITY

Blade Reliability Collaborative

Improve the reliability of blades through field investigations, inspection technology, evaluating effects of defects, and improved design, analysis and certification



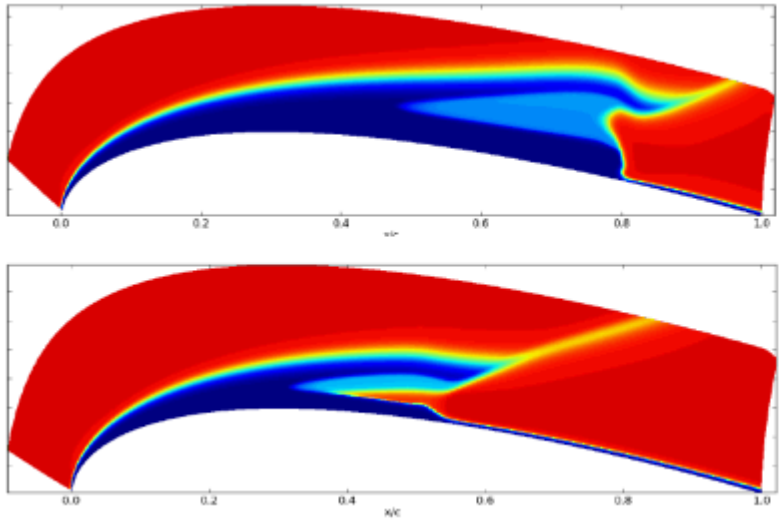


Many industry participants

Leading-Edge Erosion:

