Wind Turbine Blade Technology

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The picture shows Sandia staff next to a minivan at the base of a GE 1.5 MW turbine in Lamar, Colorado.

Outline

- Overview of wind energy technology
- Overview on the wind energy business
- Perspective of wind turbine blades
- Blade manufacturing
- Blade research
- Critical issues for advanced technology
  - Design
  - Materials
  - Embedded devices and sensors

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Stanford Composites Class, 11-September-2007, Paul Veers

This presentation is intended to give a broad overview of the current status of wind technology, the blades being manufactured for this technology, and the future research issues on composite blade design and manufacturing.

Courtesy of LM Glassfiber

Current Blade Technology

- All composite with steel bolt circle to attach to the pitch bearing
- 34 - 61.5 meters
- 5 - 18 tonnes
- Fiberglass
- Small amounts of carbon fiber in some blades
- Size limited by overland transportation

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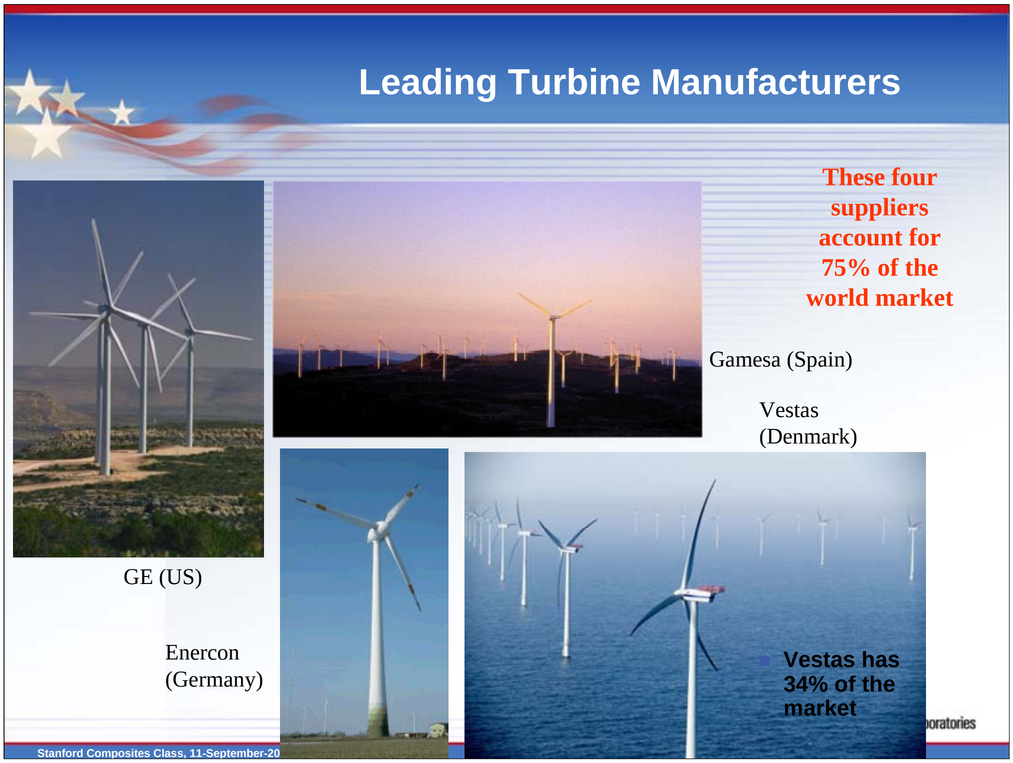
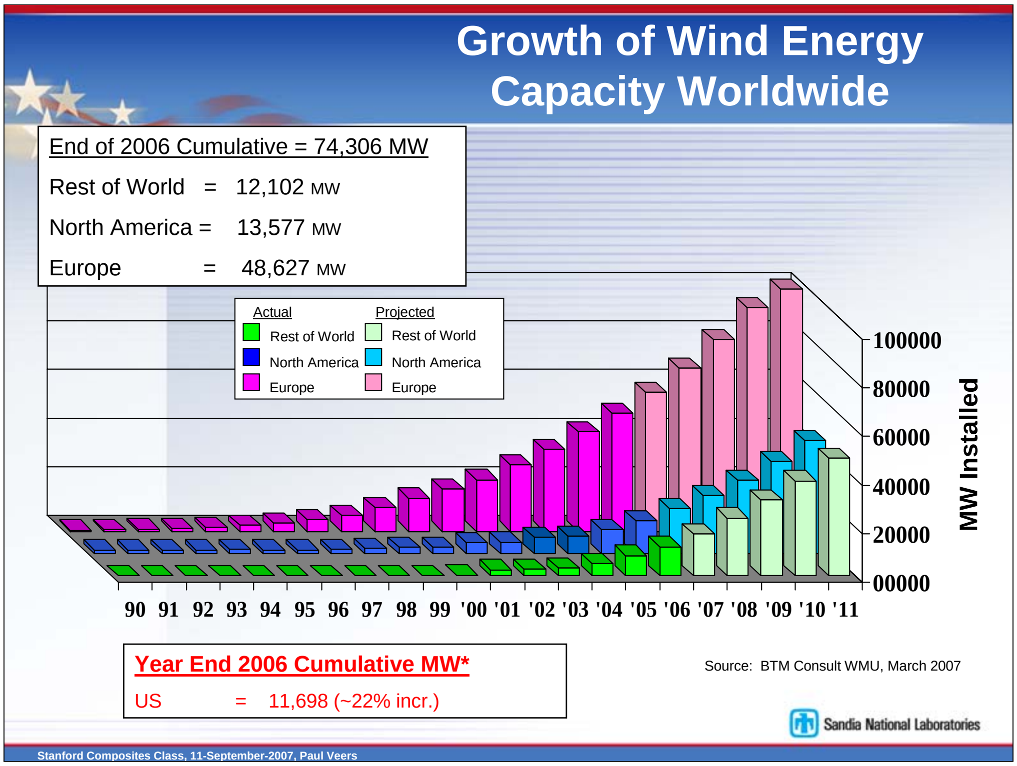
Current wind turbine blades are some of the largest composite structures being manufactured on the planet. These blades are almost 100% composites, with the exception of the bolting hardware at the root of the blade – where it attaches to the turbine hub. They are mostly glass fiber with a variety of resins and core materials depending on the manufacturer. Carbon fiber is finding increasing use as the size gets larger and the constraints on both strength and stiffness become more difficult to match with glass. However, there is no consensus that glass can not continue to provide the bulk of the fiber used in their manufacture. The size of turbines is beginning to push up against some constraints for on-land transportation of several components, not just blades.



