Wind Blade Manufacturing Innovation

Juan Camilo Serrano

Fiber Glass Science and Technology

Sandia National Laboratories · 2012 Wind Turbine Blade Workshop · May 30-31 2012

Presented by Juan Camilo Serrano · PPG Industries Inc.

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Outline

- PPG Wind Energy
- Project Motivation and Objectives
- Project Tasks and Results
  - Manufacturing and Automation
  - Materials Evaluation and Testing
  - Predictive Analysis
  - Feasibility Assessment
- Generation Observations and Industry Trends

PPG Wind Energy

- Offering a multitude of products for wind turbines
  - Fiberglass for blades & nacelles
  - Coatings for blades & towers
- World leader in fiber glass manufacturing
  - Established in wind energy for 15+ years
  - Production & Sales from 3 major continents
  - HYBON(R) 2002 and 2001 fiber glass rovings are standard product for wind blades
    - Specified in blades from most major manufacturers around the world.
- Continuing to develop new products to enhance future wind energy production






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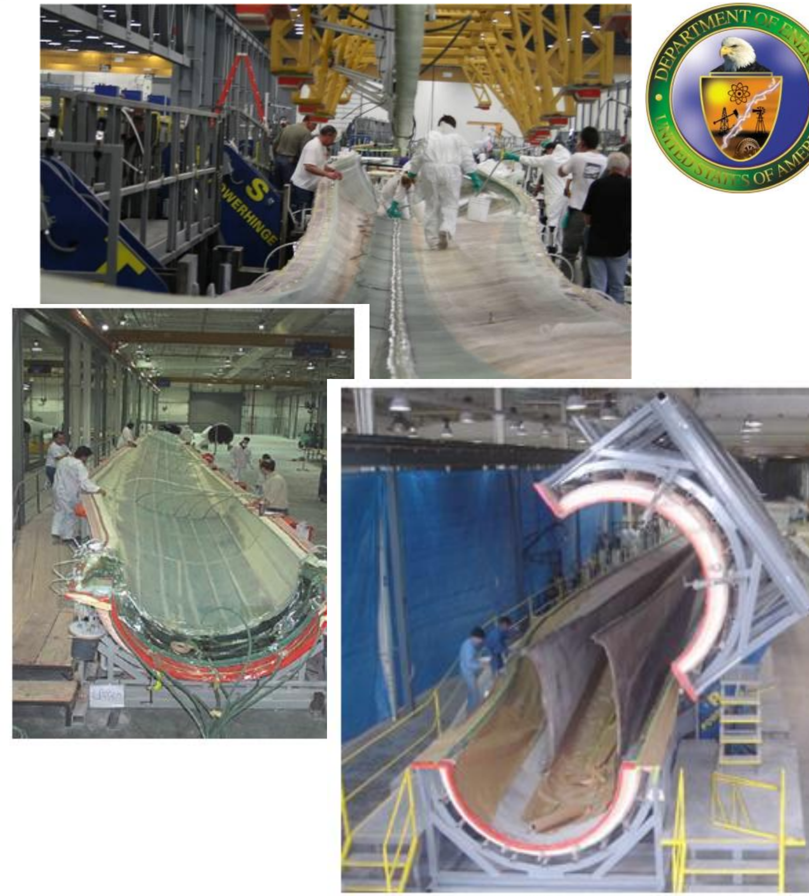
Project Motivation

- Blades are ~22% of total cost of turbine.
- Existing production process is labor intensive.
- ~60% of the blade is fiber glass.
- Cost of Energy (COE)
  - Today: ~8.2 ₵ /kWH (on shore)
  - 2030 Goal: <6 ₵ /kWH



Shell Moulds / Shear Webs Installed / Blade Assembly
Source: TPI Composites

Is there a better way to make blades?

Project Objective

Evaluate the feasibility of automation processes for the cost effective production of wind turbine blades

Technology Approach

PPG Enabling Energy Fiber Glass and Coatings for Wind Power

MAG Industrial Automation Systems

Material design

- Database review
- Material selection
- Experimental design
- Laminate production and testing

Process design

- Process benchmarking
- Manufacturing concept development

- Material processing characteristics
- Surrogate process trials
- Laminate analysis
- Predictive analysis via NUMAD model

Feasibility assessment

Technical

Economic

Project Tasks

1. Materials investigations
   - Database analysis
   - Analysis of performance variables (DOE)

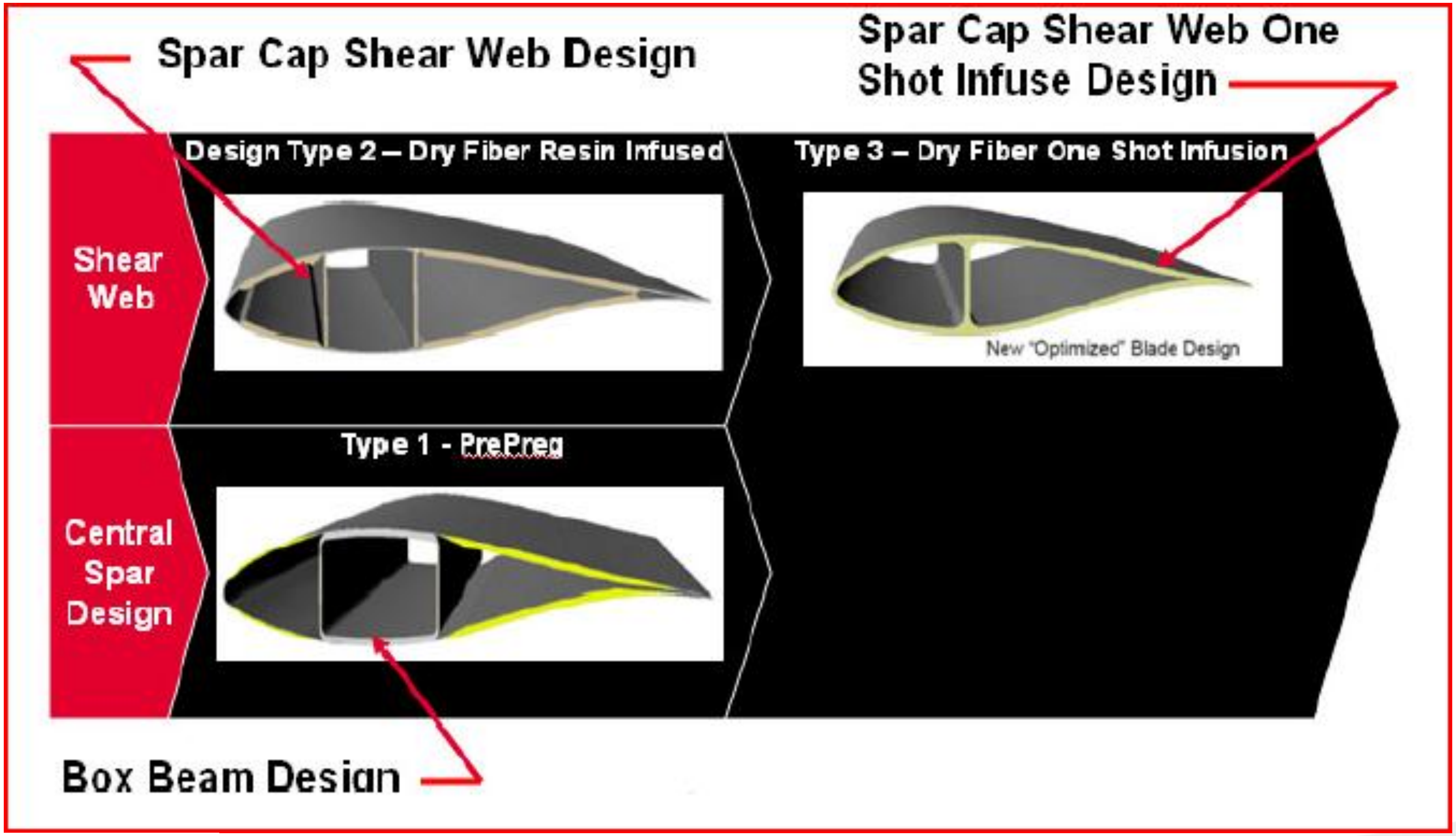
Covered by PPG during
Sandia Blade workshop 2010

