SAND REPORT

SAND2003-1428
Unlimited Release
Printed May 2003

Cost Study for Large Wind Turbine Blades: WindPACT Blade System Design Studies

TPI Composites, Inc.
373 Market Street
Warren, RI 02885

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia is a multiprogram laboratory operated by Sandia Corporation,
a Lockheed Martin Company, for the United States Department of
Energy under Contract DE-AC04-94AL85000.

Sandia National Laboratories

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

Available to DOE and DOE contractors from
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Telephone: (865)576-8401
Facsimile: (865)576-5728
E-Mail: reports@adonis.osti.gov
Online ordering: http://www.doe.gov/bridge

Available to the public from
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Rd
Springfield, VA 22161

Telephone: (800)553-6847
Facsimile: (703)605-6900
E-Mail: orders@ntis.fedworld.gov
Online order: http://www.ntis.gov/ordering.htm

SAND2003-1428
Unlimited Release
Printed May 2003

Cost Study for Large Wind Turbine Blades

WindPACT Blade System Design Studies

TPI Composites, Inc.
373 Market Street
Warren, RI 02885

ABSTRACT

The cost study for large wind turbine blades reviewed three blades of 30 meters, 50 meters, and 70 meters in length. Blade extreme wind design loads were estimated in accordance with IEC Class I recommendations. Structural analyses of three blade sizes were performed at representative spanwise stations assuming a stressed shell design approach and E-glass/vinylester laminate. A bill of materials was prepared for each of the three blade sizes using the laminate requirements prepared during the structural analysis effort. The labor requirements were prepared for twelve major manufacturing tasks. TPI Composites developed a conceptual design of the manufacturing facility for each of the three blade sizes, which was used for determining the cost of labor and overhead (capital equipment and facilities). Each of the three potential manufacturing facilities was sized to provide a constant annual rated power production (MW per year) of the blades it produced. The cost of the production tooling and overland transportation was also estimated. The results indicate that as blades get larger, materials become a greater proportion of total cost, while the percentage of labor cost is decreased. Transportation costs decreased as a percentage of total cost. The study also suggests that blade cost reduction efforts should focus on reducing material cost and lowering manufacturing labor, because cost reductions in those areas will have the strongest impact on overall blade cost.

ACKNOWLEDGEMENTS

TPI Staff: Derek Berry and Steve Lockard
Dynamic Design: Kevin Jackson
MDZ Consulting: Mike Zuteck
UC Davis: Case Van Dam

Sandia Technical Monitors: Tom Ashwill and Paul Veers

This is a Contractor Report for Sandia National Laboratories that partially fulfills the deliverables under Contract #15890.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 ANALYSIS APPROACH

1.1 Goals and Objectives

The primary goal of the WindPACT Blade System Design Study (BSDS) was investigation and evaluation of design and manufacturing issues for wind turbine blades in the one to ten megawatt size range. The results of the initial engineering study [1] will guide design specifications and preliminary engineering for candidate blades in the range of 30 to 70 meters in length. Subsequent efforts will generate detailed recommendations for sub-scale and sub-structure testing that will help determine the feasibility of innovations and provide data for detailed design in follow-on contracts.

The initial BSDS project task, described in this report, was to assess the fundamental physical and manufacturing issues that govern and constrain large blades. This Issues and Constraints phase of the project entails three basic elements: 1) a parametric study [1] to assess the viability of large blade structures designed and fabricated using current technology, 2) an economic study of the cost to manufacture, transport, and install large blades, and 3) identification of promising innovative design approaches that show potential for overcoming fundamental physical and manufacturing constraints.

This report discusses the approach used to perform the large blade cost evaluation and the results obtained from that work. During this effort we reviewed critical fabrication and transportation constraints as a function of blade length in the range from 30 meters to 70 meters. The results have been summarized in dimensional and non-dimensional format to aid in interpretation. These results form the baseline for the upcoming assessment of blade cost and have been used to guide our review of potential innovative design approaches.

1.2 Direct Manufacturing Cost

1.2.1 Material Cost

TPI Composites has considerable prior experience with the fabrication of large wind turbine blades. As a result of this prior work, TPI has developed techniques for estimating costs of new products. This analytical cost estimation framework was applied to each of the three blade sizes (30 m, 50 m and 70 m) assuming that currently available technology would be used. Laminate requirements obtained from the structural model were used to develop a detailed bill of materials for each blade size according to the cost categories summarized in Table 1.1.

Table 1.1 Blade Material Cost Categories

No.	Material Cost Category
1	Gelcoat
2	Continuous Strand Mat
3	Double-Bias E-Glass Fabric
4	Unidirectional E-Glass Fabric
5	Core
6	Resin
7	Promotor
8	Catalyst
9	Bonding Adhesive
10	Root Attachment System

1.2.2 Labor Cost

TPI Composites developed a detailed manufacturing task list which was used to estimate labor costs. The primary manufacturing tasks are summarized in Table 1.2 and each contains a series of subtasks. This process task list was used to assess work flow, labor hours, and equipment needs.

Table 1.2 Blade Manufacturing Tasks

No.	Manufacturing Task
1	Material
2	High Pressure Skin
3	Low Pressure Skin
4	Leading Edge Shear Web
5	Trailing Edge Shear Web
6	Assembly Prep
7	Bonding
8	Root Attachment System
9	Finishing
10	Inspection
11	Testing
12	Shipping

1.3 Indirect Manufacturing Costs

1.3.1 Overhead Cost

Operating a commercial wind turbine blade manufacturing plant requires staffing and overhead costs which are not directly related to the fabrication cost of an individual blade. These costs include management oversight, sales and marketing, after-sales customer support, warranty repairs, insurance, and other miscellaneous costs associated with running a manufacturing business.

1.3.2 Development Cost

Blade development costs were calculated for each of the three blade sizes. It was assumed that the costs for engineering design and documentation were essentially constant with the blade size if current fabrication materials and methods were used. This simplifying assumption is based upon the need for similar types of analyses and design documents regardless of the blade scale. The cost associated with the fabrication of tooling and prototypes was estimated by assuming the cost to be dependent upon the blade scale, as is the cost of static, fatigue, and operational field testing.

1.3.3 Facilities Cost

The manufacturing plant layout is dependent upon the size of the rotor blades. As part of this effort TPI Composites developed a conceptual design of the manufacturing facility for each of the three blade sizes. This exercise provided information necessary for determining the cost of labor and overhead (capital equipment and facilities). Each of the three potential manufacturing facilities was sized to provide a constant annual rated power production (approximately 650 to 700 MW per year). The annual blade production capacity and the plant conceptual design were used to develop tooling, equipment, and facilities cost estimates.

1.4 Transportation Costs

Transportation of large wind turbine blades can be difficult and expensive. TPI Composites estimated the cost of transportation by overland trucking. We considered several different manufacturing plant locations in the Northeast, Southwest, and Western United States and computed the cost for trucking the blades to a number of wind sites. We also identified potential constraints for movement of large blades on public roadways.

2.0 DIRECT MANUFACTURING COST

2.1 Blade Planform Definition

The cost study for large wind turbine blades reviewed three blades of 30 meters, 50 meters, and 70 meters in length. The blade planform characteristics were defined non-dimensionally as a function of the rotor radius, as shown in Table 2.1 and Figure 2.1 and scaled to match each blade length in the study list. The wind turbine was assumed to have a conventional, three bladed rotor with the blades mounted at the root to a central hub.

Table 2.1 Non-Dimensional Blade Planform Definition

Radius Ratio	Chord Ratio	Twist (deg)	Thickness Ratio
5%	5.2%	29.5	100%
15%	7.8%	19.5	42%
25%	8.6%	13.0	28%
35%	7.6%	8.8	24%
45%	6.6%	6.2	23%
55%	5.7%	4.4	22%
65%	4.9%	3.1	21%
75%	4.0%	1.9	20%
85%	3.2%	0.8	19%
95%	2.4%	0.0	18%

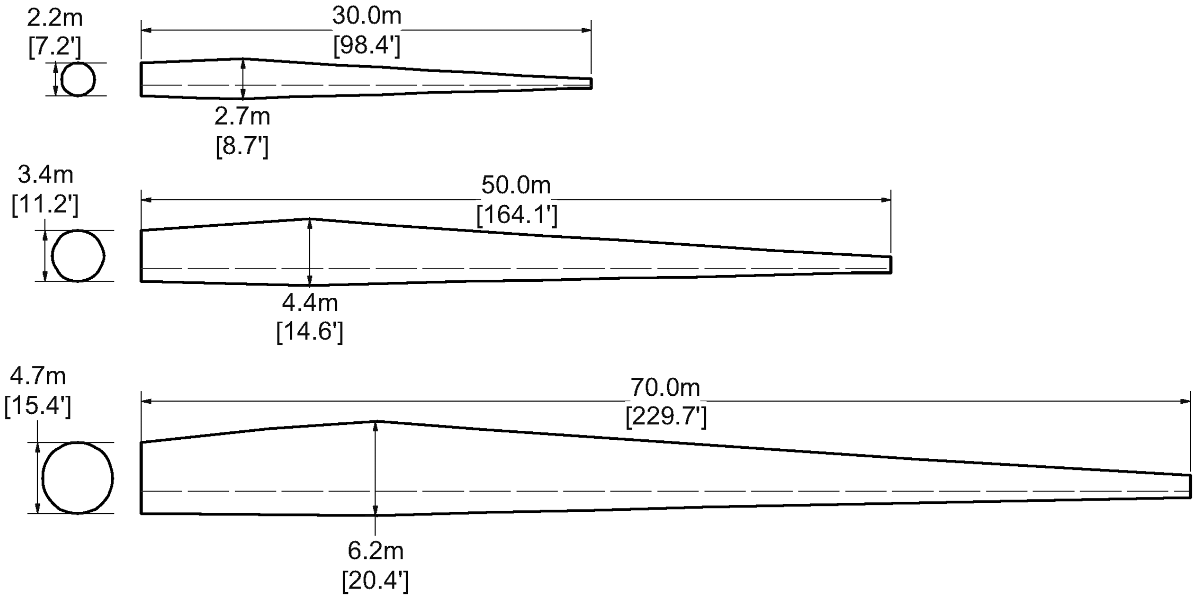

Figure 2.1 Blade Planform Drawings

2.2 Blade Design Loads

Blade extreme wind design loads were estimated in accordance with IEC Class I recommendations. This method assumed the wind speed was 70 m/s at the rotor hub and wind shear increased with hub height according to power law with an exponent of 0.11 (per Germanischer Lloyd rules). Standard air density and a partial load factor of 1.35 were assumed in the analysis.