Characterization
Measurement
Modeling

Oran W. Nicks Low Speed Wind Tunnel

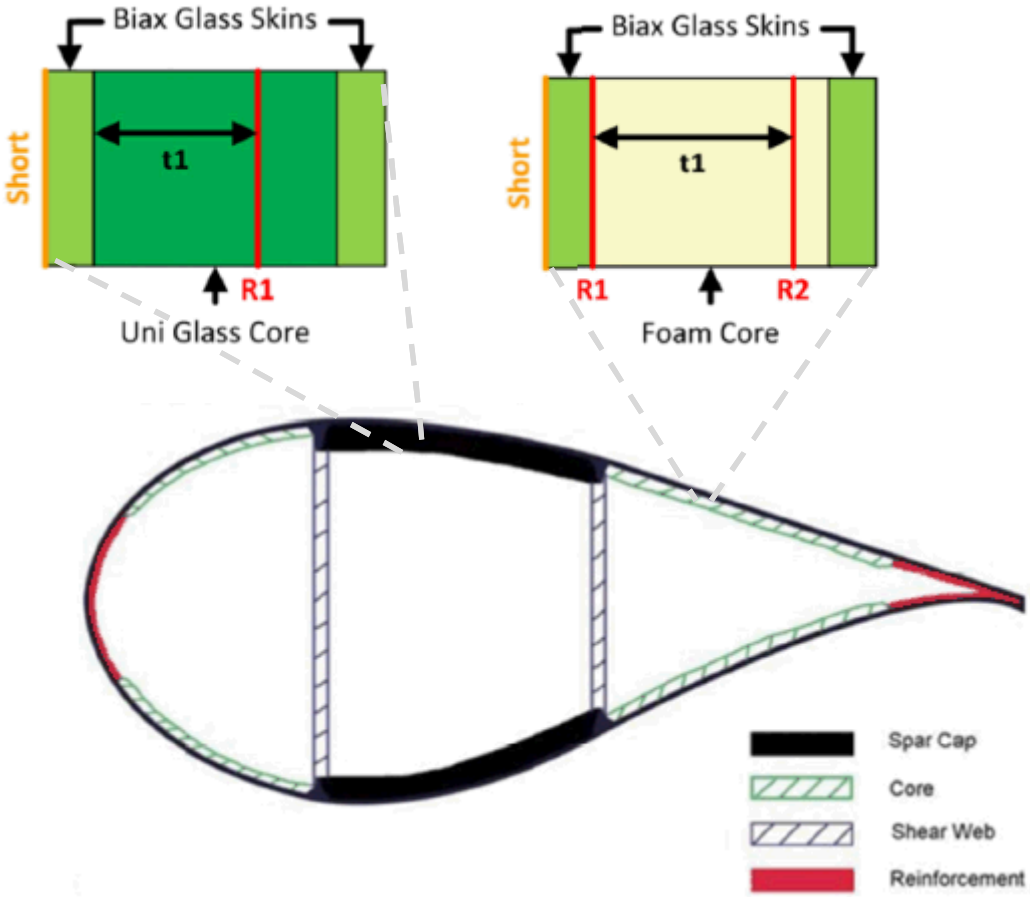


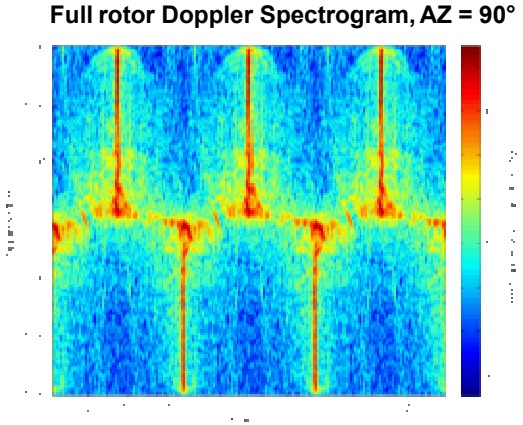
No Roughness

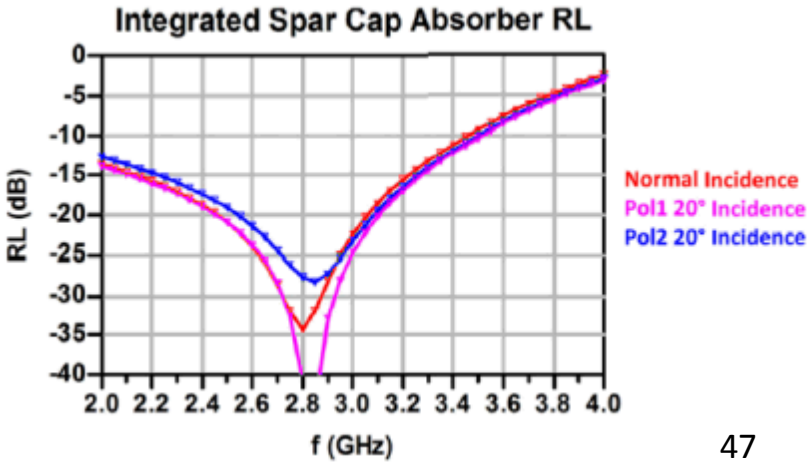
k_s = 350 μm

Radar friendly blade

Develop a low-cost material treatment compatible with current manufacturing processes that can reduce the RCS by 20 dB