2. Manufacturing and automation
   - Process benchmarking
   - Concept development

Covered by PPG during
Sandia reliability workshop 2011

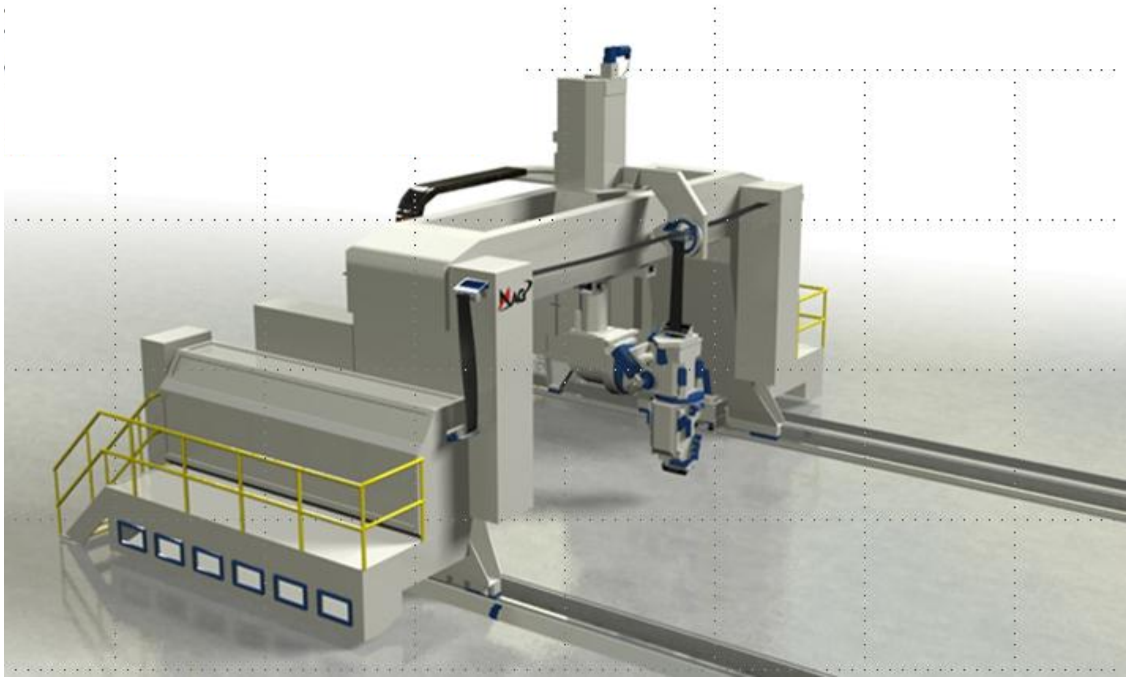
3. Process development
   - Material process characteristics and prepreg production
   - Surrogate process trials
   - Laminate production and testing
4. Predictive analysis (FEA)
5. Feasibility assessment
   - Technical feasibility
   - Economic feasibility

Manufacturing and Automation:
Process Benchmarking



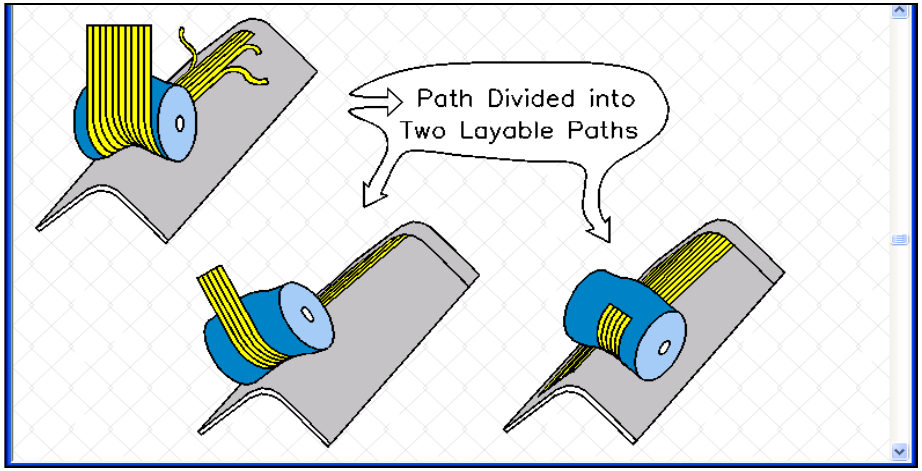
Manufacturing and Automation:
Concept Development

- Increase material placement accuracy
- Elimination of wrinkles
- Reduced scrap generation
- Higher throughput in less floor space



Manufacturing and Automation:
Machine Capabilities

- Single skin mould lay-up tool or two spar cap lay-up tools
- Capability to produce a blade skin 2.5M minimum root diameter and up to 60M in length
- High speed material processing
- Up to 64 material spools
- Auto-splicing capability
- Fiber placement head



Materials Evaluation and Testing:

Materials Evaluation Matrix

Glass: E-Glass (PPG)
Input: HYBON® 2026 Roving
Diameter: 17 μm
Linear Density: 2400 TEX

Materials Evaluation

Fiber Production

- **Infusion**
  - **NCF**
  - **UD Filament Wound** — Reference
- **Rewinding**
  - 3 lb. spools
  - 3" diameter
  - No Twist
  - **Prepreg**
    - **Fiber Placement (FP)**
      - **Towpreg 1**
      - **Towpreg 2**
      - **Slit tape**
    - **Tape Layup (ATL)**
      - **Direct UD Prepreg**
      - **NCF prepreg tape**

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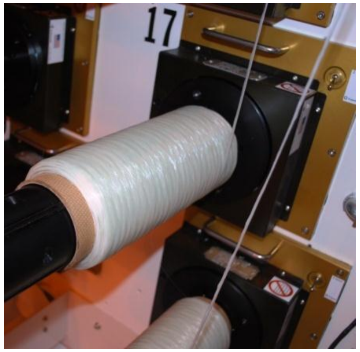
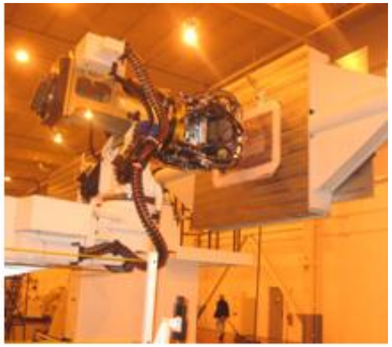
Materials Evaluation and Testing:

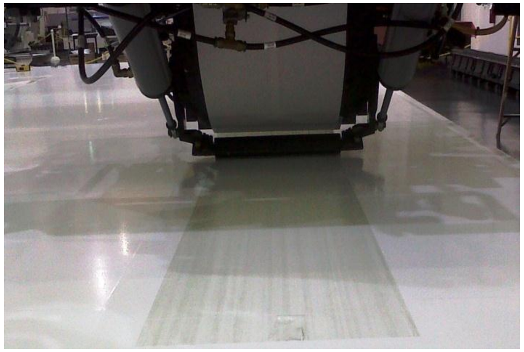
Process Trials with Automated Equipment

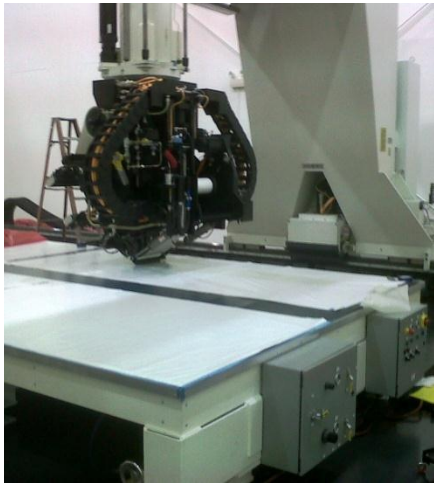
Fiber Placement (FP)