Table 2.2 Blade Extreme Wind Design Bending Moments

Rotor Station (%)	30 m Moment (kNm)	50 m Moment (kNm)	70 m Moment (kNm)
0.0%	4231	20198	56249
10.0%	3300	15763	43914
20.0%	2455	11738	32717
30.0%	1751	8380	23367
40.0%	1191	5704	15910
50.0%	760	3640	10156
60.0%	442	2118	5911
70.0%	222	1067	2978
80.0%	86	415	1158
90.0%	19	90	251

2.3 Blade Structural Design

Structural analyses of three blade sizes were performed at representative spanwise stations. The evaluation approach used a beam section analysis methodology that has been successfully applied in previous blade development projects. The properties of the blade cross-sections were computed using standard two-dimensional beam theory. The blade construction was assumed to be a stressed shell, which was composed of four primary components: a low pressure (LP) shell on the downwind side, a high pressure (HP) shell on the upwind side, and two shear webs bonded between the two shells as shown in Figure 2.2.

The blade shells were assumed to have E-glass skins. The skins were assumed to fabricated from double bias material. The skin layers were separated by coring in the aft panels to provide buckling stability. A structural spar cap composed of uni-directional (0°) glass material was assumed to be located in each shell between the shear webs. The two shear webs were assumed to be double bias glass fabric with coring.

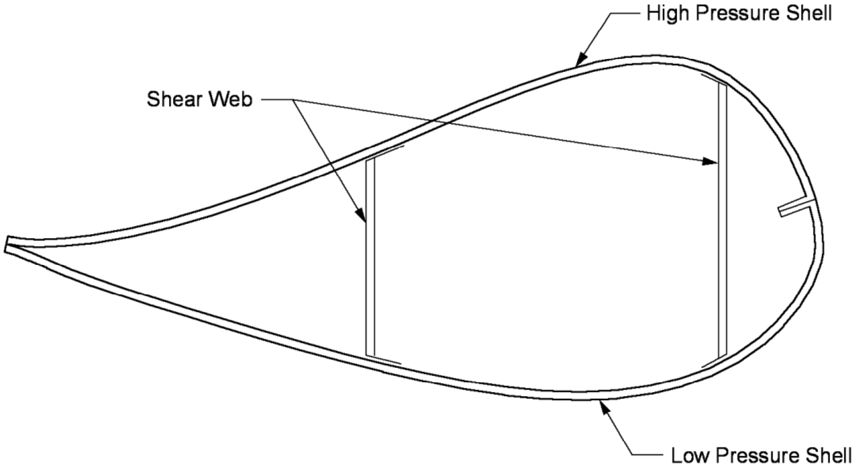

Figure 2.2 Typical Blade Construction

The double-bias fabric that is the primary skin structure was assumed to increase linearly in thickness with blade length. It was taken to be 3.05e-5 times the length. For a 50m blade, this would be 1.5mm (0.06”). The outside of the skin was assumed to have gelcoat to provide UV protection, and random mat to suppress print through of the double-bias fabric. The gelcoat and random mat thicknesses were held constant.

The shear web core thickness was taken to be 3% of the airfoil thickness. This reflects the fact that the webs of thicker airfoils will have to span a longer top to bottom distance, and will therefore need a thicker core to resist buckling loads. The shear web skins were taken to be 5/3 the thickness of the blade skins, a value which was found sufficient to handle the estimated peak web shear loads.

Spar cap thickness was derived from the imposed load in an iterative fashion. As the airfoil thickness increases, the spar cap becomes thinner because the separation between tension and compression side material increases. Table 2.3 shows the spar cap results for each of the blade lengths and thickness distribution variations. The percentage thickness numbers are as a percentage of airfoil maximum thickness.

Table 2.3 Spar Cap Thickness Distribution

Station	Section	Spar Cap	
	Thickness	Thickness	Thickness
(%)	(mm)	(mm)	(%)
30 Meter Blade			
85	188	9.2	4.9%
65	317	25.7	8.1%
45	473	39.3	8.3%
25	746	39.3	5.3%
15	1009	22.1	2.2%
50 Meter Blade			
85	315	16.5	5.2%
65	532	44.6	8.4%
45	794	67.0	8.4%
25	1252	66.8	5.3%
15	1693	37.5	2.2%
70 Meter Blade			
85	443	23.4	5.3%
65	747	63.3	8.5%
45	1114	94.1	8.4%
25	1758	93.8	5.3%
15	2376	51.8	2.2%

The number of blade root fasteners were assumed to be roughly constant for all three blade sizes. The diameter of the fasteners was scaled to provide the necessary strength capacity for the blade attachment joint. The size and number of fasteners is summarized in Table 2.4.

Table 2.4 Blade Root Fastener Summary

Blade Length (m)	Number of Bolts	Bolt Diameter (mm)	Bolt Circle (mm)	Laminate Thickness (mm)	Bolt Spacing (mm)
30	50	24	2100	76.2	132
50	54	40	3300	127.0	192
70	56	56	4600	177.8	258

2.4 Blade Natural Frequency Scaling

Blade natural frequency scaling was also estimated for each of the three blade sizes and for both the non-rotating and rotating condition. The results of these analyses are summarized in Table 2.5. They indicate that the reduction in blade flatwise natural frequency is approximately linear with blade length, and that the reduction of the edgewise natural frequency is less than linear as a result of the trailing edge spline added to provide strength against gravity cyclic bending.

Table 2.5 Blade Natural Frequency for the First Bending Modes

Blade Length (m)	Non-Rotating Frequency		Rotating Frequency	
	Flatwise (Hz)	Edgewise (Hz)	Flatwise (Hz)	Edgewise (Hz)
30	1.61	1.94	1.61	1.94
50	1.00	1.46	1.03	1.47
70	0.72	1.19	0.74	1.20

The blade natural frequency analysis indicates that maintaining adequate separation between the blade natural frequencies and the turbine operating frequency will not constrain blade design as they are scaled to larger sizes. The ratio between the blade flatwise frequency and the rotor operating frequency was found to increase slightly over the range of blade sizes studied (Table 2.6). In the edgewise direction the frequency ratio will increased significantly with blade scale due to the increased strength and stiffness required to overcome gravity bending moments.

Table 2.6 Blade Frequency Ratio Assuming Constant 70 m/s Tip Speed

Blade Length (m)	Rotor Speed (rpm)	Operating Frequency (Hz)	Frequency Ratio	
			Flatwise (%)	Edgewise (%)
30	21.6	0.36	448%	540%
50	12.9	0.21	481%	686%
70	9.2	0.15	487%	786%

2.5 Blade Fabrication Process

The large blade cost study assumed that TPI Composites would continue with its existing manufacturing processes and assembly techniques. TPI currently employs the patented Seemans Composite Resin Infusion Molding Process (SCRIMP™) to build 9 meter and 26.5 meter wind turbine blades. Resin infusion is environmentally responsible because it minimizes the release of volatile organic compounds (VOC) in the atmosphere and improves working conditions for manufacturing staff. Resin infusion also provides excellent laminate quality because it completely eliminates entrained air, resulting in undetectable void content. Resin infusion has become the leading process for fabrication of large wind turbine blades and is representative of the current state-of-the-art.

SCRIMP™ can be used with a full range of resin systems, including: polyesters, vinylesters, epoxies, and phenolics. SCRIMP™ is also compatible with any type of fiber reinforcement and allows use of heavier fabrics, or much larger yarn size, resulting in reduced labor hours for cutting and layout. During fabrication of components the glass reinforcement is placed in the mold dry. This allows for exact placement of the material for precise weight control and enhances the effectiveness of quality assurance procedures. For this study we assumed the blades would be fabricated using vinylester resin and e-glass fabrics, for which prior material property data are available[2].

TPI Composites has prior experience with a several different root attachment approaches. We currently believe bonded root studs are the most cost efficient method. Our team has completed engineering analyses and laboratory tests [3] that confirmed the strength of bonded studs originally developed for use in wood-epoxy wind turbine blades [4]. These studs are highly tapered to minimize the effects of stress concentrations in the joint. Specialized forms in the blade root are used to create tapered cavities for bonding the root studs. During the final manufacturing step the root studs are bonded into position using a high strength epoxy. This approach has an extensive history of success in long-term fatigue of wood blades and delivers a structurally efficient and low-cost method of root attachment.

2.6 Blade Bill of Materials

A bill of materials was prepared for each of the three blade sizes using the laminate requirements prepared during the structural analysis effort. The bill of materials was developed from the laminate schedules and planform drawings of the blades. A layer by layer description of the blade was developed and the area of each layer of dry material was calculated for each material category. The weight of resin was estimated from the dry material weight using known glass-to-resin ratios (Table 2.7)

Table 2.7 Material Glass-to-Resin Ratios

Material Category	E-Glass (% weight)	Resin (% weight)
Continuous Strand Mat	60%	40%
Double-Bias E-Glass Fabric	65%	35%
Unidirectional E-Glass Fabric	70%	30%

Separate calculations were performed for each of the main structural elements (high pressure (HP) skin, low pressure (LP) skin, leading edge (LE) shear web, and trailing edge (TE) shear web). Additional estimates were prepared for the bonding adhesive used to assemble the blades and for the steel root studs used in the blade root attachment. The diameter of the blade root and the number of fasteners were calculated to match commercially available pitch bearings. The results of the bill of materials analysis are summarized in Tables 2.8 and 2.9 with graphical representations shown in Figures 2.3, 2.4 and 2.5. This analysis suggests that there is a small improvement in the specific material cost with blade scale.