About 75% of the wind turbine systems sold on the world market come from just four companies. Vestas (Denmark) had over a quarter of the total market in 2006. The next three, GE (US), Enercon (Germany), and Gamest (Spain) each had roughly 15%. There are two growing companies that combine for another 15% - Suzlon (India) and Siemens (previously Bonus of Denmark).

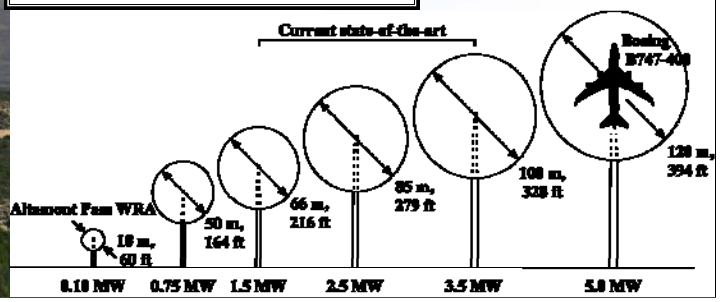


The growth in the world market has been exponential over the last 20 years and is expected by the experts (BTM Consult) to stay on a roughly 20% per year growth trajectory. While Europe is expected to continue to lead the market for some time, the US market is expected to passed by the “rest of the world” category that includes everything that is not North America and Europe.

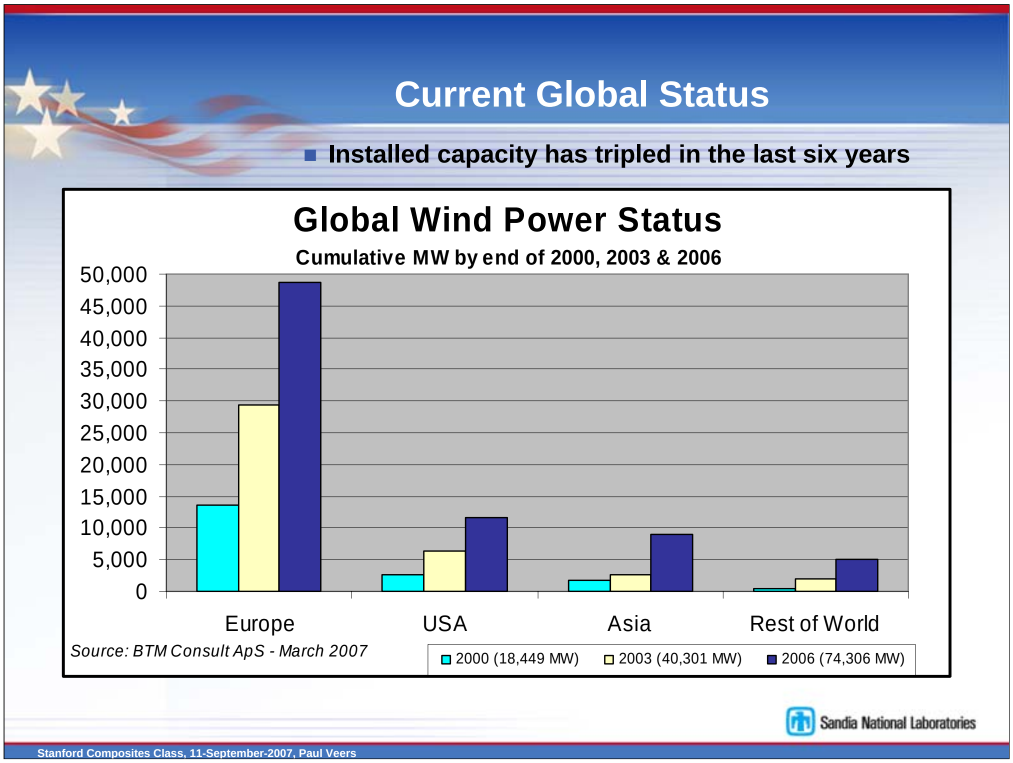
Wind Industry Trends & Challenges

- Recent Costs (2003)
  - System ~$3/lb
  - Blades ~$5/lb
  - ~ $1000/KiloWatt
  - 4 - 6 ¢/kWh
- 2006 costs are up over 50%
  - Steel & copper
  - Currency exchange rate
  - **Limited Suppliers**

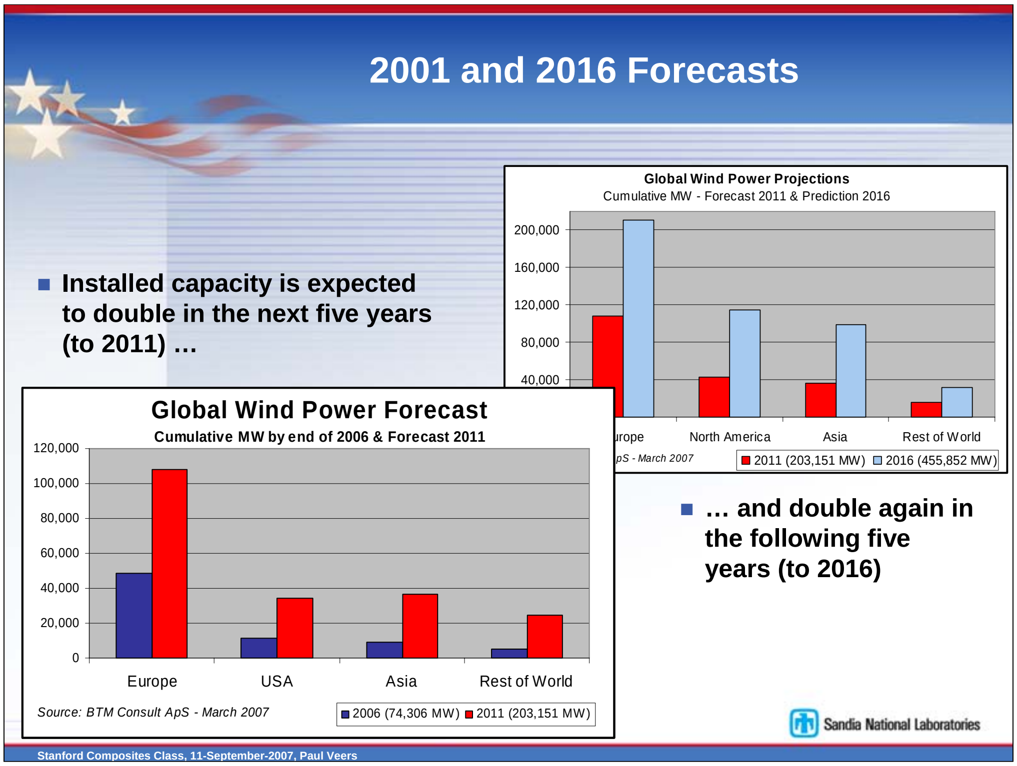
- Size
- 1.5-5.0 MW
- Towers: 65-100 meters
- Blades: 34-60 meters
- Weight: 150-500 tons