Tape Layup (ATL)





MAG INDUSTRIAL AUTOMATION SYSTEMS

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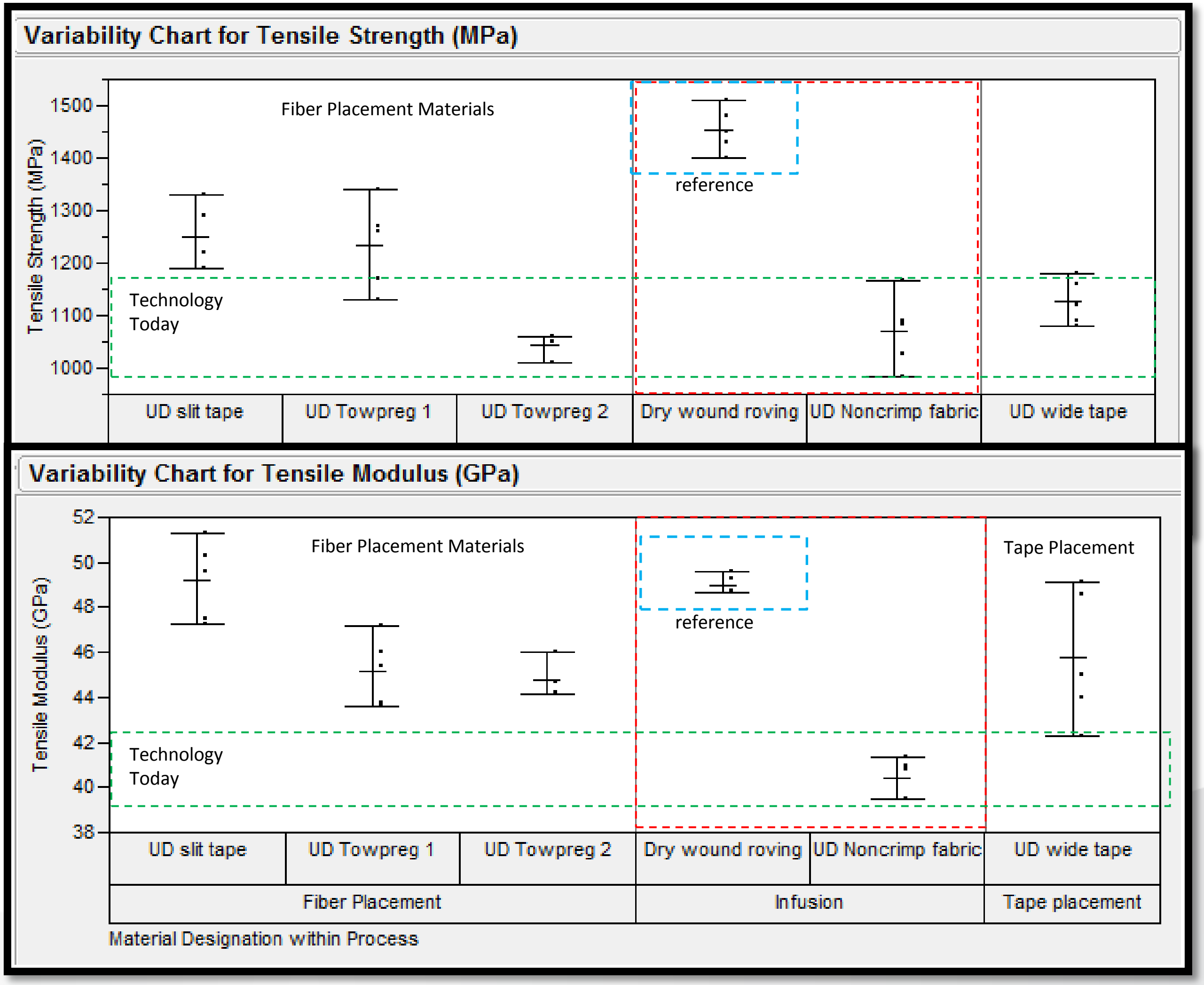
Materials Evaluation and Testing:

Static Properties

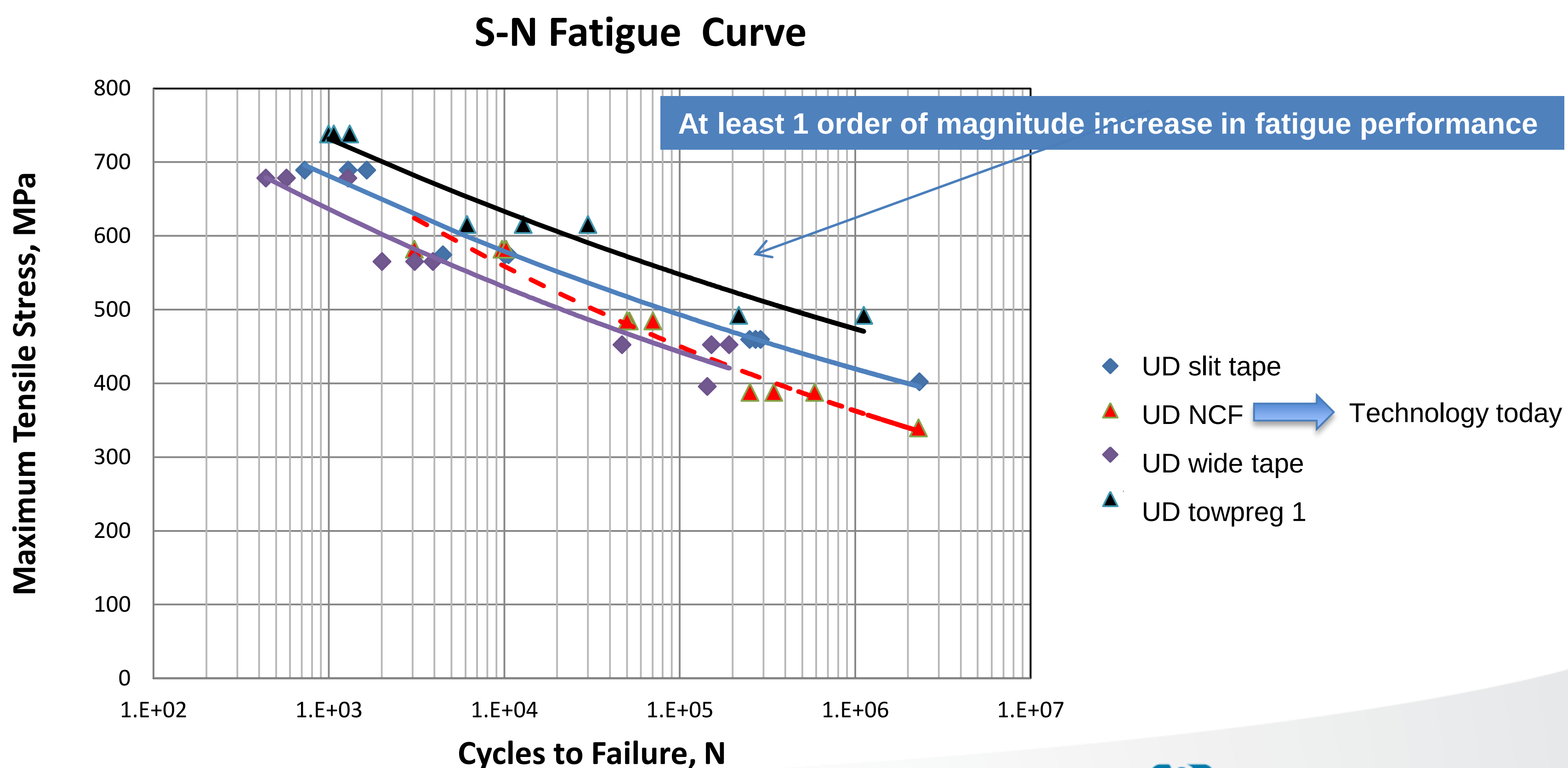
Potential for 15% increase stiffness with existing materials