Table 2.8 **Blade Bill of Materials Weight Summary**

Material Category	30 m (kg)	50 m (kg)	70 m (kg)	Growth Exponent
Fiberglass	2523	11590	30857	2.96
Core	190	864	2313	2.95
Resin	1252	5800	15527	2.97
Adhesive	77	189	363	1.84
Root Studs	66	414	1177	3.40
Total	4108	18856	50238	2.96

Table 2.9 **Blade Bill of Materials Cost Summary**

Material Category	30 m ($)	50 m ($)	70 m ($)
Fiberglass	$7,374	$33,700	$89,530
Core	$991	$4,828	$14,531
Resin	$2,329	$10,785	$28,874
Adhesive	$674	$1,660	$3,193
Root Studs	$874	$4,550	$12,950
Total	$12,241	$55,523	$149,079

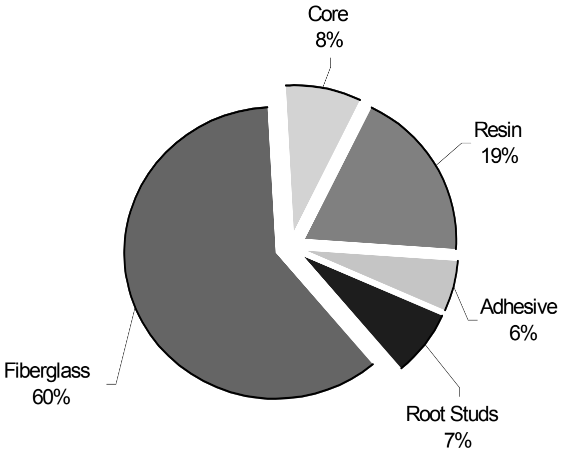

Figure 2.3 **30 Meter Blade Bill of Materials Cost Breakdown**

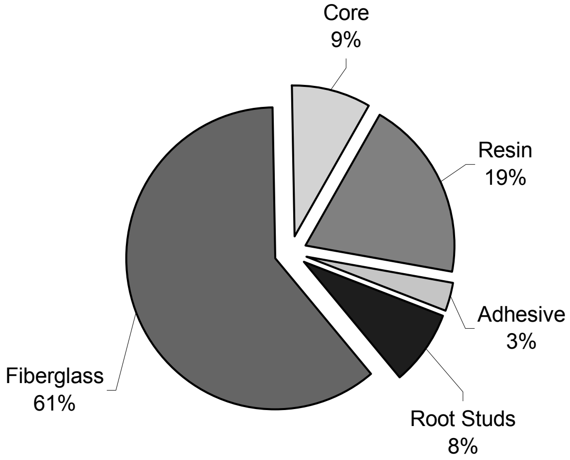

Figure 2.4 **50 Meter Blade Bill of Materials Cost Breakdown**

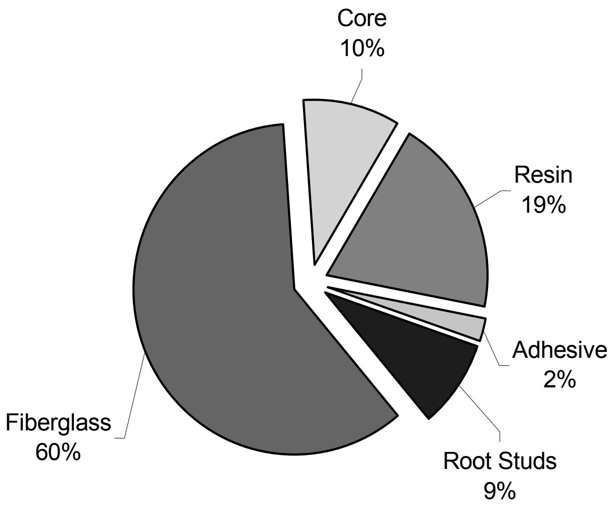

Figure 2.5 70 Meter Blade Bill of Materials Cost Breakdown

2.7 Blade Manufacturing Labor

The labor requirements were estimated using the manufacturing process approach detailed in this section. Labor estimates were prepared for twelve major tasks. The manufacturing approach was as follows:

1.0 Material Kitting
2.0 High Pressure Skin
3.0 Low Pressure Skin
4.0 Leading Edge Shear Web
5.0 Trailing Edge Shear Web
6.0 Assembly Preparation
7.0 Bonding
8.0 Root Stud
9.0 Finishing
10.0 Inspection
11.0 Testing
12.0 Shipping

The labor to complete the manufacturing tasks was estimated for the 30 meter size. The labor requirements were scaled to the larger blade sizes by assuming a power law and growth exponent for each subtask. The blade labor growth rates and total labor hours are summarized in Table 2.10 and 2.11. Blade manufacturing tasks are displayed as a ratio to the entire blade in Table 2.12.

Table 2.10 Blade Manufacturing Task Growth Rates

Task No.	Manufacturing Task	Growth Rate
1.0	Material Kitting	2.42
2.0	High Pressure Skin	2.66
3.0	Low Pressure Skin	2.66
4.0	Leading Edge Shear Web	2.68
5.0	Trailing Edge Shear Web	2.68
6.0	Assembly Prep	1.57
7.0	Bonding	1.64
8.0	Root Stud	1.60
9.0	Finishing	1.28
10.0	Inspection	1.54
11.0	Testing	0.87
12.0	Shipping	1.55
	Total	2.40

Table 2.11 Blade Manufacturing Labor Summary

Total Manufacturing Hours	Growth Rate	30 m (hours)	50 m (hours)	70 m (hours)
	2.40	450.0	1200.9	2802.5

Table 2.12 Blade Manufacturing Labor Task Breakdown

Manufacturing Task	30 m	50 m	70 m
Material	10.1%	10.4%	10.3%
High Pressure Skin	18.0%	20.9%	22.5%
Low Pressure Skin	18.0%	20.9%	22.5%
Leading Edge Shear Web	12.3%	14.4%	15.5%
Trailing Edge Shear Web	12.3%	14.4%	15.5%
Assembly Prep	4.9%	3.3%	2.4%
Bonding	7.9%	5.6%	4.2%
Root Stud	3.3%	2.3%	1.7%
Finishing	5.7%	3.3%	2.2%
Inspection	4.1%	2.7%	2.0%
Testing	2.5%	1.2%	0.7%
Shipping	1.1%	0.7%	0.5%
Total	100%	100%	100%

3.0 MANUFACTURING OVERHEAD COST

3.1 Manufacturing Facilities

The manufacturing plant design depends to some degree on the size of the rotor blades. As part of this effort, TPI Composites developed a conceptual design of the manufacturing facility for each of the three blade sizes. This exercise provided information necessary for determining the cost of labor and overhead (capital equipment and facilities). Each of the three potential manufacturing facilities was sized to provide a constant annual rated power production (MW per year) of the blades it produced (Table 3.1). The manufacturing plants were sized assuming 48 operating weeks per year and will provide an annual production capacity in a range between 608 and 672 MW.

Table 3.1 Blade Manufacturing Plant Capacity

Blade Length (m)	Basic Rating (MW)	Manufacturing Capacity		
		Blades (blades/wk)	Blades (blades/yr)	Power (MW/yr)
30	1.4	30	1440	672
50	4.0	10	480	640
70	7.6	5	240	608

The annual blade production capacity and the plant conceptual design were used to develop tooling and equipment requirements. Tooling costs were estimated for each of the major tooling elements in the blade manufacturing facility.

Conceptual design of the manufacturing facilities assumed the use of standard sized buildings and work bays. The length of the blades reviewed in this effort greatly constrains movement within the plant. TPI Composites reviewed a number of potential plant layouts and ultimately selected a linear flow arrangement (Figures 3.1, 3.2, and 3.3), which simplifies movement of the blades through the facility.