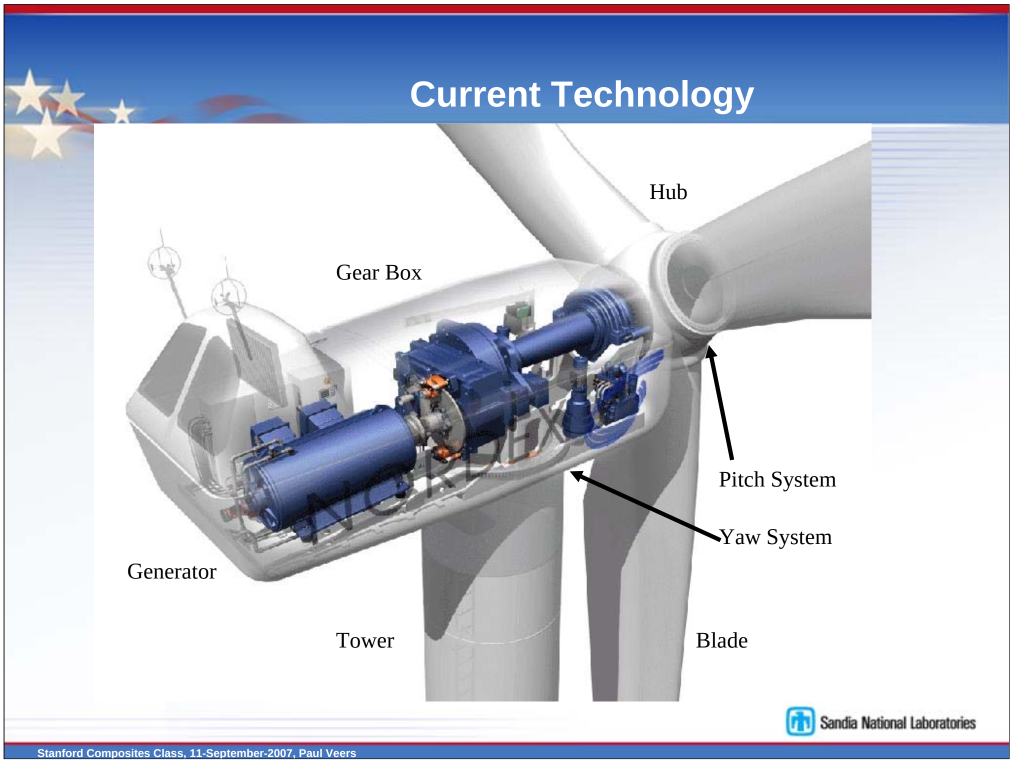
The size of modern wind turbines has grown from 15m diameter (50kW) machines in the 1980s to 120m diameter (5MW) machines aimed at the offshore market today. The most common size now in production ranges from 1.5MW to about 3MW, with diameters ranging from 70m to 90m. Cost of turbine systems have continued to drop until reaching a minimum in 2003 at about 4-6 cents per kWh. Since 2003 prices have increased in the US due to a drop in the value of the dollar, steep increases in commodity prices (steel, copper, concrete, transportation fuel, etc.) and a limited number of suppliers has made it a seller's market.



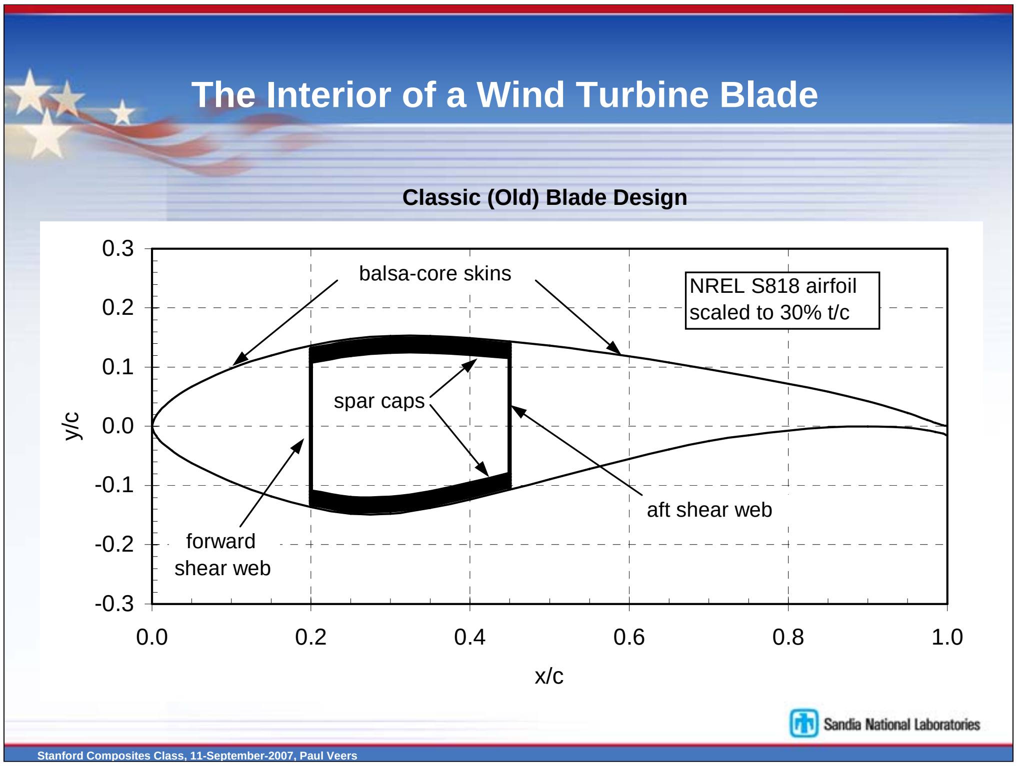
The global market has tripled installed capacity in the last six years, the result of a 25% per year growth rate. This has been largely due to the strong and sustained support for wind energy development in Europe, but the largest market in the next few years is expected to be in the US.