Materials Evaluation and Testing:

Fatigue Performance

Tension-Tension Fatigue: R=0.1 F=5Hz



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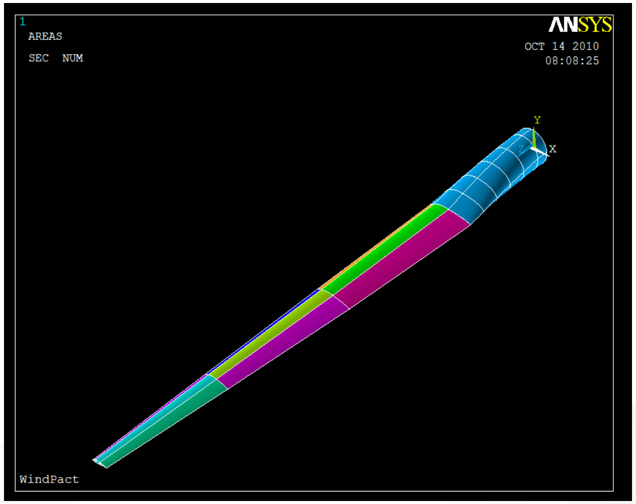
Predictive Analysis:

Objective

- Determine process/property influence on structural performance of a full blade.
- Preprocessing in NUMAD (33 m blade S818)
- Boundary conditions, solving and post processing in ANSYS®
- Input material property data generated experimentally by PPG
  - Effect of fiber properties on blade stiffness, weight

Blade Component	Weight (Kg)	%
Spar Cap (Low Pressure Surface)	1437	30%
Spar Cap (High Pressure Surface)	1457	31%
Shear Web (Forward)	53	1%
Shear Web (Aft)	55	1%
Skin (Low Pressure Surface)	242	5%
Skin (High Pressure Surface)	238	5%
Root	1251	26%
Total Blade	**4733**	**100%**



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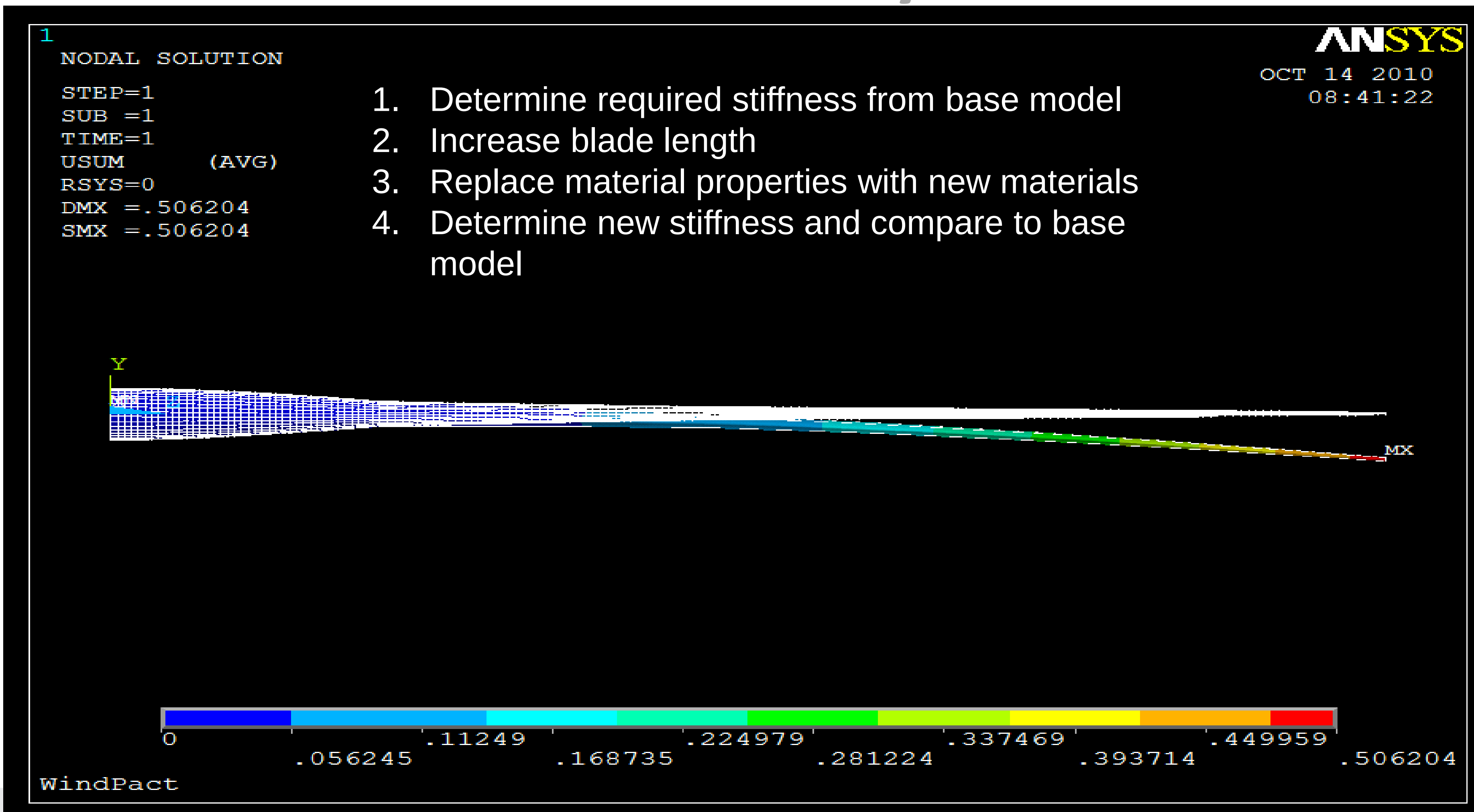
Predictive Analysis:

Blade Finite Element Analysis



1. Determine required stiffness from base model
2. Increase blade length
3. Replace material properties with new materials
4. Determine new stiffness and compare to base model

Predictive Analysis:
COE Calculation Methodology

Project Assumptions

FIBER
- Fiber level evaluation
- Composite laminate evaluation

FEA
- Develop blade geometry, assign material
- Apply loads, obtain deflections, mass
- Determine turbine output potential

COE
- Obtain cost of turbine
- Estimate $/kWH

Variable	Value
Project size	60 MW
Wind speed range	13-17mph (Class 4)
Turbine size	1.5 MW, 33 meter long blade
Net capacity factor	30%*

COE* = (ICC X FCR)/AEP + AOE

**NREL/TP-500-40566 2006*

Predictive Analysis:
COE Findings

- Advanced manufacturing of wind blades with innovative glass fiber composites can enable increased generation capacity and decrease COE
- Asserts the importance of automation as high performance alternative to resin infusion

% Increase in blade length	% Increase in weight	% Increase in produced energy output	% Decrease in COE
3.76%	3.5%	7.7%	3.57%