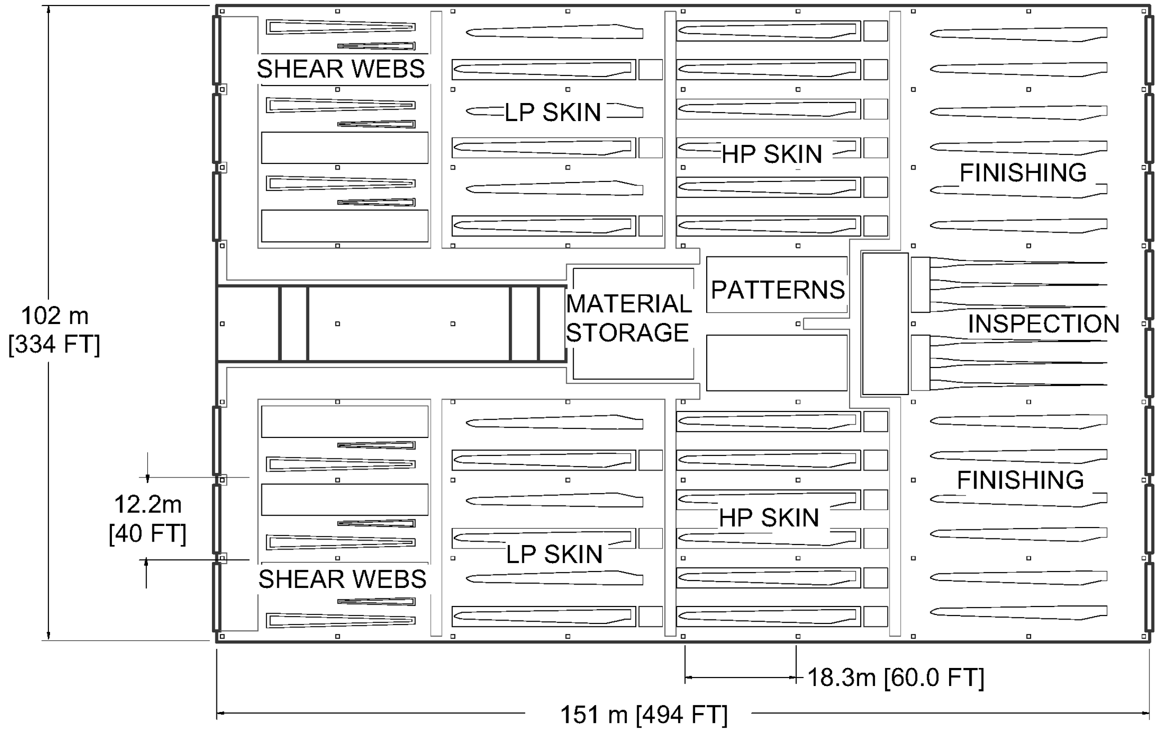

Figure 3.1 30 Meter Blade Manufacturing Plant Conceptual Layout

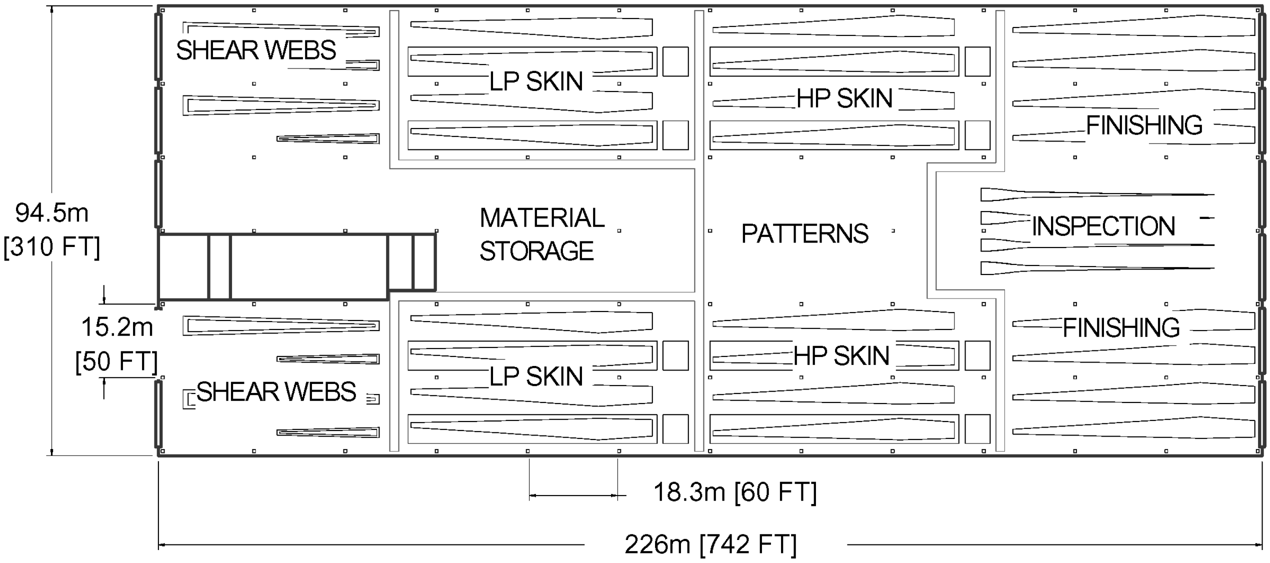

Figure 3.2 50 Meter Blade Manufacturing Plant Conceptual Layout

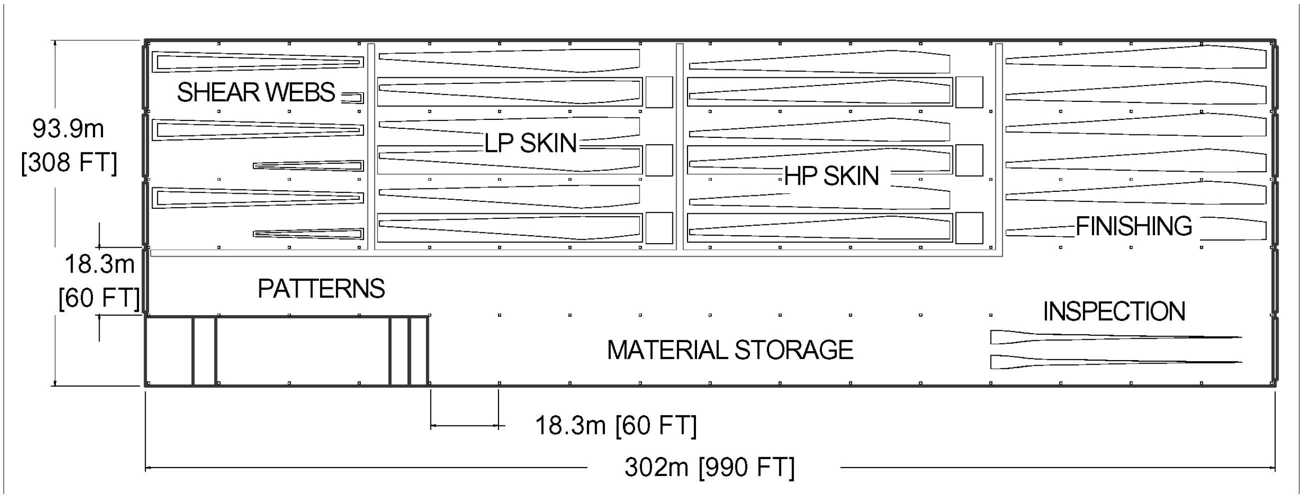

Figure 3.3 70 Meter Blade Manufacturing Plant Conceptual Layout

The dimensions of the manufacturing plant changed considerably as the blade size increased. The size and shape of each plant were determined by the number of work bays in the width and length directions (Table 3.2). The 30 meter blade plant provided space for six (6) assembly lines operating in parallel. Each line was assumed to produce one (1) blade per day yielding a plant output of six (6) blades per day. The 50 meter plant had four (4) assembly lines, but the added assembly time reduced line throughput to one (1) blade every second day, providing a plant output of two (2) blades per day. The 70 meter plant had three (3) assembly lines each delivering a completed blade every third day. Average output for the 70 meter plant is one (1) blade per day.

Table 3.2 Blade Manufacturing Plant Dimensions

Blade Length (m)	Number of Bays	Plant Width		
		Bay (ft)	Overall (ft)	Overall (m)
30	8	40	334	101.8
50	6	50	310	94.5
70	5	60	308	93.9

Blade Length (m)	Number of Bays	Plant Length		
		Bay (ft)	Overall (ft)	Overall (m)
30	8	60	494	151
50	12	60	742	226
70	16	60	990	302

The annual cost to operate each plant was estimated from the floor area.

Table 3.3 Blade Plant Floor Area and Annual Cost

Blade Length (m)	Plant Floor Area (ft2)	(m2)	Plant Cost ($/yr)	Plant Cost ($/MW)
30	164,996	15,329	$1,319,968	$1,813
50	230,020	21,370	$1,840,160	$2,654
70	304,920	28,328	$2,439,360	$3,703

3.2 Production Tooling Costs

The cost of the production tooling can significantly impact total capital requirements for the blade facility. The unit cost of each tool was scaled with results shown in Table 3.4.

Table 3.4 Blade Production Tooling Unit Cost

Tooling Cost Category (Single Tool Set)	30 m (m2)	50 m (m2)	70 m (m2)	30 m ($)	50 m ($)	70 m ($)
HP Skin Mold	53.5	147.2	300.5	$ 86,397	$ 237,651	$ 485,216
LP Skin Mold	53.5	147.2	300.5	$ 86,397	$ 237,651	$ 485,216
LE Shear Web Mold	20.7	57.5	113.0	$ 33,438	$ 92,790	$ 182,368
TE Shear Web Mold	20.7	57.5	113.0	$ 33,438	$ 92,790	$ 182,368
Total per Assembly Line	148.4	409.3	826.9	$ 239,669	$ 660,883	$ 1,335,166

The initial cost for tooling was estimated for each plant along with an estimate of the annual tooling cost (Table 3.5). Each assembly line in the plant was assumed to require a complete tooling set. For purposes of this study it was assumed that the average lifetime for production tooling was four hundred (400) molding operations. The initial capital cost was significantly higher for the large blade sizes; however, the annual cost remains relatively constant.

Table 3.5 Blade Production Tooling Initial and Annual Cost

Blade Length (m)	No. of Assembly Lines	Initial Cost ($)	Annual Mold Cycles	Annual Cost ($/MW)
30	6	$1,438,015	240	$ 1,185.18
50	4	$2,643,530	120	$ 1,143.84
70	3	$4,005,499	80	$ 1,216.24

4.0 TRANSPORTATION COSTS

4.1 Transportation Issues and Constraints

Tractor trailers operating on public roadways are constrained by 1) the overall length of the vehicle, 2) the width, 3) the total height, and 4) the combined weight. The size and weight limitations are dependent upon the individual states and there are significant differences between them as shown in Table 4.1.

Table 4.1 Tractor Trailer Size and Weight Limits for Example States

State	Routinely Permitted to:			Escorts Required Over:			Non-Divisible
Overall Allowable	Length (ft)	Width (ft)	Height (ft)	Length (ft)	Width (ft)	Height (ft)	Weight (lbs)
Arizona	120	14	16	120	14	16	104,000
Arkansas	no limit	16	17	110	14	15	100,000
California	135	15	17	120	12	17	112,500
Colorado	130	17	16	115	13	16	106,000
Idaho	110	16	15.5	120	15	16	106,000
Illinois	145	14.5	15	110	14.5	14.5	100,000
Indiana	110	16	15	85	12.33	14.5	108,000
Iowa	120	18	18	120	14.5	14.33	92,000
Kansas	126	16.5	n/a	n/a	n/a	n/a	95,000
Kentucky	110	16	15.5	100	12	n/a	96,000
Michigan	150	16	15	90	12	14.5	n/a
Minnesota	n/a	14.5	15.5	95	14	15.5	92,000
Missouri	150	16	16	n/a	12.33	16	92,000
Montana	110	18	17	120	16	n/a	107,000
Nebraska	120	16	n/a	n/a	n/a	14.5	99,000
Nevada	n/a	17	16	105	14	17	92,000
New Mexico	n/a	n/a	n/a	90	14	16	105,000
North Dakota	120	18	18	120	18	18	103,200
Ohio	n/a	14	14.83	90	13	14.5	104,000
Oklahoma	n/a	16	21	n/a	12	17	95,000
Oregon	140	14	n/a	120	14	n/a	98,000
South Dakota	n/a	n/a	n/a	n/a	16	n/a	n/a
Tennessee	120	16	15	85	12.5	15	100,000
Texas	125	20	18.9	110	14	17	105,000
Utah	n/a	17	17.5	120	14	17.3	100,000
Wisconsin	n/a	16	n/a	n/a	15	n/a	100,000
Wyoming	110	18	17	110	15	n/a	100,000
Maximum	150.0	20.0	21.0	120.0	18.0	18.0	112500
Minimum	110.0	14.0	14.8	85.0	12.0	14.3	92000
Median	120.0	16.0	16.0	110.0	14.0	16.0	100000

The constraints governing blade size are reduced because of the vehicle height and weight. For purposes of this work we assumed the use of a standard tractor with lowered trailer bed (Table 4.2).

Table 4.2 Typical Tractor Trailer Size and Weight

Tractor Length	24 ft	7.3 m
Trailer Floor Height	3.25 ft	1.0 m
Truck Weight	39,360 lbs	17891 kg

The constraints placed upon the blade geometry and weight were determined by subtracting the tractor trailer values in Table 4.1 from the limits in Table 4.2 and are summarized in Table 4.3.