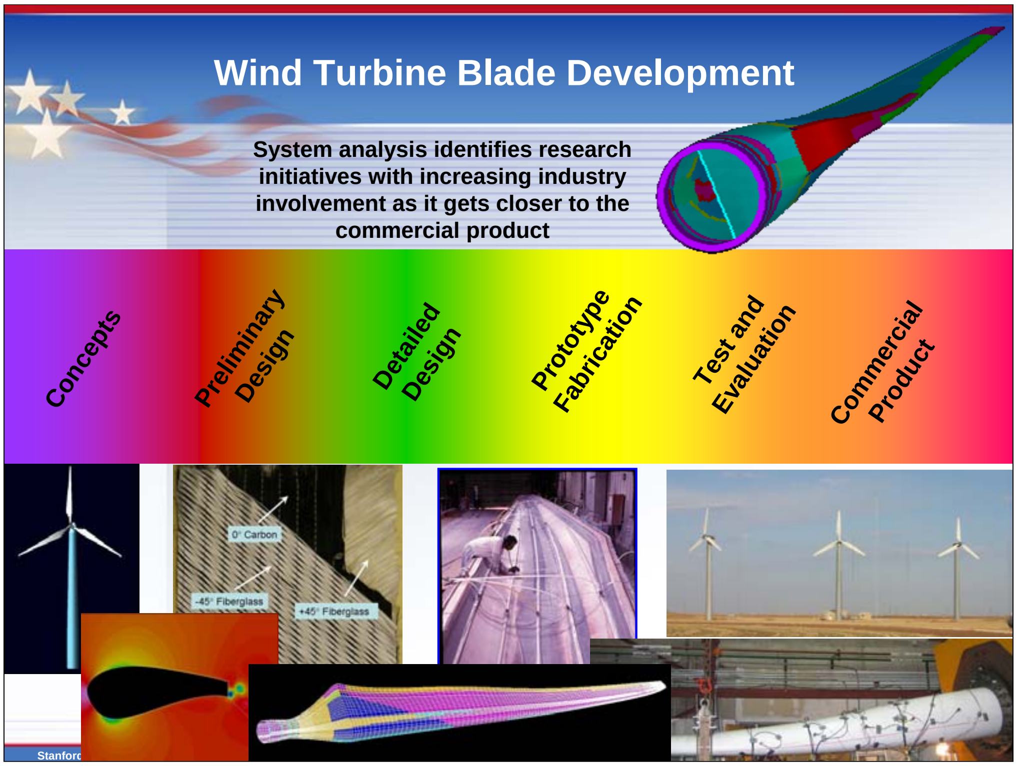
The market is expected to more than double every five years for the next decade. This doubling is expected in every major world market – even while individual country markets may fluctuate.



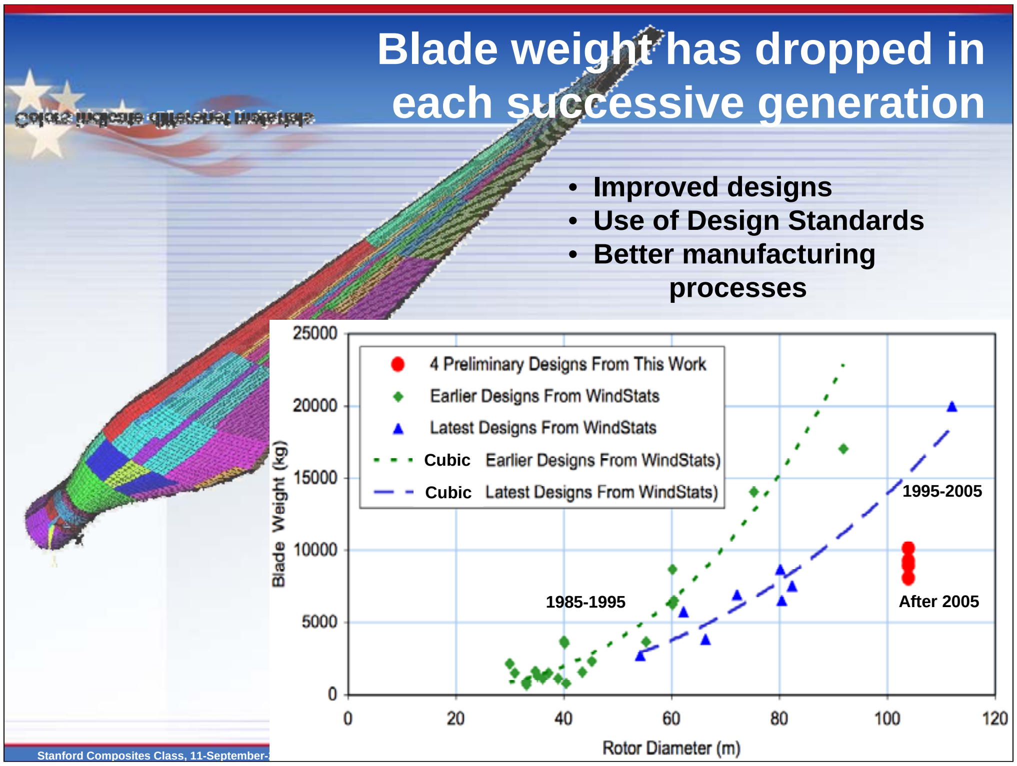
This picture shows the major components in a wind turbine system. The large covering containing the mechanical and electrical components is called the nacelle. The yaw system points the rotor into the wind. The pitch system orients the blades to achieve peak performance in moderate winds and to limit power production in high winds. Most machines now operate with variable speed to match the rotor speed to the wind speed for optimal efficiency. Power electronics to control frequency and voltage and an electrical transformer are located either on the ground or near the generator in the nacelle.



