Wind Turbine Development: Location of Manufacturing Activity

R E P P

Renewable Energy Policy Project

George Sterzinger
Matt Svrcek

Technical Report | September, 2004

CONTENTS

Acknowledgements: A number of people have contributed to this effort, including Fred Beck, Alex Zvinakis, John Buethe, and Richard Colley . We also want to thank the Energy Foundation for supporting the initial phase of the project. The bulk of this project is being carried out under a contract with the Department of Energy.

Executive Summary

The United States is in the midst of an unresolved debate over energy policy. An important part of that debate is over whether and how best to accelerate the development of renewable energy. An important concern about renewable energy centers on how widely the benefits from a national commitment to renewable energy development will be spread across all regions and areas of the country.

In this national debate two prominent policy proposals have been offered to support renewable development: Production Tax Credits (PTC) and a Renewable Portfolio Standard (RPS). The PTC allows a tax credit for each kWh generated from qualified sources. An RPS is a commitment to generate a certain percent of electricity sold from renewable resources.

Wind, one of the lowest cost renewable energy resources, would be very likely to provide a large part of the renewable energy developed under any national program using these two support mechanisms. Since the best wind resource is in the upper Great Plains region, it is reasonable to conclude that a large portion of the wind developed to meet a national standard will be in that region. Some have interpreted that to mean that a majority of the benefits from a national policy would flow to that region. That conclusion is shortsighted because it neglects to look at the chain of manufacturing related to components and sub-components that go into constructing a modern wind generator. While the economic benefits produced by the construction and operation phases of wind development are important and significant, a substantial portion of the benefits from the investment will result from manufacturing the equipment and will flow to those states and localities that either have or can develop the firms to supply the subcomponents.