Table 4.3 Blade Size and Weight Constraints for Example States

State	Routinely Permitted to:			Escorts Required Over:			Non-Divisible
Blade Allowable	Length (m)	Width (m)	Height (m)	Length (m)	Width (m)	Height (m)	Weight (kg)
Arizona	29.3	4.3	3.9	29.3	4.3	3.9	29,382
Arkansas	n/a	4.9	4.2	26.2	4.3	3.6	27,564
California	33.8	4.6	4.2	29.3	3.7	4.2	33,245
Colorado	32.3	5.2	3.9	27.7	4.0	3.9	30,291
Idaho	26.2	4.9	3.7	29.3	4.6	3.9	30,291
Illinois	36.9	4.4	3.6	26.2	4.4	3.4	27,564
Indiana	26.2	4.9	3.6	18.6	3.8	3.4	31,200
Iowa	29.3	5.5	4.5	29.3	4.4	3.4	23,927
Kansas	31.1	5.0	n/a	n/a	n/a	n/a	25,291
Kentucky	26.2	4.9	3.7	23.2	3.7	n/a	25,745
Michigan	38.4	4.9	3.6	20.1	3.7	3.4	n/a
Minnesota	n/a	4.4	3.7	21.6	4.3	3.7	23,927
Missouri	38.4	4.9	3.9	n/a	3.8	3.9	23,927
Montana	26.2	5.5	4.2	29.3	4.9	n/a	30,745
Nebraska	29.3	4.9	n/a	n/a	n/a	3.4	27,109
Nevada	n/a	5.2	3.9	24.7	4.3	4.2	23,927
New Mexico	n/a	n/a	n/a	20.1	4.3	3.9	29,836
North Dakota	29.3	5.5	4.5	29.3	5.5	4.5	29,018
Ohio	n/a	4.3	3.5	20.1	4.0	3.4	29,382
Oklahoma	n/a	4.9	5.4	n/a	3.7	4.2	25,291
Oregon	35.4	4.3	n/a	29.3	4.3	n/a	26,655
South Dakota	n/a	n/a	n/a	n/a	4.9	n/a	n/a
Tennessee	29.3	4.9	3.6	18.6	3.8	3.6	27,564
Texas	30.8	6.1	4.8	26.2	4.3	4.2	29,836
Utah	n/a	5.2	4.3	29.3	4.3	4.3	27,564
Wisconsin	n/a	4.9	n/a	n/a	4.6	n/a	27,564
Wyoming	26.2	5.5	4.2	26.2	4.6	n/a	27,564
Maximum	38.4	6.1	5.4	29.3	5.5	4.5	33245
Minimum	26.2	4.3	3.5	18.6	3.7	3.4	23927
Median	29.3	4.9	3.9	26.2	4.3	3.9	27564

The transportation constraints fall within a general band of values, most of which can be exceeded with special permitting. Height is a relatively “hard” constraint, because it is based upon the passage of the trailer under bridges and power lines. It is possible to find routes which avoid underpasses and to have power lines temporarily removed. However, it is unlikely that these approaches will be economically viable as a general rule. Vehicle weight is also a “hard” constraint, since excessive loads can damage road surfaces. It is possible to move overweight loads using specialized, multi-axle trailers. Length and width are relatively “soft” constraints which can be exceeded with special permits and escort requirements. Increased blade length will require longer turning radii and can preclude routes on winding, rural roadways.

The median value of blade length routinely permitted in the states reviewed here was just 29.3 meters. As a result all of three blade sizes reviewed in this effort would require special permits based on length restrictions alone. For the planform used in this effort, the maximum chord was defined as 8.6% of the blade radius. If the blades are loaded on edge, the height constraint becomes important for blade lengths above 42 meters.

However, loading the blades flat will allow blade lengths up to 50 meters based upon the width constraint (Figure 4.1). The diameter of the blade root becomes an issue as the blade sizes approaches 60 meters (Figure 4.2). The constraint on overall weight becomes critical for blades above 54 m in length (Figure 4.3).

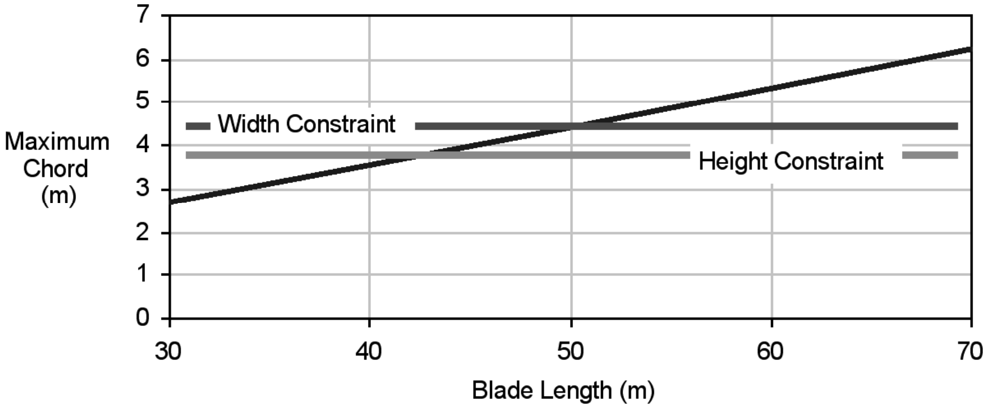

Figure 4.1 Maximum Chord as a Function of Blade Length With Transport Constraints

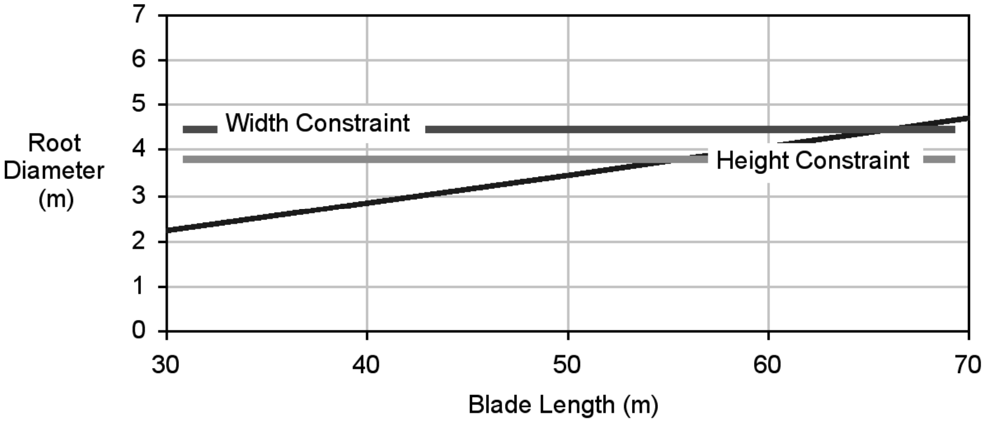

Figure 4.2 Root Diameter as a Function of Blade Length With Transport Constraints

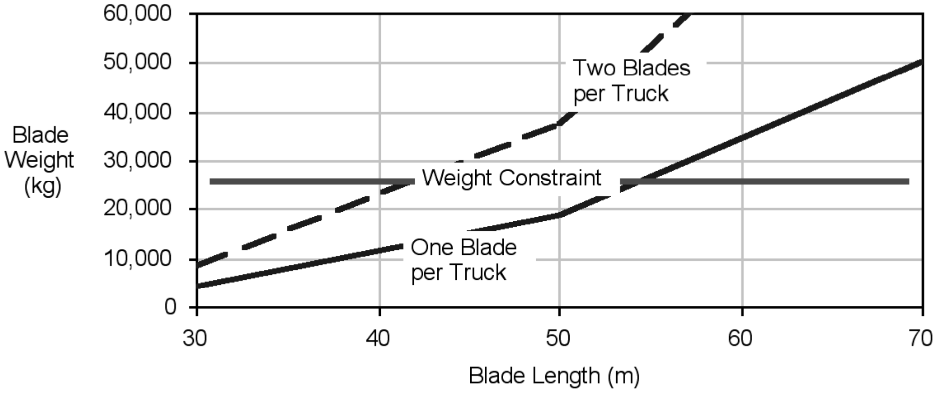

Figure 4.3 Weight as a Function of Blade Length With Transport Constraint

Our review of the transportation issues suggests a large increase in shipping costs will occur for blade lengths above 50 meters. A convergence of dimensional and weight constraints will sharply increase blades transport costs above this length.

4.2 Transportation Scenarios

For purposes of this study, we assumed that transportation would be by tractor trailer (truck), and that the blades would be transported using several routing scenarios:

- Blades fabricated in Warren, Rhode Island and shipped to: a) Burlington, Vermont, b) Buffalo, New York, and c) Morgantown, West Virginia.
- Blades fabricated in El Paso, Texas and shipped to: a) Ventura, Iowa, b) Rock Creek, Wyoming, and c) Pendleton, Oregon.
- Blades fabricated in Reno, Nevada and shipped to: a) Mojave, California, b) Rock Creek, Wyoming, and c) Pendleton, Oregon.

4.3 Transportation Costs

Transportation costs from the manufacturing facility to the windplant site was also estimated. TPI Composites using a freight cost model that included the five cost categories summarized in Table 4.4.

Table 4.4 Blade Transportation Cost Categories

Transportation Cost Category	Cost Factor	
Freight	$ 1.55	per mile
Overdimension Charge	$ 1.25	per mile
Escort Charges	$ 1.40	per escort per mile
Permits	$ 50.00	per state
Return Freight	$ 1.35	per mile

The transport routes and mileage were calculated using a standard road mapping computer program. The selection of potential manufacturing locations and windplant sites was designed to provide representative transportation costs for a few potential examples. However, it is important to note that transportation costs for large blades are related to a range of issues that could not be fully modeled in these examples.

TPI Composites currently operates a blade manufacturing facility in Warren, Rhode Island. This location has shipped blade across the United States for installation in Texas, Wyoming, and California. As the blade market grows it is anticipated that TPI will use the existing Warren facility to supply blades to windplant sites in the eastern United States. Three routes were evaluated (Figure 4.4) and transportation costs estimated (Table 4.5) on a per truck basis.