The traditional design for a blade structure used spar caps to carry the majority of the load in the soft or “flap” direction. The stiffer “edge” direction has usually not required additional reinforcement above what is already present in the skins. The spar caps are held apart by one or two shear webs. The skins resist buckling by incorporating core material such as balsa or a rigid foam. The entire blade uses airfoil shapes.



The process of blade development starts with concepts modeled numerically (using CFD, finite element models of the blade and aeroelastic models of the turbine system), then goes through detailed design and prototype fabrication to laboratory and field testing.



The growth in blade weight would follow a cubic increase with length if the blades were simply scaled up. Historic trends in blade weight have grown much more slowly due to continued improvement in blade design, manufacturing quality and, most recently, material selection.

Blade Manufacturers: A sampling

- **LM Glasfiber: the largest supplier of wind turbine blades in the world**
- **TPI Composites: Partner with Mitsubishi (Vientek) and with Sandia on several blade research initiatives**

Courtesy of TPI Composites

Two blade suppliers, LM Glassfiber and TPI Composites, provide a snapshot of the industry.

LM Glassfiber


Courtesy of LM Glassfiber

- The leading world-wide independent supplier of wind turbine blades
  - 12 factories
  - Six countries
  - Three continents
- In-house engineering from wind tunnel to coupon testing
- Mostly glass fiber
  - Some larger blades use carbon fiber
- Infusion manufacturing process

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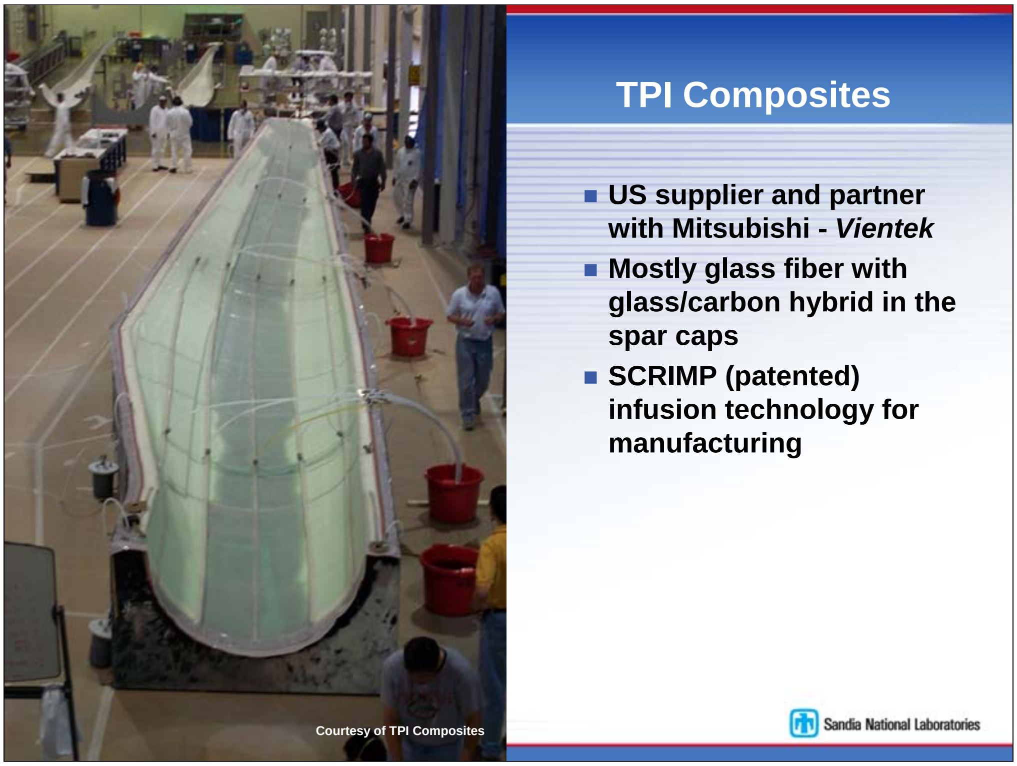
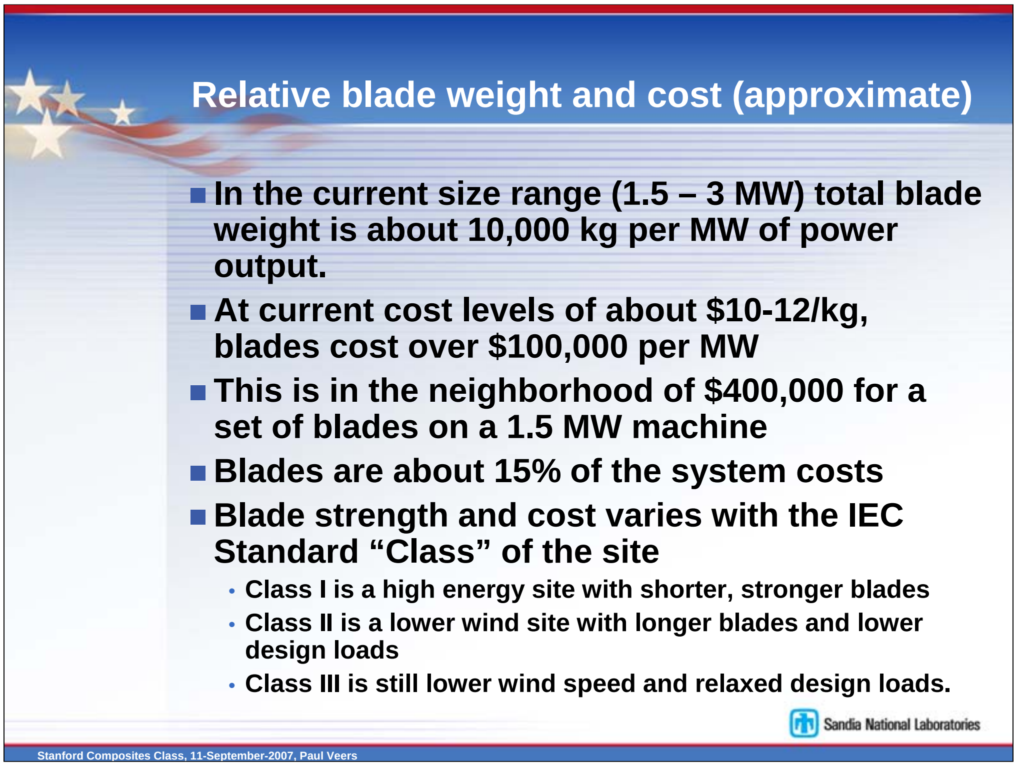
See text above. The photo shows a half mold in one of the LM blade manufacturing plants.