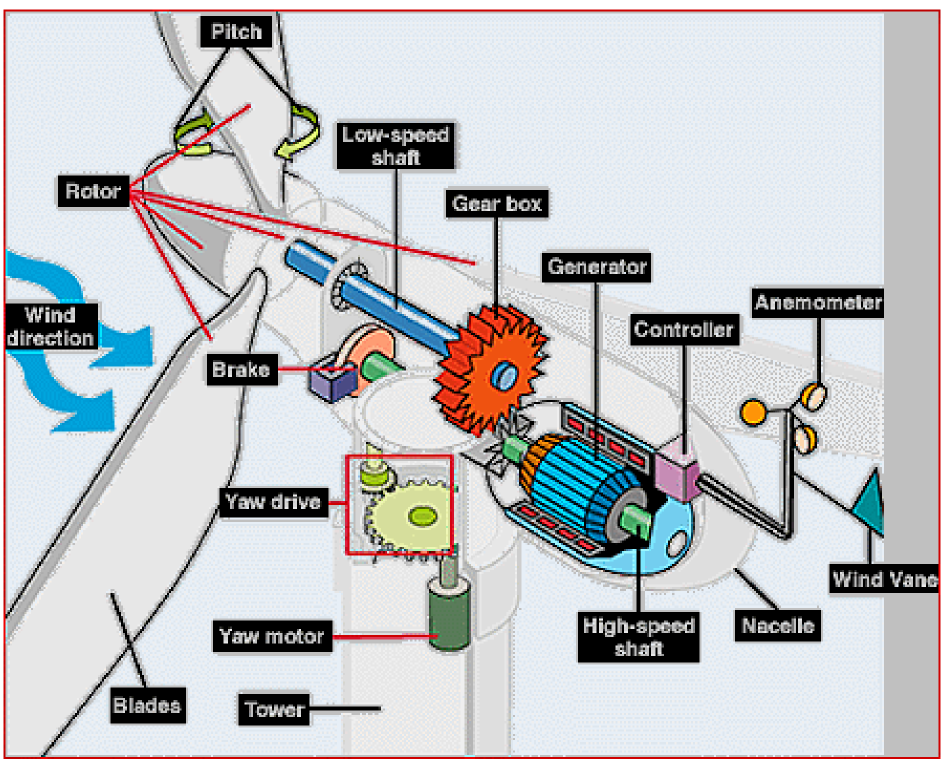


Figure 1 - Wind Turbine Major Components

In order to assess how the benefits could be distributed, this Report takes a modern wind turbine and reduces it to its 20 separate component parts. The Report first identifies 90 companies in 25 states already active in manufacturing these components. However, a large national investment in wind would likely spread beyond these active companies. Hence, as a second step this Report identifies the number of companies with the technical potential to enter the wind turbine market. To identify this potential, the North American Industrial Classification System (NAICS) codes for the 20 components are searched for companies operating in those industry codes. Based on this analysis the Report shows that the manufacturing activity related to the development of wind energy is substantial and widely dispersed. There are 16,163 firms currently operating in one or more of the NAICS codes related to the manufacturing of wind components. These firms are spread over every one of the 50 states, however, they are concentrated in the most populous states, and the states that have suffered the most from loss of manufacturing jobs. The 20 states that, according to our analysis, would receive the most investment and most new manufacturing jobs from investment in wind account for 75% of the total U.S. population, and 76% of the manufacturing jobs lost in the last 3 1/2 years.

U.S. Summary Table – Manufacturing Firms with Technical Potential to Enter Wind Turbine Market

NAICS code	Code Description	Total Employees	Annual Payroll ($1000s)	Number of Companies
326199	All other Plastics Products	501,009	15,219,355	8,174
331511	Iron Foundries	75,053	3,099,509	747
332312	Fabricated Structural Metal	106,161	3,975,751	3,033
332991	Ball and Roller Bearings	33,416	1,353,832	198
333412	Industrial and Commercial fans and blowers	11,854	411,979	177
333611	Turbines, and Turbine Generators, and Turbine Generator Sets	17,721	1,080,891	110
333612	Speed Changer, Industrial	13,991	539,514	248
333613	Power Transmission Equip.	21,103	779,730	292
334418	Printed circuits and electronics assemblies	105,810	4,005,786	716
334519	Measuring and Controlling Devices	34,499	1,638,072	830
335312	Motors and Generators	62,164	2,005,414	659
335999	Electronic Equipment and Components, NEC	42,546	1,780,246	979
Total		**1,025,327**	**35,890,079**	**16,163**

Investment in new wind will create a demand for all of the components that make up a wind generator. As a rule of thumb, every 1000 MW requires a $1 Billion investment in rotors, generators, towers and other related investments. According to a recent analysis done by the Renewable Energy Policy Project (REPP) for a proposed Renewable Portfolio Standard in Pennsylvania, every 1000 MW of wind power developed created a potential for 3000 jobs in manufacturing, 700 jobs in installation, and 600 in operations and maintenance. For the purposes of this Report, a job is defined as one Full Time Equivalent (FTE) employment or 2000 hours of labor. A national program could easily lead to the development over a period of years of 50,000 –77,000 MW or $50 - $77 billion in investments that would in turn drive new orders for manufacturing related to all the components that are required to build a new wind generator.

This Report assumes 50,000 MW will be developed and proceeds in three steps to trace the distribution of benefits. First we determine how the total installed cost of the new wind development will flow into demand for each of the 20 separate components of the turbines (grouped into 5 categories). Second, we spread the total demand among the regions of the country by allocating the $50 billion investment according to the number of employees at firms identified by the NAICS codes. The number of employees is used rather than number of firms to account for the different impact of large vs. small companies, and hence to more accurately distribute the investment. This produces a "map" of manufacturing activity across the United States based on firms that have the technical potential to become active manufacturers of wind turbine components. Third, we translate the regional dollar allocation by assuming that all component manufacturing has the same ratio of jobs/total investment of 3000 FTE jobs/$1 billion of investment.