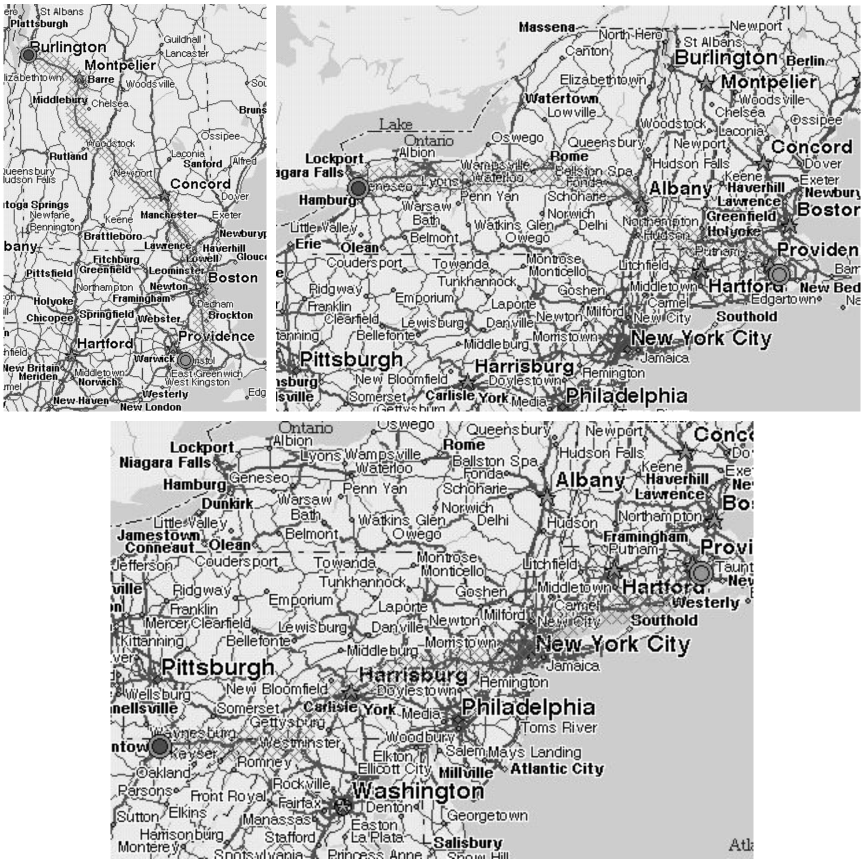

Figure 4.4 Warren Transportation Routes

Table 4.5 Warren Transportation Costs

Origin:	Warren, Rhode Island
Destination	Burlington, Vermont
Routed Miles	274
States Enroute	3

Cost Category	Cost
Freight	$ 424.70
Overdimension Charge	$ 342.50
Escort Charges	$ 383.60
Permits	$ 150.00
Return Freight	$ 369.90
Cost per Truck	$ 1,670.70

Origin:	Warren, Rhode Island
Destination	Buffalo, New York
Routed Miles	462
States Enroute	3

Cost Category	Cost
Freight	$ 716.10
Overdimension Charge	$ 577.50
Escort Charges	$ 646.80
Permits	$ 150.00
Return Freight	$ 623.70
Cost per Truck	$ 2,714.10

Origin:	Warren, Rhode Island
Destination	Morgantown, West Virginia
Routed Miles	571
States Enroute	6

Cost Category	Cost
Freight	$ 885.05
Overdimension Charge	$ 713.75
Escort Charges	$ 799.40
Permits	$ 300.00
Return Freight	$ 770.85
Cost per Truck	$ 3,469.05

TPI Composites also evaluated locating a manufacturing plant in El Paso, Texas. This location offers a low cost labor pool and can easily ship blades to many wind sites. We reviewed three routes (Figure 4.5) and estimated the transportation costs (Table 4.6).

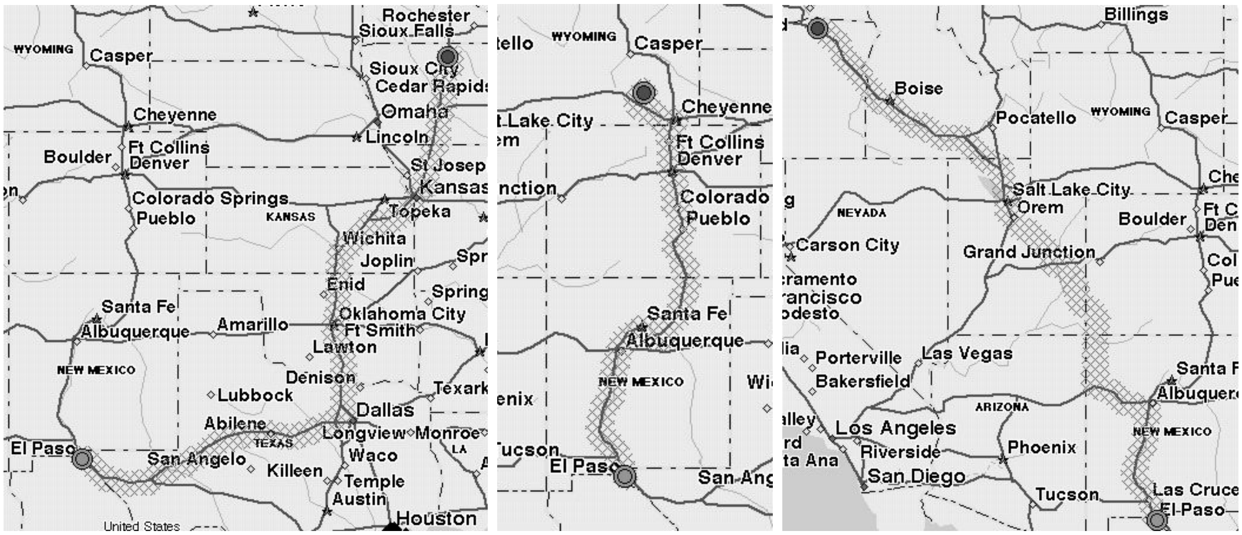

Figure 4.5 El Paso Transportation Routes

Table 4.6 El Paso Transportation Costs

Origin:	El Paso, Texas
Destination	Ventura, Iowa
Routed Miles	1462
States Enroute	5

Cost Category	Cost
Freight	$ 2,266.10
Overdimension Charge	$ 1,827.50
Escort Charges	$ 2,046.80
Permits	$ 250.00
Return Freight	$ 1,973.70
Cost per Truck	$ 8,364.10

Origin:	El Paso, Texas
Destination	Rock Creek, Wyoming
Routed Miles	921
States Enroute	4

Cost Category	Cost
Freight	$ 1,427.55
Overdimension Charge	$ 1,151.25
Escort Charges	$ 1,289.40
Permits	$ 200.00
Return Freight	$ 1,243.35
Cost per Truck	$ 5,311.55

Origin:	El Paso, Texas
Destination	Pendleton, Oregon
Routed Miles	1421
States Enroute	6

Cost Category	Cost
Freight	$ 2,202.55
Overdimension Charge	$ 1,776.25
Escort Charges	$ 1,989.40
Permits	$ 300.00
Return Freight	$ 1,918.35
Cost per Truck	$ 8,186.55

The study also included a plant in Reno, Nevada. This location offers access to western and Pacific wind sites (Figure 4.6 and Table 4.7).

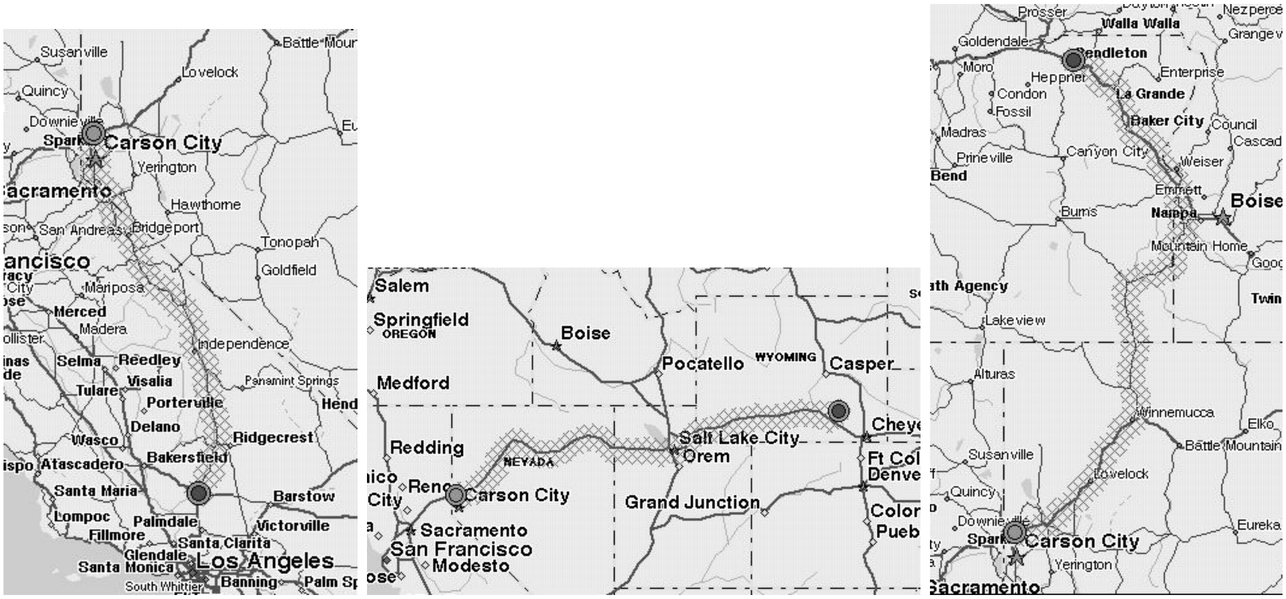

Figure 4.6 Reno Transportation Routes

Table 4.7 Reno Transportation Costs

Origin:	Reno, Nevada
Destination	Mojave, California
Routed Miles	375
States Enroute	2

Cost Category	Cost
Freight	$ 581.25
Overdimension Charge	$ 468.75
Escort Charges	$ 525.00
Permits	$ 100.00
Return Freight	$ 506.25
Cost per Truck	$ 2,181.25

Origin:	Reno, Nevada
Destination	Rock Creek, Wyoming
Routed Miles	895
States Enroute	3

Cost Category	Cost
Freight	$ 1,387.25
Overdimension Charge	$ 1,118.75
Escort Charges	$ 1,253.00
Permits	$ 150.00
Return Freight	$ 1,208.25
Cost per Truck	$ 5,117.25

Origin:	Reno, Nevada
Destination	Pendleton, Oregon
Routed Miles	591
States Enroute	3

Cost Category	Cost
Freight	$ 916.05
Overdimension Charge	$ 738.75
Escort Charges	$ 827.40
Permits	$ 150.00
Return Freight	$ 797.85
Cost per Truck	$ 3,430.05

5.0 CONCLUSIONS

5.1 Overall Costs

TPI Composites estimated the total blade cost by combining the results from each individual category. The overall cost percentages per blade are summarized in Table 5.1 and the specific blade cost ($/MW and $/kg) are provided in Figures 5.4 and 5.5.