Feasibility Assessment:
Technical Feasibility

- Surrogate process trials:
  - Material quality parameters:
    - Tack, fuzz, width control, flatness, ease of release
  - Material performance parameters:
    - Minimum static and dynamic performance
- Technically feasible approach for production of high fiber volume fraction composites
  - Improved static and dynamic properties (higher stiffness, higher strength)

Feasibility Assessment:

Sample Material Specification Development

Fiber Glass Roving	PPG HYBON 2026	
Sizing chemistry	Epoxy compatible roving	
Fiber diameter	17um	+/- 3um
LOI	0.7%	+/- 0.2
Linear Density	2400TEX	+/- 200
Resin system	OOA grade epoxy	
cure temp	80-120 C	
cure time	5H	
Prepreg Resin Content	40%	+/- 1%

Class A	Preimpregnated slit tape	
Manufacturing Process	Automated Fiber Placement – Slit tape	
Tack Level	Medium Tack - self adhesion to tooling surface, adequate release from separation media	
Separation media	Siliconized paper, PE or equivalent.	
width	12mm	+/- 0.7 mm
Thickness	0.35mm	+/- 0.05 mm
Class B	**Unidirectional Towpreg**	
Manufacturing Process	Automated Fiber Placement – Towpreg	
Tack Level	Medium Tack - self adhesion to tooling surface, adequate release from separation media	
Separation media	No separation media required if appropriate tack is achieved	
width	12mm	+/- 0.5 mm
Thickness	0.35mm	+/- 0.07 mm

Feasibility Assessment:
Sample Material Specification Development (cont'd)

Packaging Requirements (applicable to class A and B materials)	
Roll diameter	76.2mm
Material build up diameter of core	101.6 mm OD or greater on 76mm core
Package Length	25.4 cm long centered on core, helically wound

Minimum Performance Requirements			
Tensile Strength - X	1350 MPa	min	ISO 527-5
Tensile Modulus - X	48000 MPa	min	ISO 527-5
Fiber Weight Fraction	76.5%	+/- 1%	ISO 1172
Tensile Strength - Y	50MPa	min	ISO 527-4
Fiber Volume Fraction	59%	+/- 1%	ISO 1172
Fatigue Performance	See slide 16 (Tension-Tension R=0.1 F- 5 Hz) 2 mm thick laminates (slit tape and Towpreg 1)		

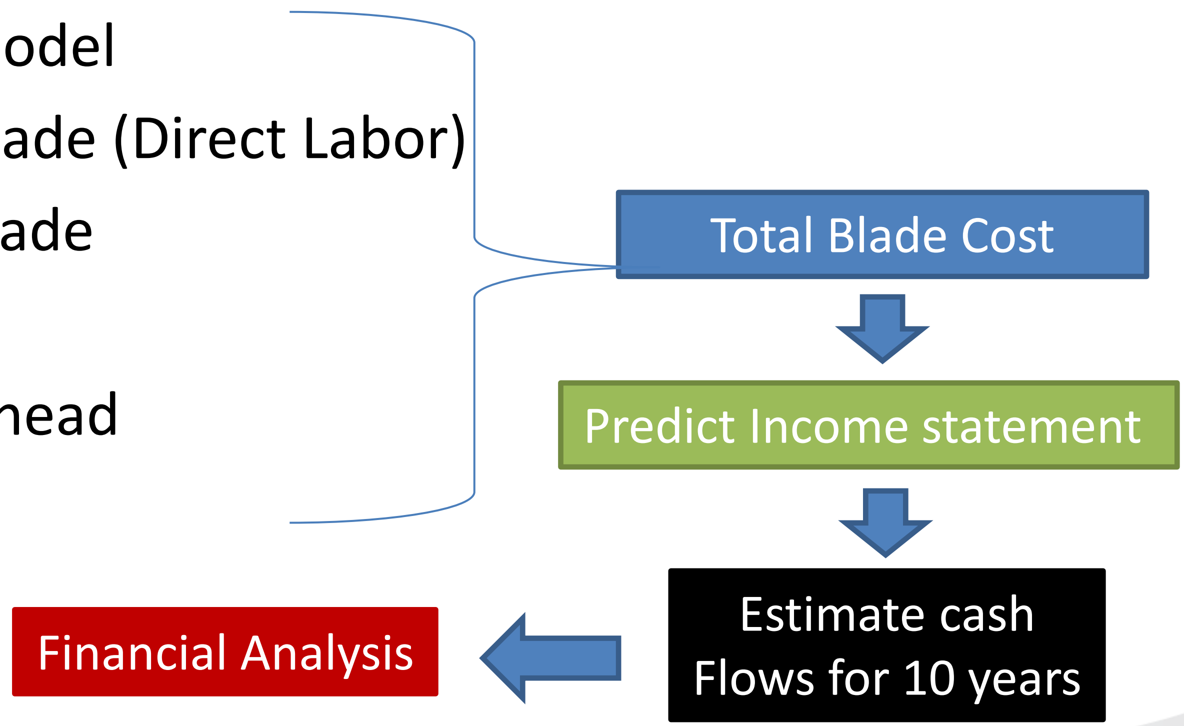
Feasibility Assessment:
Economic Feasibility

Method 1	Method 2	Method 3
• Shell: • Vacuum Infusion • Spar cap: • Vacuum Infusion • Root: • Wet layup/Infusion	• Shell: • Vacuum Infusion • Spar cap: • Automation • Root: • Wet layup/Infusion	• Shell: • Automation • Spar cap: • Automation • Root: • Automation

Feasibility Assessment:
Procedure

Benchmark: 40 m blade, 3.1 MW turbine for class IV wind

- (BOM) from the FEA model
- Total man-hours per blade (Direct Labor)
- Production time per blade
- Capital equipment
- Depreciation and overhead



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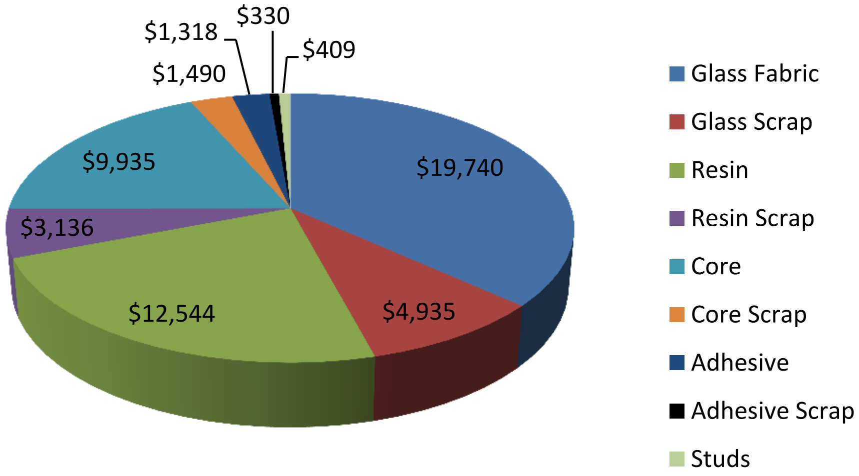
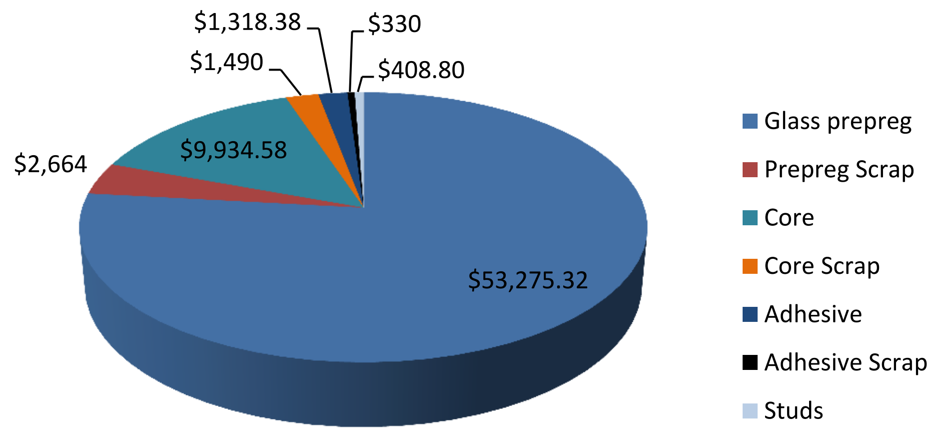
Feasibility Assessment:
BOM – Infusion/Automation