Employment at Potential Active Companies, Investment and Job Creation Potential
Top 20 States Ranked by Average Investment

State	Employees at Potential Companies	Rotor	Nacelle and Controls	Gearbox & Drive Train	Generator & Power Electronics	Tower	Number of New FTE Jobs	Average Investment ($ Billions)
California	**102,255**	25226	52490	1380	14889	8270	**12,717**	**4.24**
Ohio	**80,511**	30578	33367	6360	3372	6834	**11,688**	**3.90**
Texas	**60,229**	15191	28339	1678	3006	12015	**8,943**	**2.98**
Michigan	**66,550**	27719	30241	2466	926	5198	**8,549**	**2.85**
Illinois	**57,304**	20001	24193	5520	3143	4447	**8,530**	**2.84**
Indiana	**53,064**	18962	20359	4783	2633	6326	**8,317**	**2.77**
Pennsylvania	**50,304**	16647	20844	2565	1997	8251	**7,622**	**2.54**
Wisconsin	**48,164**	17795	21317	3796	567	4689	**6,956**	**2.32**
New York	**47,375**	10855	24188	4020	5966	2347	**6,549**	**2.18**
South Carolina	**20,532**	4398	4510	6780	1765	3079	**4,964**	**1.65**
North Carolina	**30,229**	9431	12814	3142	2036	2806	**4,661**	**1.55**
Tennessee	**28,407**	9761	12513	2128	381	3624	**4,233**	**1.41**
Alabama	**21,213**	6607	7686	927	620	5374	**3,571**	**1.19**
Georgia	**20,898**	6610	8245	2335	253	3456	**3,532**	**1.18**
Virginia	**20,201**	6692	7372	1549	567	4021	**3,386**	**1.13**
Florida	**24,008**	5138	12197	254	1923	4497	**3,371**	**1.12**
Missouri	**23,634**	8389	11031	1202	537	2475	**3,234**	**1.08**
Massachusetts	**27,955**	6956	15952	659	3331	1057	**3,210**	**1.07**
Minnesota	**26,131**	8364	14427	711	1142	1488	**3,064**	**1.02**
New Jersey	**22,535**	8552	10191	819	1299	1675	**2,920**	**0.97**

The results of this initial research into the distribution of manufacturing activity are encouraging. Twenty-five states have firms currently active in manufacturing components or sub-components for wind turbines; all fifty states have firms with the technical potential to become active. The Table provides a breakdown of the twenty states with would receive the greatest portion of the investment, based on the number of employees at potentially active firms identified by the NAICS codes for wind components.

The results indicate that a significant national investment in wind has clear potential to benefit regions of the U.S. other than only those states that have a significant wind resource. Furthermore, investigating the demographics of the top 20 states benefiting from wind manufacturing indicates that investment in wind will particularly target the most populous regions of the country, and will especially benefit regions that are most in need of new manufacturing jobs. The table below juxtaposes the demographics of the top 20 states with the results of this study.

Top 20 States Benefiting from Wind Investment, with Population and Job Loss Demographics

State	Potential Number of Jobs	Average Investment ($ Billions)	2001 Population	Rank in U.S.	Manufacturing Jobs Lost, Jan. 2001 - May 2004*	Rank in U.S.
California	12,717	4.24	34,501,130	1	318,000	1
Ohio	11,688	3.90	11,373,541	7	165,500	3
Texas	8,943	2.98	21,325,018	2	169,600	2
Michigan	8,549	2.85	9,990,817	8	129,300	8
Illinois	8,530	2.84	12,482,301	5	131,500	6
Indiana	8,317	2.77	6,114,745	14	63,500	13
Pennsylvania	7,622	2.54	12,287,150	6	155,200	5
Wisconsin	6,956	2.32	5,401,906	18	68,300	10
New York	6,549	2.18	19,011,378	3	130,500	7
South Carolina	4,964	1.65	4,063,011	26	56,800	17
North Carolina	4,661	1.55	8,186,268	11	156,600	4
Tennessee	4,233	1.41	5,740,021	16	59,700	15
Alabama	3,571	1.19	4,464,356	23	45,300	19
Georgia	3,532	1.18	8,383,915	10	65,700	11
Virginia	3,386	1.13	7,187,734	12	57,500	16
Florida	3,371	1.12	16,396,515	4	56,800	18
Missouri	3,234	1.08	5,629,707	17	36,700	23
Massachusetts	3,210	1.07	6,379,304	13	84,900	9
Minnesota	3,064	1.02	4,972,294	21	38,800	21
New Jersey	2,920	0.97	8,484,431	9	65,400	12
20 State Total	120,017	40	212,375,542		2,055,600	
% U.S. Total	80%	80%	75%		76%	