See text above. The photo shows a blade half being infused with resin at the Vientek blade plant.



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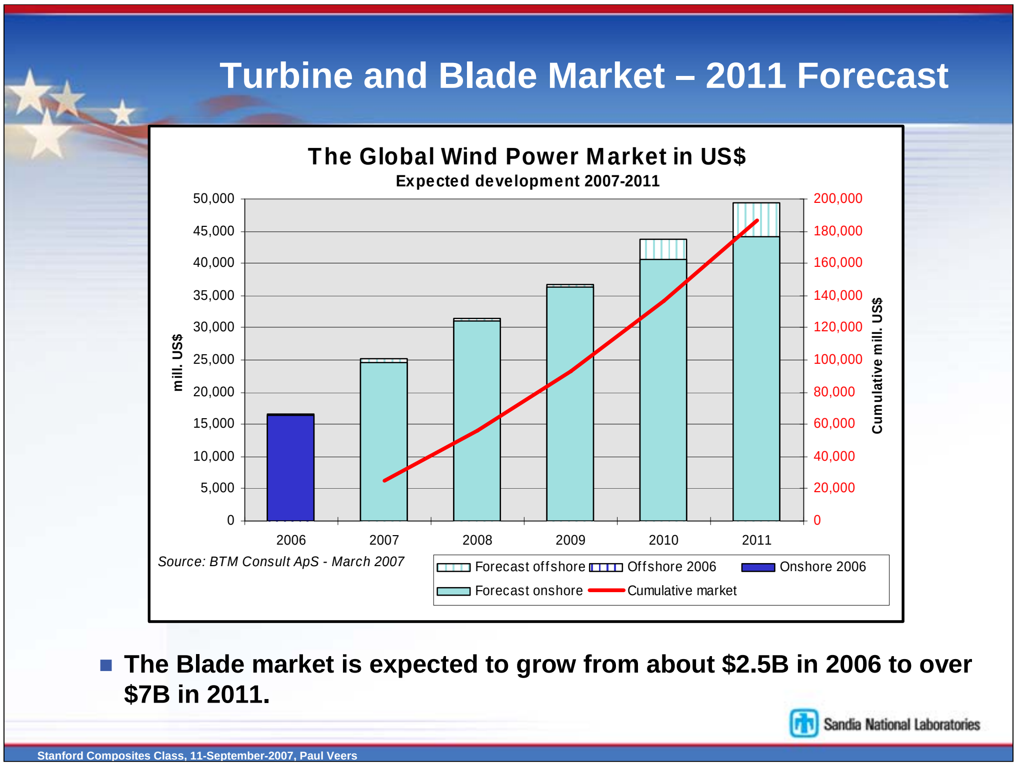
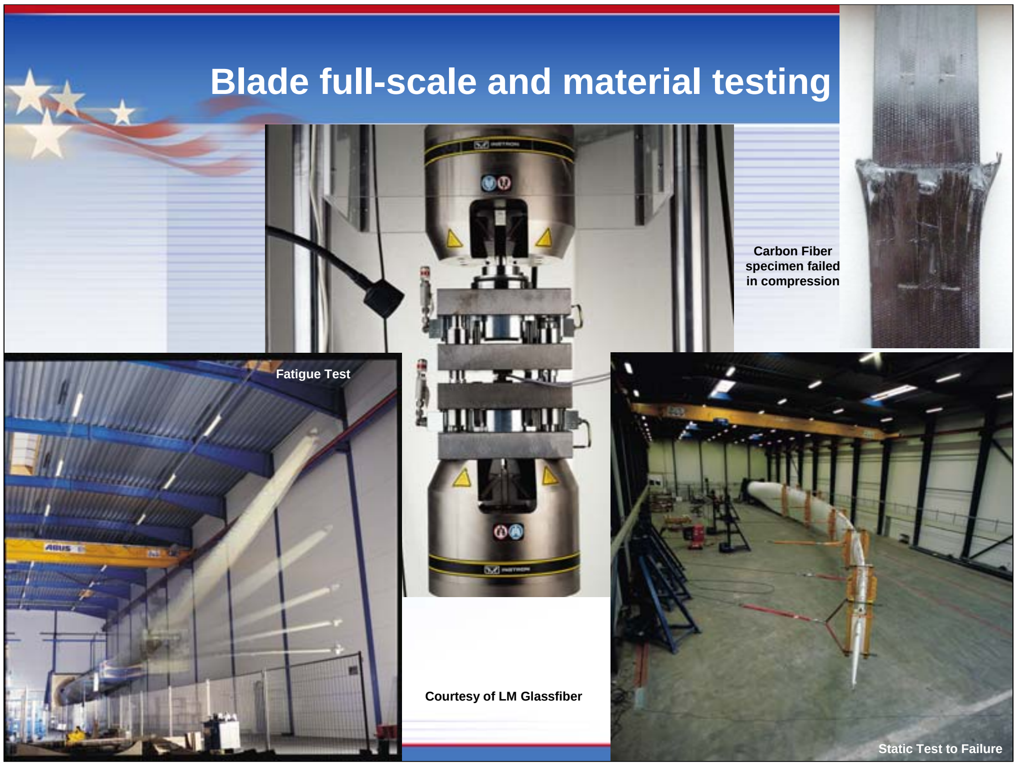


In dollar amounts, it is expected that the total wind market will grow to a $50 billion per year market by 2011. If the blade portion remains roughly the same, blades will be a $7 billion per year market. As the offshore market becomes a greater portion of the total, much larger turbines (perhaps up to 10MW each) will be of interest, leading to blades of up to 100 meters each. This growth could necessitate some fundamental examination of material choice, manufacturing process, and even basic design concept.



Blades are currently subjected to comprehensive testing requirements, especially at full scale. Materials are tested at the coupon level (center photo and upper right). Full scale fatigue testing is done with resonant excitation and extra mass to tune the distribution of strain (lower left). Static testing is done with multipoint load application to mimic the design loads from extreme wind conditions (lower right).