Method 1 BOM Total $53,836



Method 3 BOM Total $69,420



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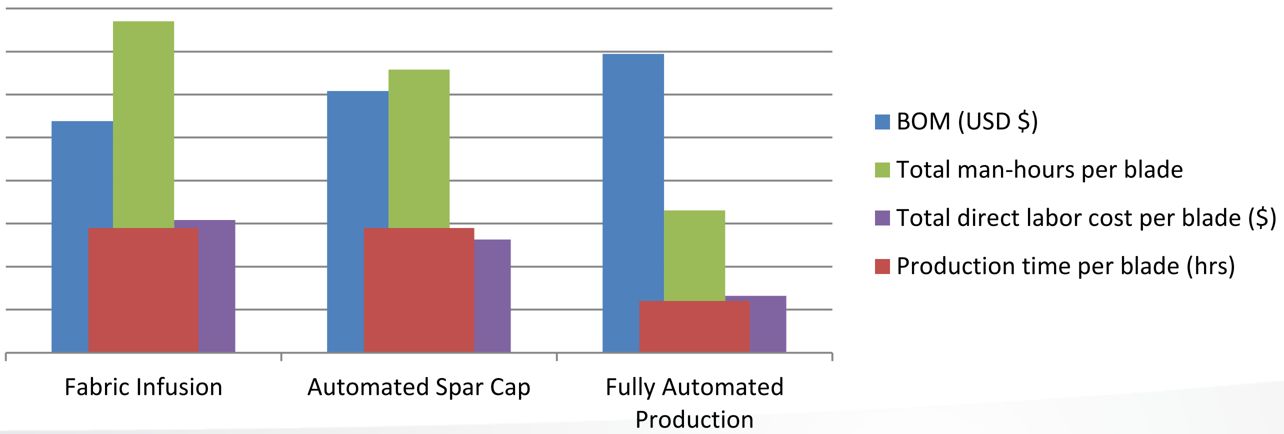
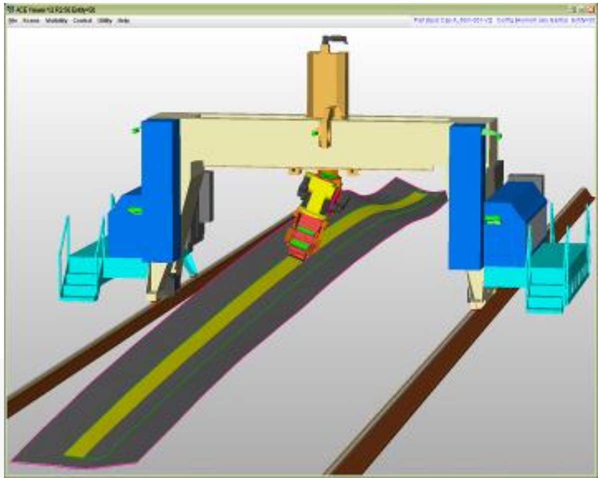
Feasibility Assessment:

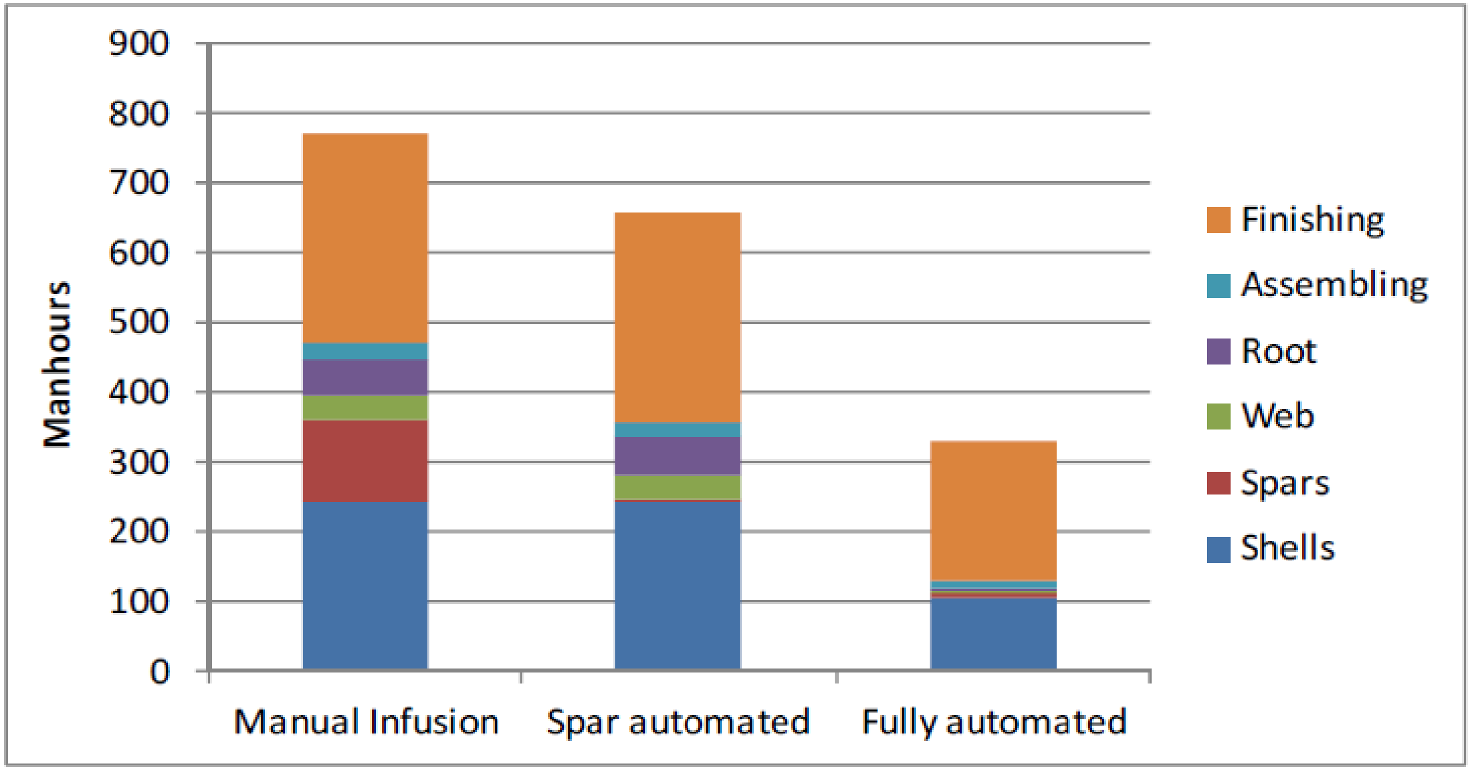
BOM and Manufacturing Time

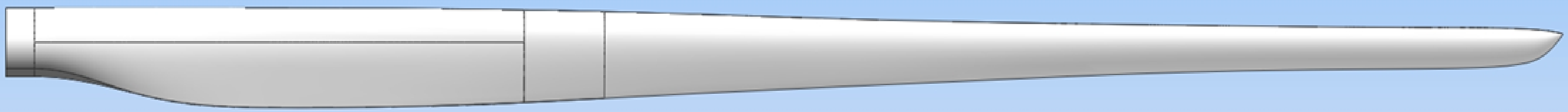
	Fabric Infusion Method 1	Automated Spar Cap Method 2	Fully Automated Production Method 3
BOM (USD $)	$53,836	$60,838	$69,421
Production time per blade (hrs)	**29**	29	**12**
Total man-hours per blade	**770**	658	**331**
Total direct labor cost per blade ($)	**$30,800**	$26,320	**$13,240**