Notably, the 20 states benefiting the most from investment in wind are almost identically the 20 states that have lost the most manufacturing jobs in the country over the past 3 years. These states account for more than 76% of the manufacturing jobs lost. Investment in wind will particularly benefit these states, sending new jobs where they are needed most. Furthermore, these states are also the most populous, indicating that investment in wind will benefit a large range of people in the country.

Wind Turbine Components

For this Report we broke wind turbines down into 20 separate components. Each component is identified with a ten-digit and therefore a six-digit North American Industrial Classification System (NAICS) code. In addition, we provide technical descriptions of each part. We also describe the Balance-of-System components; however, for this Report we do not count these in the 20 components used to identify manufacturing activity due to the varying nature of Balance-of-System for different installations.

Figure 2 provides a schematic view of a wind turbine's major components.

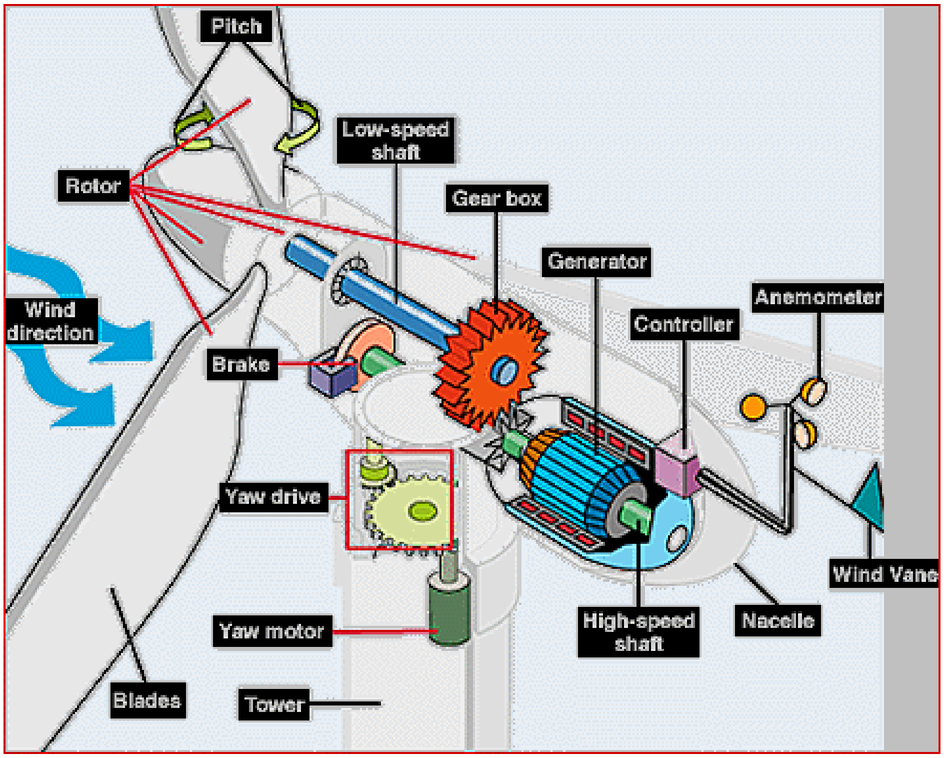


Figure 2 - Schematic of Wind Turbine Major Subcomponents

The nacelle includes:

- An outer frame protecting machinery from the external environment
- An internal frame supporting and distributing weight of machinery
- A power train to transmit energy and to increase shaft speeds
- A generator to convert mechanical energy into electricity
- A yaw drive to rotate (slew) the nacelle on the tower
- Electronics to control and monitor operation

Description of Nacelle Components

Subcomponent	Description
Low Speed Shaft and High Speed Shaft	Transmits rotational work from the rotor hub to the gearbox and from the gearbox to the generator.
Gearbox	Converts low-speed rotation from the input shaft of the rotor to high-speed rotation, which drives the high-speed shaft of the generator assembly. Wind turbine gearboxes typically use a planetary gear system.
Coupling	Attaches the gearbox to the generator. Flexible couplings may be used to reduce oscillating loads that could otherwise cause component damage.
Bearings	A number of bearings are required for the shafts, gearbox, yaw mechanism, generator, and other rotating parts.
Mechanical Brakes	A mechanical friction brake and its hydraulic system halt the turbine blades during maintenance and overhaul. A hydraulic disc brake on the yaw mechanism maintains nacelle position when nacelle is stationary.
Electrical Generator	Converts high-speed shaft work into electrical energy
Power Electronics	Couples the generator output to the step-up transformer input, typically with an IGBT bridge, allowing the generator to run at variable speed while still outputting 50 or 60 Hz AC to the grid. Also makes reactive power possible.
Cooling Unit	A large fan drives air to convectively cool the generator and gearbox and exhausts waste heat from the nacelle assembly. Ducting directs cool air to the generator.

Yaw Mechanism and Four-Point Bearing	Rotates the turbine directly into the wind in order to generate maximum power. Typically, four yaw sensors monitor the wind direction and activate the yaw motors to face the prevailing wind. A four-point bearing connects the nacelle to the tower. The yaw mechanism turns the blades 90 degrees from prevailing winds under high winds to reduce stress on internal components and avoid over-speed conditions.
Electronic Controller(s)	(a) A base controller, located at the base of the tower, utilizes PC's and fiber optics to monitor and record performance data, as well as to facilitate communication between both sub-controllers and external parties. (b) A nacelle controller monitors activity within the nacelle assembly. (c) A hub controller, being used in more recent models, communicates directly with the nacelle controller to more precisely monitor rotor activity
Sensors	(a) An anemometer, located on the tower, measures wind velocity and relays data to the yaw mechanism. (b) A wind vane measures wind direction and relays data to the yaw mechanism. (c) A cable twist counter monitors cables within the tower to determine if the turbine has been yawing in one direction for an extended period of time. (d) A thermocouple senses temperature within the nacelle assembly.

The rotor includes:

- Blades, which are generally made of glass-reinforced fiber up to 50m in length. Lighter and stronger carbon fibers are being used in the larger blades.
- Extenders attach the blades to the central hub
- Pitch drives to control the angle of the blades
- The rotor typically has three blades because that number provides the best balance of high rotation speed, load balancing, and simplicity.

Description of Rotor Components

Subcomponent	**Description**
Rotor Blades	Blades utilize the principles of lift to convert the energy of the wind into mechanical energy. Stall-regulated blades limit lift, or momentum, when wind speeds are too great to avoid damaging the machine. Variable-pitch blades rotate to minimize their surface area and thereby regulate rotational speed.
Pitch Drive	This system controls the pitch of the blades to achieve the optimum angle for the wind speed and desired rotation speed. At lower wind speeds a perpendicular pitch increases the energy harnessed by the blades, and at high wind speeds, a parallel pitch minimizes blade surface area and slows the rotor. Typically one motor is used to control each blade. Power is either electric or provided by hydraulics in the nacelle, and supplemented by a hydraulic accumulator in the event of system failure.
Extenders	These steel components serve as a means to support the rotor blades and secure them to the hub
Hub	The hub serves as a base for the rotor blades and extenders, as well as a means of housing the control systems for the pitch drive. It rotates freely and attaches to the nacelle using a shaft and bearing assembly.