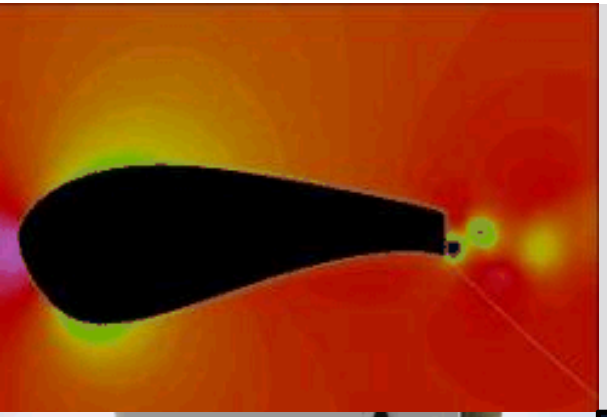


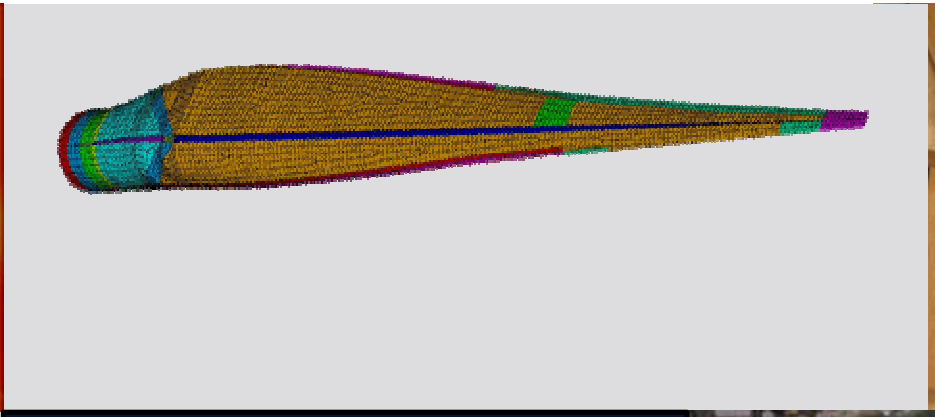
Funding and Partnerships

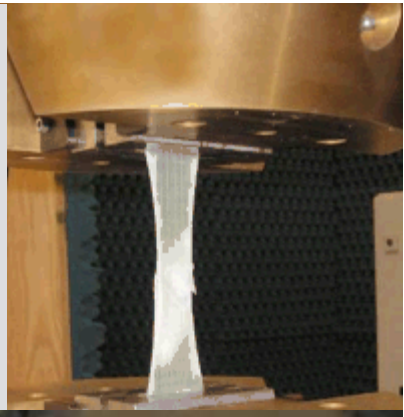
Sandia National Laboratories

- Primary customer is Department of Energy Wind and Water Power Technologies Office
- Partnerships with industry and universities is common and instrumental to many research projects
- Various funding mechanisms exist to support partnerships as well as information sharing

Rotor Technology Integrators





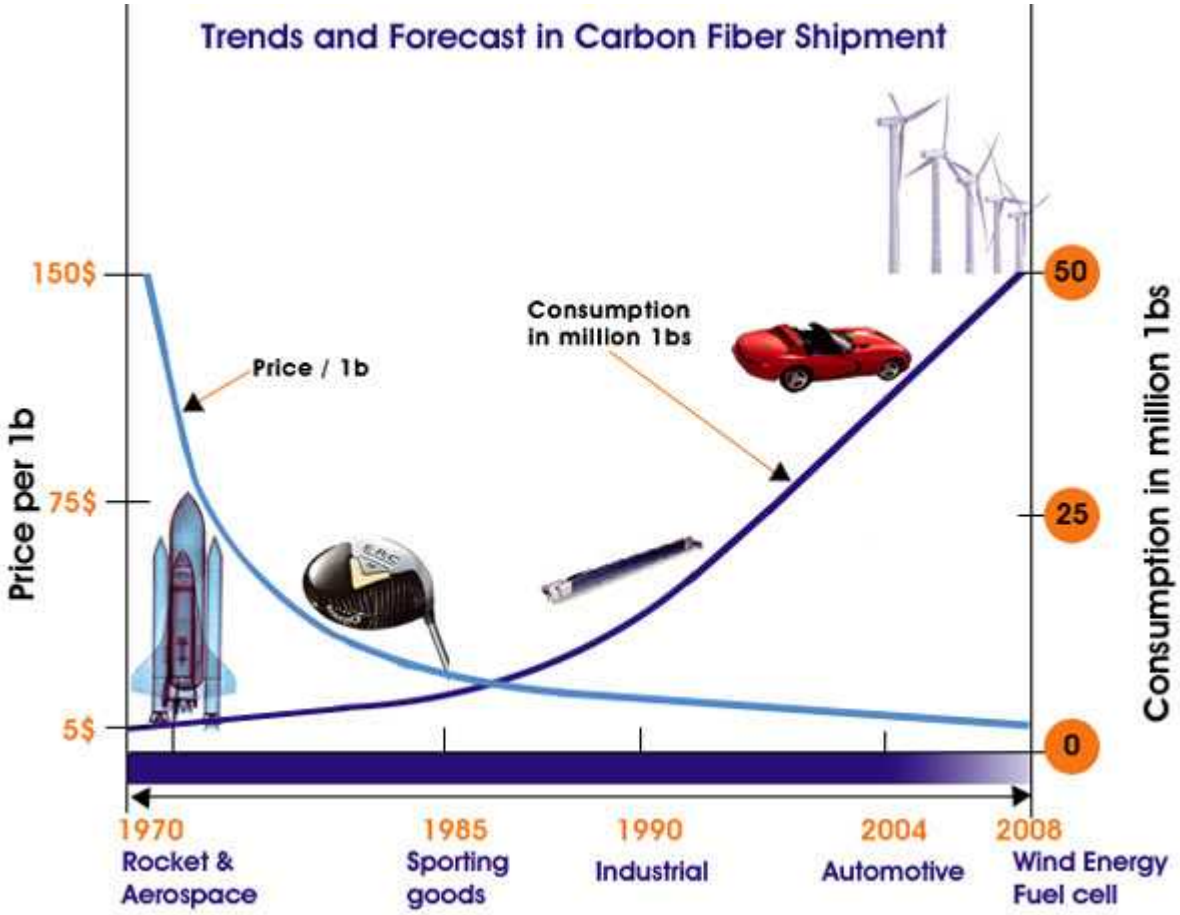


Sandia National Laboratories

wind.sandia.gov

Addendum

Carbon Fiber Market Is Growing



15,000 metric tons c-fiber used in wind in 2012