Table 5.1 Overall Blade Cost

Overall Blade Cost (5 yr Production Run)	30 m	50 m	70 m
Materials	30.7%	35.9%	37.9%
Labor	36.8%	31.1%	28.5%
Profit and Overhead	21.6%	21.4%	21.2%
Other	4.3%	4.8%	5.6%
Transportation (El Paso to Rock Creek)	6.7%	6.9%	6.8%
Total Cost	100.0%	100.0%	100.0%

The results indicate that as blades get larger, the blade materials become a greater proportion of total cost, while the percentage of labor cost is decreased. The blade development costs (included in Table 5.1 in the "other" category) increase substantially as a result of the higher prototype costs and the shorter production runs over which to amortize development costs. Transportation costs decreased as a percentage of total cost because total blade cost increased. Overall blade component cost is shown graphically for each blade size in Figures 5.1, 5.2 and 5.3. Blade power specific cost and blade weight specific cost are both shown as a function of blade length in Figures 5.4 and 5.5.

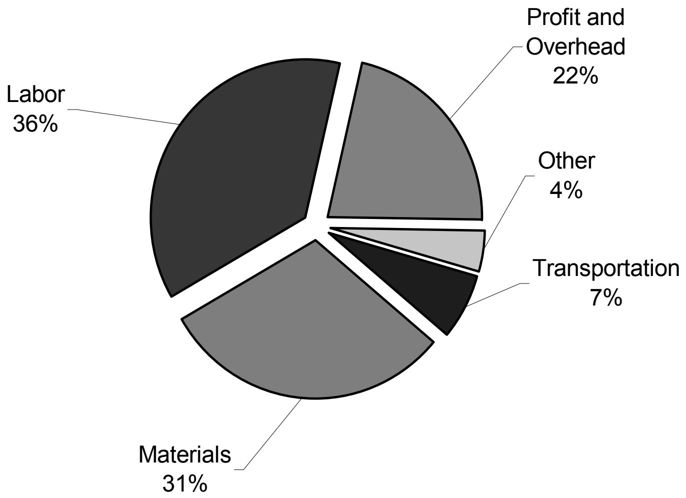

Figure 5.1 30 m Blade Overall Cost

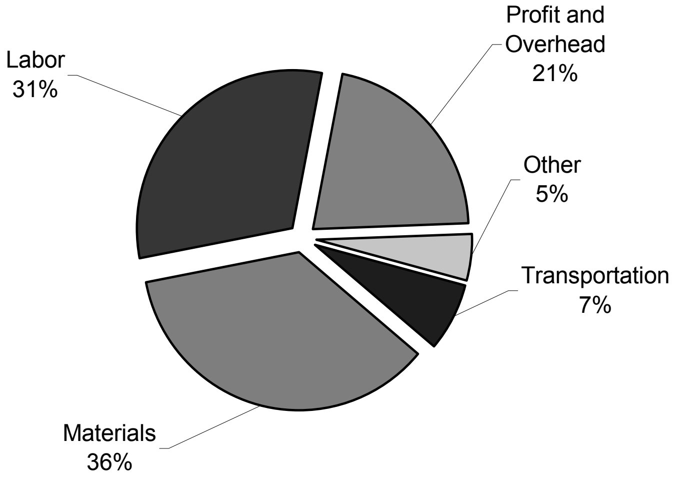

Figure 5.2 50 m Blade Overall Cost

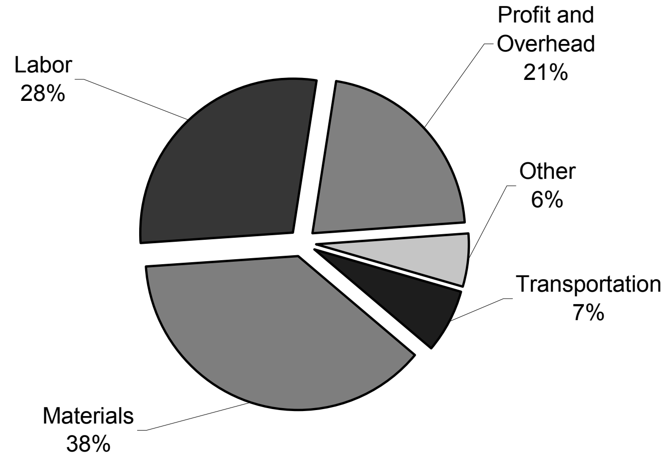

Figure 5.3 70 m Blade Overall Cost

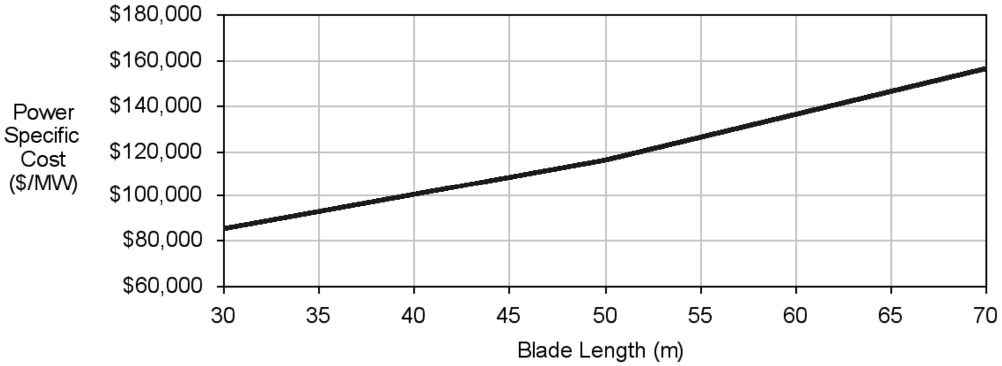

Figure 5.4 Blade Power Specific Cost as a Function of Blade Length

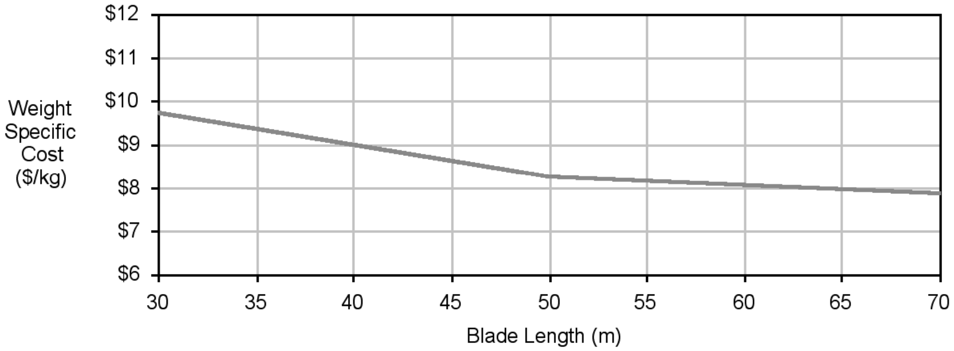

Figure 5.5 Blade Weight Specific Cost as a Function of Blade Length

5.2 Conclusions

We performed a cost growth analysis in order to assess the importance of the certain assumptions and input variables on the results. We reviewed the sensitivity to materials cost, labor cost, development cost, plant cost, tooling cost, and transport cost. The results of that analysis are summarized in Table 5.2.

The results of this study indicate that overall blade cost scales at a rate less than the growth in the weight. This is due primarily to a lower rate of growth for estimated manufacturing labor costs. Many of the cost categories are proportional to blade area, rather than material volume. Even with a somewhat more favorable scaling trend, the blade cost share as a percentage of the total turbine installed cost can be expected to nearly double when the blade size increases from 30 to 70 meter, as shown Figure 5.6.

Table 5.2 Overall Blade Cost Growth

Overall Blade Cost (5 yr Production Run)	30 m => 50 m Growth Exponent	50m => 70 m Growth Exponent	30m => 70 m Growth Exponent
Materials	2.96	2.94	2.95
Labor	2.32	2.52	2.40
Profit and Overhead	2.64	2.75	2.68
Development	3.97	4.24	4.08
Plant	2.80	2.90	2.84
Tooling	1.99	2.09	2.03
Transportation	2.71	2.72	2.72
Total Cost	2.66	2.78	2.71

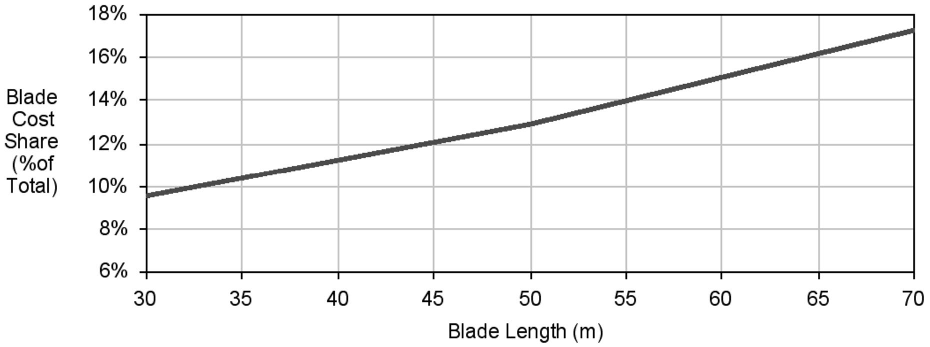

Figure 5.6 Blade Cost Share as a Function of Blade Length

The study also suggests that blade cost reduction efforts should focus on reducing material cost and lowering manufacturing labor requirements. Cost reductions in those areas will have the strongest impact on overall blade cost. A sensitivity analysis of blade cost was prepared by assuming that blade cost as a portion of total installed cost was constant. The results of that study (Table 5.3 and Figure 5.7) show that large cost reductions are necessary to maintain constant specific cost. The cost reductions necessary for labor and materials are very nearly equivalent to those required when all cost categories are included.