The tower includes:

- Rolled steel tubes connected in series
- Flanges and bolts joining each section
- A concrete base serving as a stable foundation for the turbine assembly

- Concrete segmented towers and hybrid steel/concrete towers may also be used for large turbines in cases where steel tower section transportation is difficult.

Description of Tower Components

Subcomponent	Description
Tower	This component is typically made of rolled, tubular steel, and built and shipped in sections because of its size and weight. Common tubular towers incorporate a ladder within the hollow structure to provide maintenance access. Utility-scale towers range in height from 60-100m and weigh between 200-400 tons.
Base	The base supports the tower and transfers the loads to the foundation soil or bedrock. The foundation size and type depends on the foundation conditions but is typically constructed with steel-reinforced concrete.
Flanges and Bolts	These items join tower segments.

The balance of station includes:

- Electrical collection system: transformer, switchgear, underground and overhead high voltage cable, and interconnecting substation
- Control system: control cable, data collection, and wind farm control station
- Roadway, parking, crane pads and other civil works

Description of Balance of System Components

Subcomponent	Description
Electrical Collection System	(a) Transformers step up voltage transmission in the collector line to convert energy generated by the turbine into usable electricity for utility grids. (b) Underground cables are used to connect the power lines until a standard 25kV overhead collector line may be used. (c) Reclosers and risers act as circuit breakers and isolate a section of the line should there be a power fault. (d) Power substations raise the voltage for standard long-distance transmission.
Communications System	The communications subsystem allows the wind turbines to monitor themselves and report performance to a control station. Data collection equipment and fiber optic cables allow the turbine to monitor and report performance. A control station consolidates data and routes information to the local utility.
Civil Works	Crane pads enable the safe operation of cranes during construction of the turbine and roads provide access during construction and maintenance activities. Maintenance buildings house workers during construction and overhauls.

Identifying Current and Potential Manufacturers

Through phone and internet survey, and by compiling existing databases of manufacturers, REPP created a database of firms that currently manufacture or had recently manufactured one or more of the above components specifically for wind projects. These 90 companies operate in 25 different states, and stand to directly benefit from investment in wind. Several of the companies manufacture more than one component, (most notably GE), and these can be counted as separate manufacturing activities. As such, these 90 companies account for 106 manufacturing activities in the 25 states in which they operate.

Table 1.6 - Wind Component NAICS Codes

Component	Sub component	NAICS 6-digit	Code description	NAICS 10-digit	Code description
Rotor	Blade	326199	All other Plastics Products	A141	Other fabricated fiberglass and reinforced products
	Blade Extender	331511	Iron Foundries	1116	Ductile iron fittings 14 in. or more
	Hub	331511	Iron Foundries	3221	Other ductile iron casting for all other uses
	Pitch Drive	335312	Motors and Generators	30	Integral horsepower motors and generators other than for land transportation equip. (746 watts or more)
Nacelle and Controls	Anemometer	334519	Measuring and Controlling Devices	7025	Other meteorological instruments and parts
	Brakes	333613	Power Transmission Equip.	3111	Friction-type Clutches and Brakes
	Controller	334418	Printed circuits and electronics assemblies	A015	Industrial process control board assemblies
	Cooling Fan	333412	Industrial and Commercial fans and blowers	04	Axial fans
	Nacelle Case	326199	All other Plastics Products	A141	Other fabricated fiberglass and reinforced products
	Nacelle Frame	331511	Iron Foundries	3221	Other ductile iron casting for all other uses
	Sensors	334519	Measuring and Controlling Devices	7	Commercial, Meteorological, Geophysical, and General Purpose Instruments
	Yaw Drive	335312	Motors and Generators	30	Integral horsepower motors and generators other than for land transportation equip. (746 watts or more)
Gearbox and Drive Train	Bearings	332991	Ball and Roller Bearings	3032	Tapered roller bearings (including cups and cones), unmounted
				1023	Complete ball bearings, unmounted, annular, including self~aligning, ground or precision, angular contact, precision
	Coupling	333613	Power Transmission Equip.	3329	Non-gear-type flexible couplings
	Gearbox	333612	Speed Change, Industrial	7438	Enclosed concentric and parallel (Planetary) center distance 6 in. or more
	High and low speed shafts	333613	Power Transmission Equip.	3792	Mechanical power transmission equipment, NEC, except parts
Generator and Power Electronics	Generator	333611	Turbines, and Turbine Generators, and Turbine Generator Sets	0871	Turbine generators
	Power Electronics	335999	Electronic Equipment and Components, NEC	3219	Other rectifying(power conversion) apparatus, except for electronic circuitry
Tower	Tower	332312	Fabricated Structural Metal	5106	Fabricated structural iron and steel for transmission towers, radio antenna, and supporting structures
	Tower Flange	331511	Iron Foundries	116	Ductile iron fittings 14 in. or more