Feasibility Assessment:
Man-hour Distribution





Feasibility Assessment:
Facility Requirements

	Fabric Infusion Method 1	Automated Spar Cap Method 2	Fully Automated Production Method 3
Shell mold cycle time (hrs)	29	29	12
Operational days/annum	250	250	287
Operational efficiency	85%	86%	90%
# of shell mold tool sets across total number of production lines	**6**	6	**2**
Total number of blades per year	**1,055**	**1,068**	**1,033**
Facility size (sq. ft.)	**310,000**	310,000	**152,741**

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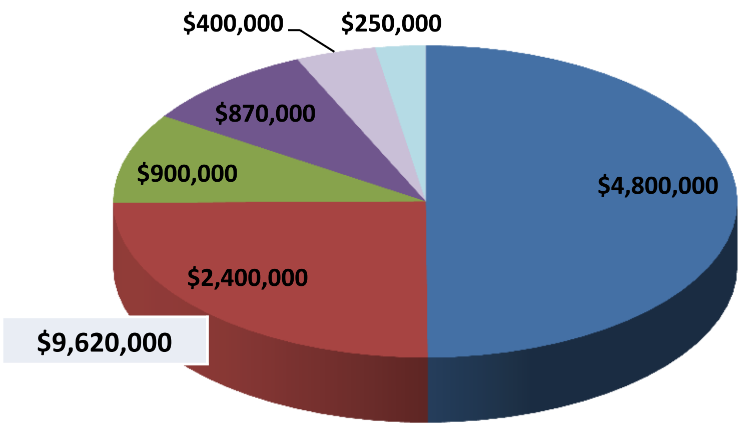
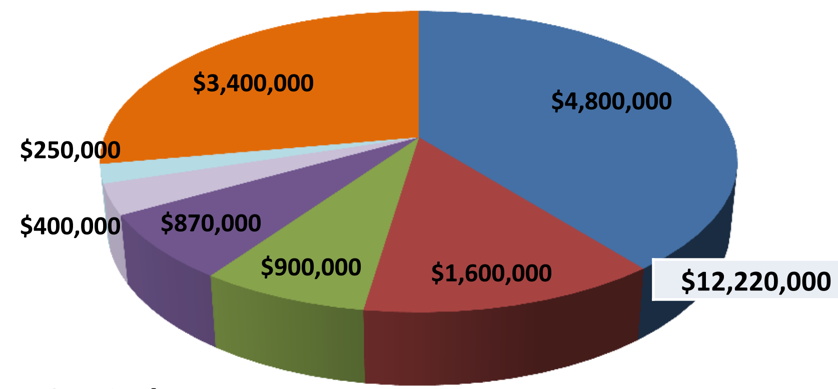
Feasibility Assessment:
Capital Equipment Costs

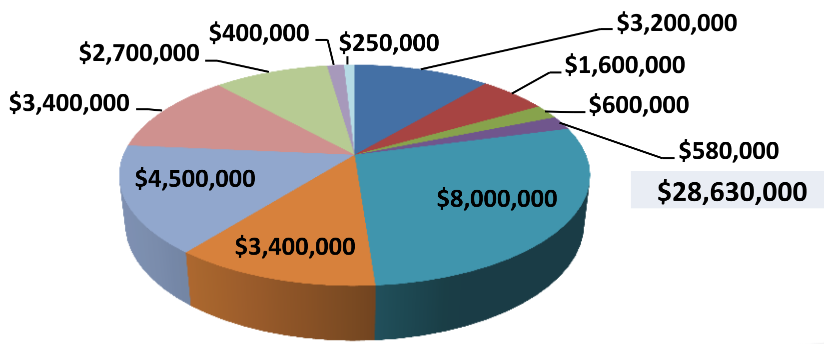
Manual Infusion (Method 1)



Automated Sparcap (Method 2)



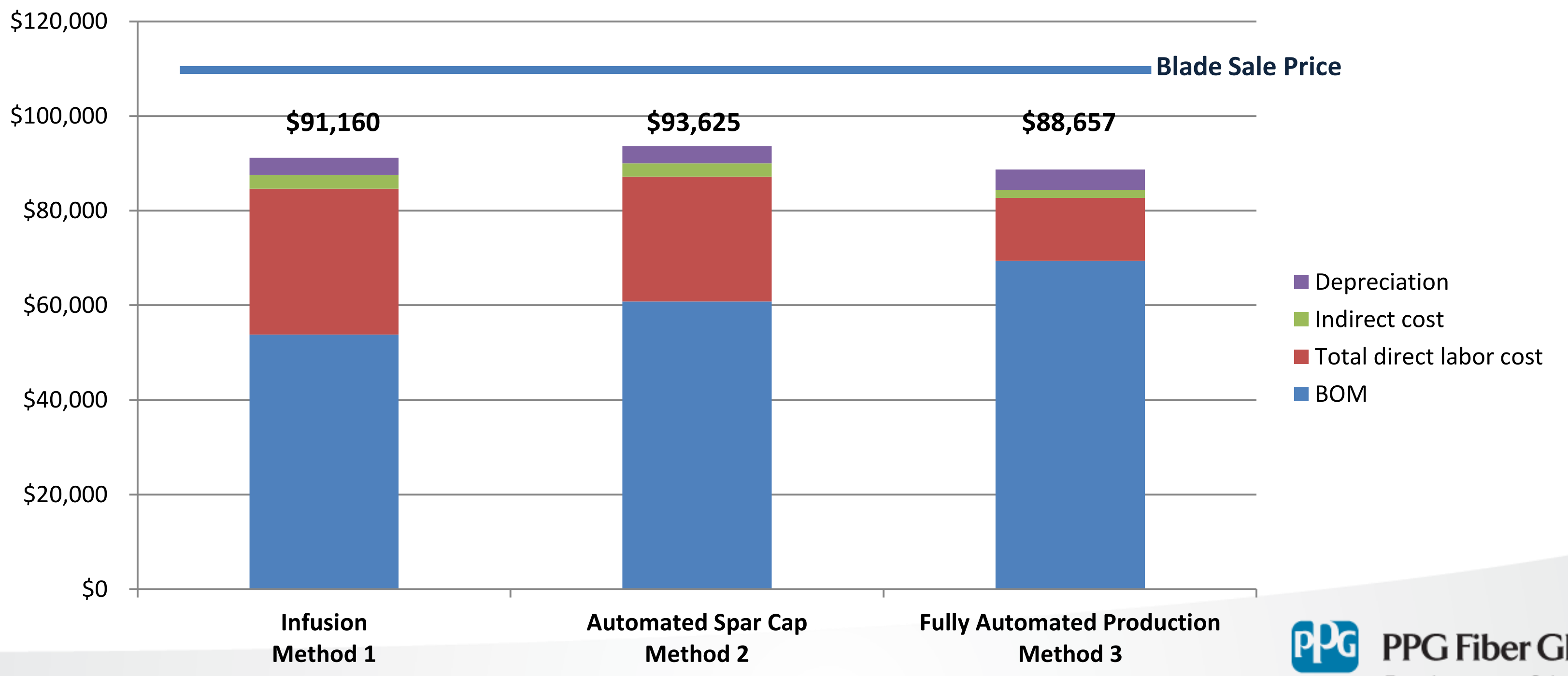
Full Automation (Method 3)