Static test to failure – the movie

Video courtesy of LM Glassfiber

Static test to failure of a 42.5 meter blade

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This movie shows a static test to failure of a 42.5 meter long blade at the test facilities of LM in Denmark.

System-level Examination

- **Rotor study results:**
  - **Blades are 15% of total system cost**
  - **Blades generate all the energy**
  - **Blades can be designed to reduce the loads passed through to the rest of the structure**
- **Grow the rotor diameter with adaptive blades:**
  - **Maintain size (cost) of the balance of plant**
  - **Energy capture increases**
  - **Cost increases marginally – or with careful design – not at all.**
  - **System return on investment increases 10-20%**

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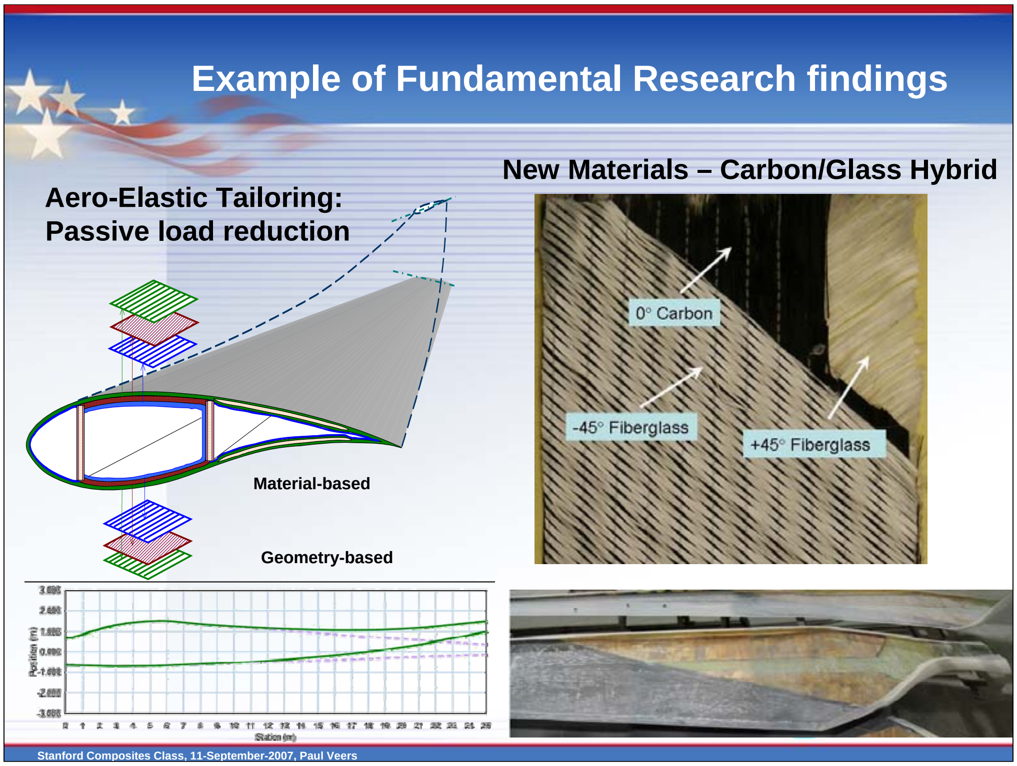
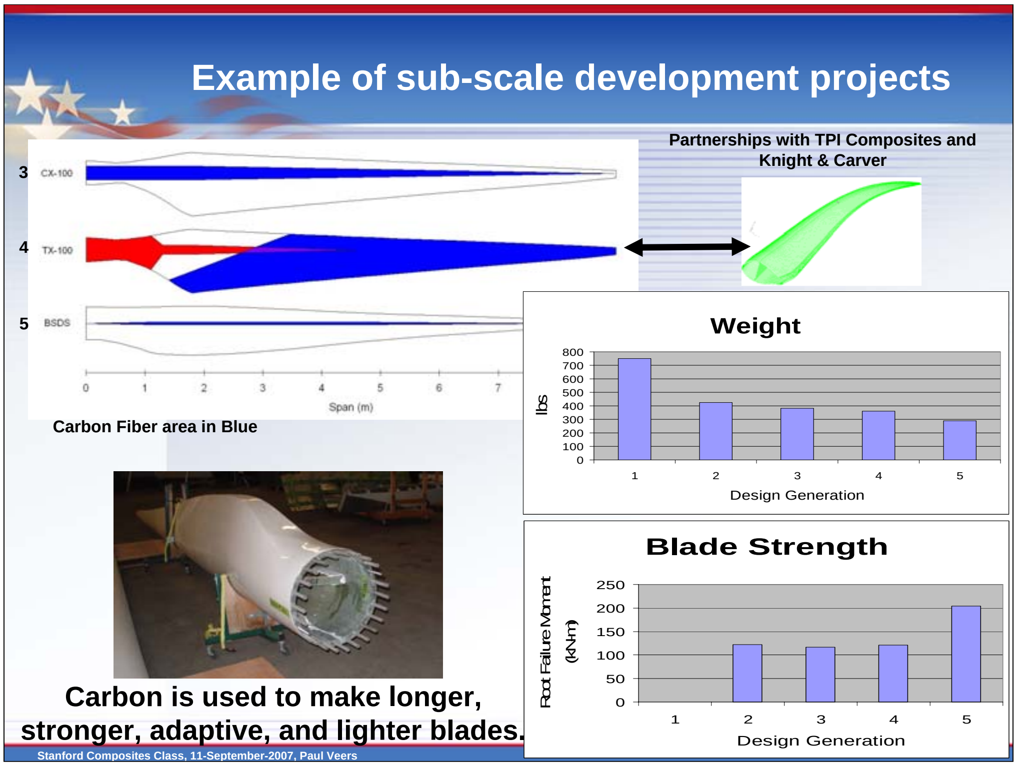
See text above.



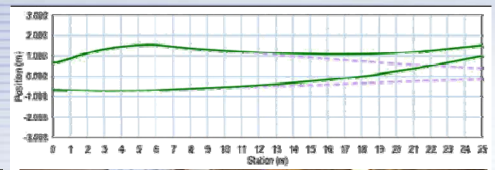
Aeroelastic tailoring has been found to provide potential load mitigating effects that can be translated into 10-20% increases in system performance if design appropriately into the system. The coupling can be achieved by orienting angled fibers in the top and bottom blade skins asymmetrically to provide bend-twist coupling (top). The same effect is achieved in a swept blade as shown on the bottom. The coupling is facilitated by using stiffer fibers such as the carbon/glass hybrid fabric shown in the upper right. This material holds the zero degree carbon fibers very straight while the plus-minus 45 degree glass holds the fabric together and provides a medium to facilitate infusion. This material can be used in the skins for bend-twist coupling or as the load-carrying material in the spar cap.