Table 5.3 Blade Cost Sensitivity

Blade Cost Sensitivity (Constant $/MW)	30 m (%)	50 m (%)	70 m (%)
All Cost Categories	100.0%	73.7%	55.0%
Material and Labor	100.0%	70.2%	48.8%
Material Only	100.0%	44.5%	10.2%
Labor Only	100.0%	35.8%	-19.5%

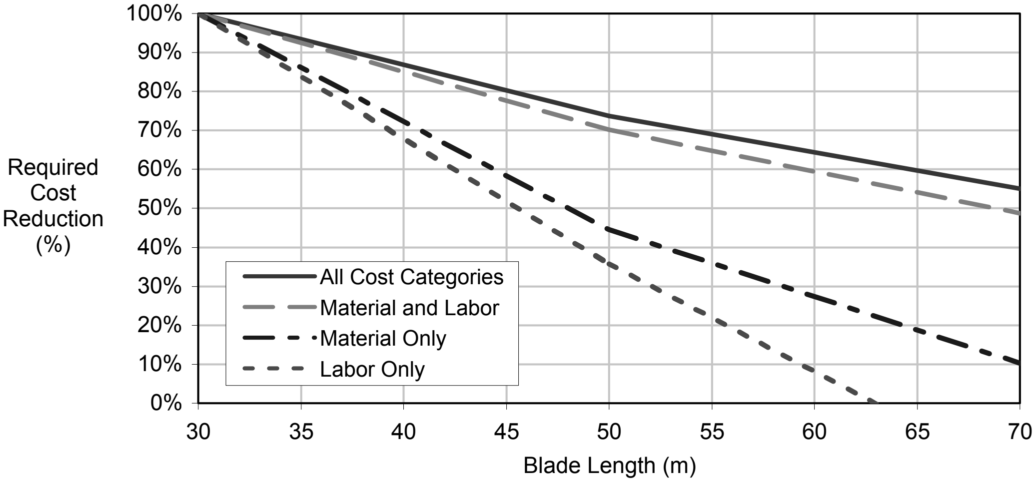

Figure 5.7 Required Cost Reduction Assuming Constant Power Specific Cost

6.0 REFERENCES

---

1. TPI Composites, "Parametric Study for Large Wind Turbine Blades", SAND2002-2519, August 2002

2. Hunsberger, R., etal.; "Final Report: Static Tensile Tests of Fiberglass Coupons for TPI Composites", NWTC Structural Testing, NREL, NWTC-ST-TPI-STA-02-012k-FR, 21 November 2001.

3. Hughes, S., etal.; "Final Report: Cold Climate Testing of Double-Ended Fiberglass/Steel Root Stud Substructures for Wind Turbine Blades", NWTC Structural Testing, NREL, NWTC-ST-NPS/BMI-LF-02-0301-FR, 17 July 2001.

4. Spera, A., Esgar, J., Gougeon, M, and Zuteck, M.,Structural Properties of Laminated Douglas Fir/Epoxy Composite Material, NASA Reference Publication 1236, DOE/NASA/20320-76, May 1990.

DISTRIBUTION

H. Ashley
Dept. of Aeronautics and
Astronautics Mechanical Engr.
Stanford University
Stanford, CA 94305

K. Bergey
University of Oklahoma
Aero Engineering Department
Norman, OK 73069

D. Berry (5)
TPI Composites Inc.
373 Market Street
Warren, RI 02885

R. Blakemore
GE Wind
13681 Chantico Road
Tehachapi, CA 93561

C. P. Butterfield
NREL
1617 Cole Boulevard
Golden, CO 80401

G. Bywaters
Northern Power Systems
Box 999
Waitsfield,VT 05673

J. Cadogan
Office of Wind and Hydro Technology
EE-12
U.S. Department of Energy
1000 Independence Avenue SW
Washington, DC 20585

D. Cairns
Montana State University
Mechanical & Industrial Engineering Dept.
220 Roberts Hall
Bozeman, MT 59717

S. Calvert
Office of Wind and Hydro Technology
EE-12
U.S. Department of Energy
1000 Independence Avenue SW
Washington, DC 20585

J. Chapman
OEM Development Corp.
840 Summer St.
Boston, MA 02127-1533

Kip Cheney
PO Box 456
Middlebury, CT 06762

C. Christensen, Vice President
GE Wind
13681 Chantico Road
Tehachapi, CA 93561

R. N. Clark
USDA
Agricultural Research Service
P.O. Drawer 10
Bushland, TX 79012

C. Cohee
Foam Matrix, Inc.
1123 East Redondo Blvd.
Inglewood, CA 90302

J. Cohen
Princeton Economic Research, Inc.
1700 Rockville Pike
Suite 550
Rockville, MD 20852

C. Coleman
Northern Power Systems
Box 999
Waitsfield, VT 05673

K. J. Deering
The Wind Turbine Company
1261 120th Ave. NE
Bellevue, WA 98005

A. J. Eggers, Jr.
RANN, Inc.
744 San Antonio Road, Ste. 26
Palo Alto, CA 94303

D. M. Eggleston
DME Engineering
1605 W. Tennessee Ave.
Midland, TX 79701-6083

P. R. Goldman
Director
Office of Wind and Hydro Technology
EE-12
U.S. Department of Energy
1000 Independence Avenue SW
Washington, DC 20585

D. Griffin
GEC
5729 Lakeview Drive NE, Ste. 100
Kirkland, WA 98033

C. Hansen
Windward Engineering
4661 Holly Lane
Salt Lake City, UT 84117

C. Hedley
Headwaters Composites, Inc.
PO Box 1073
Three Forks, MT 59752

D. Hodges
Georgia Institute of Technology
270 Ferst Drive
Atlanta, GA 30332

Bill Holley
3731 Oakbrook
Pleasanton, CA 94588

K. Jackson (3)
Dynamic Design
123 C Street
Davis, CA 95616

E. Jacobsen
GE Wind
13000 Jameson Rd.
Tehachapi, CA 93561

G. James
Structures & Dynamics Branch, Mail Code ES2
NASA Johnson Space Center
2101 NASA Rd 1
Houston, TX 77058

M. Kramer
Foam Matrix, Inc.
PO Box 6394
Malibu CA 90264

A. Laxson
NREL
1617 Cole Boulevard
Golden, CO 80401

S. Lockard
TPI Composites Inc.
373 Market Street
Warren, RI 02885

J. Locke, Associate Professor
Wichita State University
207 Wallace Hall, Box 44
Wichita, KS 67620-0044

D. Malcolm
GEC
5729 Lakeview Drive NE, Ste. 100
Kirkland, WA 98033

J. F. Mandell
Montana State University
302 Cableigh Hall
Bozeman, MT 59717

T. McCoy
GEC
5729 Lakeview Drive NE, Ste. 100
Kirkland, WA 98033

L. McKittrick
Montana State University
Mechanical & Industrial Engineering Dept.
220 Roberts Hall
Bozeman, MT 59717

P. Migliore
NREL
1617 Cole Boulevard
Golden, CO 80401

A. Mikhail
Clipper Windpower Technology, Inc.
7985 Armas Canyon Road
Goleta, CA 93117

W. Musial
NREL
1617 Cole Boulevard
Golden, CO 80401

NWTC Library (5)
NREL
1617 Cole Boulevard
Golden, CO 80401

B. Neal
USDA
Agricultural Research Service
P.O. Drawer 10
Bushland, TX 79012

V. Nelson
Department of Physics
West Texas State University
P.O. Box 248
Canyon, TX 79016

T. Olsen
Tim Olsen Consulting
1428 S. Humboldt St.
Denver, CO 80210

R. Z. Poore
Global Energy Concepts, Inc.
5729 Lakeview Drive NE
Suite 100
Kirkland, WA 98033

R. G. Rajagopalan
Aerospace Engineering Department
Iowa State University
404 Town Engineering Bldg.
Ames, IA 50011

J. Richmond
MDEC
3368 Mountain Trail Ave.
Newbury Park, CA 91320

Michael Robinson
NREL
1617 Cole Boulevard
Golden, CO 80401

D. Sanchez
U.S. Dept. of Energy
Albuquerque Operations Office
P.O. Box 5400
Albuquerque, NM 87185

R. Santos
NREL
1617 Cole Boulevard
Golden, CO 80401

R. Sherwin
Atlantic Orient
PO Box 1097
Norwich, VT 05055

Brian Smith
NREL
1617 Cole Boulevard
Golden, CO 80401

J. Sommer
Molded Fiber Glass Companies/West
9400 Holly Road
Adelanto, CA 93201

K. Starcher
AEI
West Texas State University
P.O. Box 248
Canyon, TX 79016

A. Swift
University of Texas at El Paso
320 Kent Ave.
El Paso, TX 79922

J. Thompson
ATK Composite Structures
PO Box 160433
MS YC14
Clearfield, UT 84016-0433

R. W. Thresher
NREL
1617 Cole Boulevard
Golden, CO 80401

S. Tsai
Stanford University
Aeronautics & Astronautics
Durand Bldg. Room 381
Stanford, CA 94305-4035

W. A. Vachon
W. A. Vachon & Associates
P.O. Box 149
Manchester, MA 01944

C. P. van Dam
Dept of Mech and Aero Eng.
University of California, Davis
One Shields Avenue
Davis, CA 95616-5294

B. Vick
USDA, Agricultural Research Service
P.O. Drawer 10
Bushland, TX 79012

K. Wetzel
K. Wetzel & Co., Inc.
PO Box 4153
4108 Spring Hill Drive
Lawrence, KS 66046-1153

R. E. Wilson
Mechanical Engineering Dept.
Oregon State University
Corvallis, OR 97331

M. Zuteck
MDZ Consulting
601 Clear Lake Road
Clear Lake Shores, TX 77565

M.S. 0557	T. J. Baca, 9125	
M.S. 0557	T. G. Carne, 9124	
M.S. 0708	P. S. Veers, 6214 (25)	
M.S. 0708	H. M. Dodd, 6214	
M.S. 0708	T. D. Ashwill, 6214 (10)	
M.S. 0708	D. E. Berg, 6214	
M.S. 0708	P. L. Jones 6214	
M.S. 0708	D. L. Laird, 6214	
M.S. 0708	D. W. Lobitz, 6214	
M.S. 0708	M. A. Rumsey, 6214	
M.S. 0708	H. J. Sutherland, 6214	
M.S. 0708	J. Zayas, 6214	
M.S. 0847	K. E. Metzinger, 9126	
M.S. 0958	M. Donnelly, 14172	
M.S. 1490	A. M. Lucero, 12660	
M.S. 0612	Review & Approval Desk, 9612 For DOE/OSTI	
M.S. 0899	Technical Library, 9616	(2)
M.S. 9018	Central Technical Files, 8945-1	