- Shell mold set which includes LP and HP
- Spar mold set which includes LP and HP
- Web mold
- Root mold
- Automation equipment for shell
- Automation equipment for spar caps
- Automation equipment for root
- Automation equipment for web
- Automation equipment for finishing
- Shell plug
- Spar plug

Feasibility Assessment:
Total Blade Cost and Profits

	Infusion Method 1	Automated Spar cap Method 2	Fully Automated Production Method 3
Building size (sqft)	310,000	300,000	152,741
Building cost @ 120$/sf	**$37,200,000**	**$36,000,000**	**$18,328,920**
Overhead cost per year	$3,100,000	$3,000,000	$1,753,467



Feasibility Assessment:
Projected Income Statement

Income Statement	Infusion Method 1	Automated Spar cap Method 2	Fully Automated Production Method 3
Theoretical blades per year	1,055	1,068	1,033
Gross Sales	$116,068,966	$117,434,483	$113,652,000
Material Costs	$56,806,599	$64,949,780	$71,725,392
Direct Labor Costs	$32,499,310	$28,098,869	$13,679,568
Indirect Costs	$3,100,000	$3,000,000	$1,753,467
Depreciation	$3,784,000	$3,904,000	$4,442,446
EBIT	**$19,879,056**	**$17,481,834**	**$22,051,127**
Profit Margin	**17%**	**15%**	**19%**
Profit Margin (w/o depreciation)	**20.4%**	**18.2%**	**23.3%**
Taxes	$6,957,670	$6,118,642	$7,717,894
Net Income	**$12,921,386**	**$11,363,192**	**$14,333,233**

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Feasibility Assessment:

Financial Analysis

	Fabric Infusion Method 1	Automated Spar Cap Method 2	Fully Automated Production Method 3
Financial Ratios and Analysis Metrics			
Asset turnover (GS/CAPEX)	**2.48**	**2.44**	**2.42**
Return on Assets	**42%**	**36%**	**47%**
ROA (w/o depreciation)	**51%**	**44%**	**56%**
Return on Capital	**27.6%**	**23.6%**	**30.5%**
NPV @ 12%WACC*	**$53,020,024**	**$43,008,629**	**$67,627,336**

Economically Feasible

t = 10 years. Cash Flow projections

Assumptions on model	3% inflation, 35% tax rate, replacement tooling costs added at year 5 **Kahn, 1995. Comparison of financing costs for wind turbine and fossil power plants. Lawrence Berkeley Lab*

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Feasibility Assessment:
Generation Observations

- Integration of material and process is key to optimize manufacturing
- Automation technology has potential for increased performance and manufacturing efficiency, technology is deemed feasible
- Mechanical property improvements could enable COE reductions
- Cost model shows potential payoff for wind blade producers who adopt automation through the complete manufacturing process
- Further material cost reductions (mainly through lower cost prepreg) can enable even higher ROI for automation processing

Industry Trends

Ingersoll to build wind blade demonstrator

With help from a $5 million grant, Ingersoll will invest more than $12 million to build an automated wind blade demonstrator based on the company's composite fiber placement technology.

| Posted on: 4/26/2010
Source: Composites World

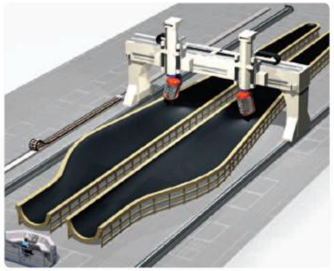
INGERSOLL
Machine Tools

BLADE COMPOSITES MANUFACTURING

BASED ON EXISTING AEROSPACE TECHNOLOGY

FEATURES INCLUDE:

- Mold release application
- Gel coat application
- Automated material trimming
- Comprehensive system for grinding and application of adhesives, etc.
- Interface to production system: e.g. infusion, curing and mold closing
- Centralized software control with simplified user interface
- Broad range of material applications:
  - Prepreg/dry tows
  - Complete range of fiber materials (carbon/glass)
- Lay-up rates of up to 1,500 lbs./hr.

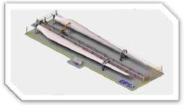


FULL FLEX MACHINE WITH INTERCHANGEABLE MODULE

Winner: GAMESA Innovation & Technology (Spain)
Partner: Grupo M. Torres (Spain)

Gamesa and M. Torres have developed a new blade technology with a revolutionary, 100% automated manufacturing process. The project focused on the following critical aspects: Blade design, structure materials adapted to the automated process, introduction of innovative tip and root solutions that will improve the aerodynamic performance of the blade (higher production capacity of the wind turbine), automatic lamination of dry glass fibre tape (tap developed by Gamesa and M.Torres).

Innovation



RAPA G3

AN AUTOMATED WIND BLADE FINISHING SYSTEM

IDPSA
Engineering & Robotics

THREATS › SOLUTIONS › INNOVATION › RAPA G3

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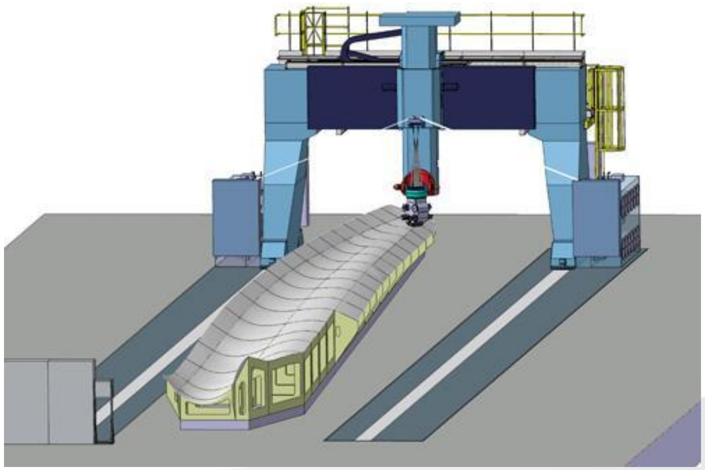

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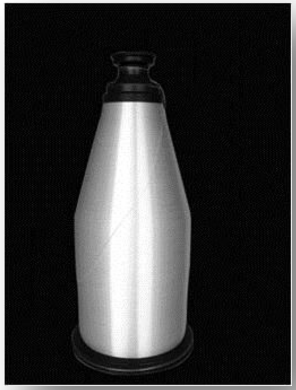
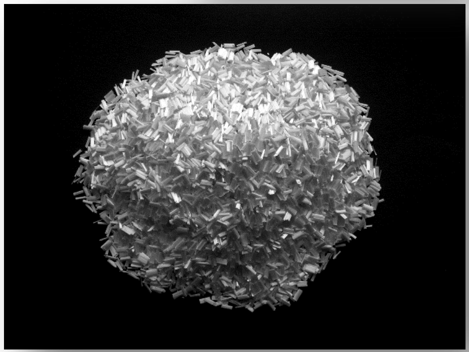
Worldwide Products

Worldwide Brands

- Direct Rovings
- Chopped Fibers
- Mats & Rovings
- Yarn
- Paper Dry Chop
- Long Fiber Thermoplastics (LFT)
- Mil-Tough® Lightweight Protective Panels
- Insulation and Processed Fibers





INNOFIBER® XM
Engineered for Performance

HYBON®
Direct Roving Fiber Glass

TUFRov®
Long Fiber Thermoplastic Fiber Glass

MIL★TOUGH®
LIGHT WEIGHT PROTECTIVE PANELS

ChopVantage®
Chopped Fiber Glass

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Thanks for your attention!

http://www.ppg.com/glass/fiberglass/markets/Pages/windenergy.aspx

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