The upper left figure shows three blade designs with the carbon usage show in blue. The top design called CX has a carbon spar cap. The middle design called TX has carbon in the skins to create bend-twist coupling. With carbon in the skins, the requirement on spar caps is so reduced that the (red) spar cap can be eliminated at about the mid-span location. The bottom design called BSDS (shown in the bottom left photo) used new airfoils and a larger root diameter to spread the load and substantially reduce the amount of carbon needed in the spar cap. This design is 30% lighter and 50% stronger than any of the previous designs. The design generations represent: 1) all glass, old technology, 2) all glass with up to date design and manufacturing, 3) Carbon spar cap (CX), 4) twist-bend coupling with carbon in the skin (TX), and 5) The BSDS with new airfoils, new root and minimal carbon in the spar cap. All these research blades were built in a subscale size to allow multiple designs to be manufactured at a reasonable cost.

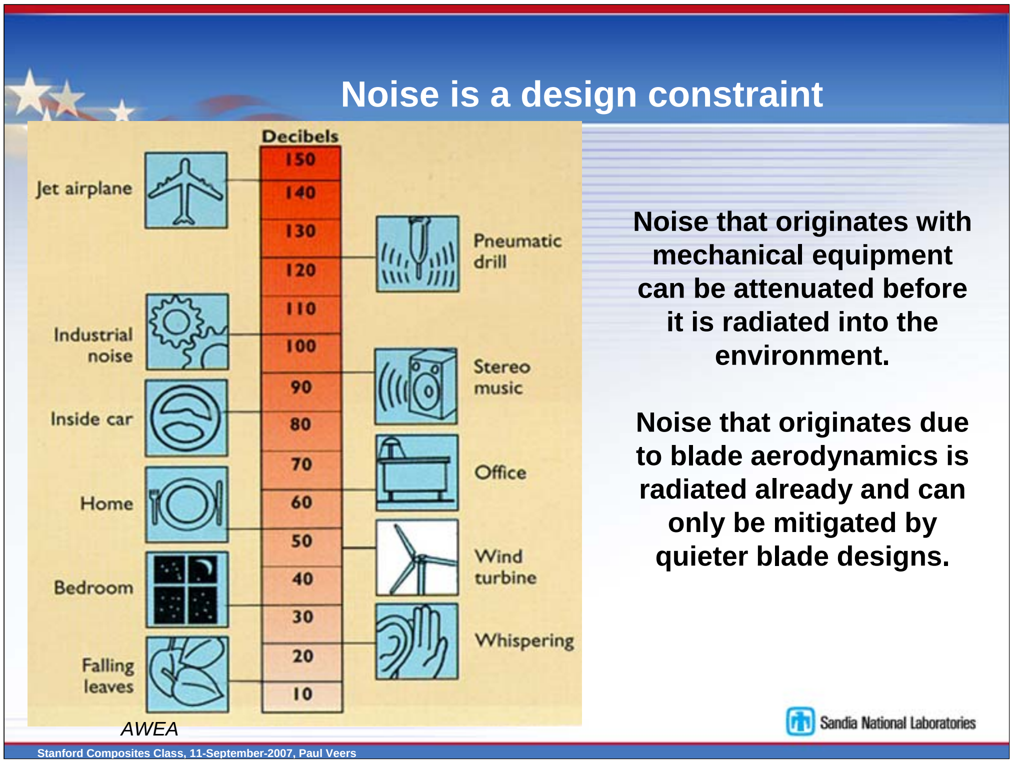
Example of full-scale commercialization project

- Knight & Carver
  - 27.1m swept blade
  - Replacement blades – Zond 750
  - 5-10% increased energy capture



Continuing Partnership with Knight & Carver in the Development of Passive-Bend Twist Coupled Swept Blade

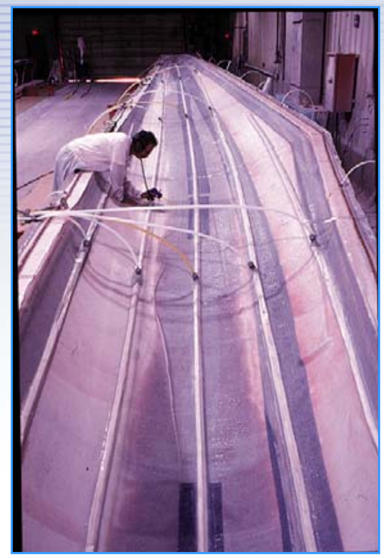
The swept blade concept has been built in a partnership between Sandia and Knight & Carver. The photos show the static test of the blade with continuous loading along the curved section to mimic aerodynamic loading. This is an all-glass blade intended as a replacement blade for existing 750kW turbines.



Noise is another design constraint for wind turbine systems driven by the blades. The blades are the major source of noise that can not be attenuated within the structure because it is radiated at the point of generation. Noise generation is proportional to the fifth power of the speed of the airflow. If blade tips can be made quieter, the rotor could be operated faster with lower torque and significant system benefits.

Important Research Issues

- Design
  - Special airfoils
  - Aeroelastic tailoring
  - Buckling resistant designs
  - Strategies for location of expensive fibers (e.g. carbon)
  - Lower weight
  - Quieter tips
- Manufacturing
  - Automation
  - Processes for very large sizes
  - Quality control and inspection
  - Joining – both seams and mid-span
  - Embedding devices and sensors
  - Local content



Courtesy of TPI Composites

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There are many areas of important research opportunities related to the blades of the wind turbine system. See text above.

US president George Bush holds a section of a research blade while visiting Sandia National Laboratories in 2005. Shortly afterward, he announced the intent to supply 20% of the nation's electrical supply with wind. The current level is just less than 1%. Reaching the goal will require more than four doublings of the current rate of installation. Similar initiatives are present in several other countries. The wind turbine blade manufacturing industry is likely to be booming for the next decade and beyond.