This Report also identifies firms not currently active in the domestic wind manufacturing but reasonably capable of providing components. The Report relied on the NAICS codes to identify the companies that do/could supply an expanded US wind industry. This required associating each component with the correct NAICS code, which was first done at the 10-digit (highest) level of detail to ensure that the codes were accurately identified. The six-digit codes are the standard level of reporting for industry classification, and hence were more useful for this study. For the 20 10-digit component codes there are 12 different 6-digit codes – some of the parts are similar, such as large steel castings, and fall under the same code. For these components that go into a modern turbine, this analysis revealed that there are 16,163 firms that currently operate in one or more of these Industrial classifications. In other words, there are 16,163 firms in 50 states that are now engaged in manufacturing parts or components that are equivalent in terms of manufacturing skills and equipment needs to those required to manufacture components for wind turbines. Our analysis of course does not draw the conclusion that all these firms will benefit. Rather it shows where a technical potential to benefit from a major development of wind exists. This Report shows where these firms are located by state. It is also possible to show these firms on a county-by-county basis.

Since there are already 16,163 firms engaged in manufacturing activities related to those required to manufacture components for wind turbines, a critical question facing policy makers is whether and how to encourage the development of the domestic manufacturing capability. A national commitment to renewable energy will establish the demand for investment, but the development of a strong, competitive domestic manufacturing industry, capable of competing with imports from an already established world industry, will require additional incentives. There are currently a number of incentives for manufacturing ranging from New Market Tax Credits to a variety of economic development zones. A critical part of a national program to expand renewable energy should include a program to collect and focus all available supports for new and expanded manufacturing in order to offer the supports in a "one stop" program. This effort could also include an expansion of the present portfolio of tax credits for firms that locate new or expand manufacturing in certain designated areas.

If the debate over whether or not to make a national commitment to renewable energy is indeed over how widespread the benefits of such a program will be, it is critical that the potential of a large-scale wind development to stimulate precisely the states that have suffered the greatest loss of manufacturing jobs be realized. A federal commitment to renewable energy should be combined with federal supports for manufacturing wind components in order to greatly increase the economic benefits of renewable development, expand the distribution of benefits, and greatly increase the number of people who will see the program as having significant benefits for them.

CHAPTER ONE – WIND TURBINE COMPONENTS

Major Components

Modern wind turbines employ four major component assemblies--the rotor, nacelle, tower, and balance of system. The rotor includes blades used to harness wind energy and convert it into mechanical work, and a hub to support the blades. In addition, most wind turbines have a pitch mechanism to rotate and change the angle of the blades based on the wind speed and the desired rotation speed. The nacelle is the structure that contains, encloses, and supports the components that convert mechanical work into electricity. These components include generators, gearboxes, and control electronics. The tower supports the rotor and nacelle, and raises them to a height where higher wind speeds maximize energy extraction. Modern utility-scale wind turbine towers are typically 60-100 meters high, with blades up to 100 meters in diameter, and rotor and nacelle assemblies weighing several hundred tons. Additional balance-of-station components at ground height are required to gather, control, and transmit power to the grid interconnection. Figure 1.1 provides a schematic view of a wind turbine and its major components.

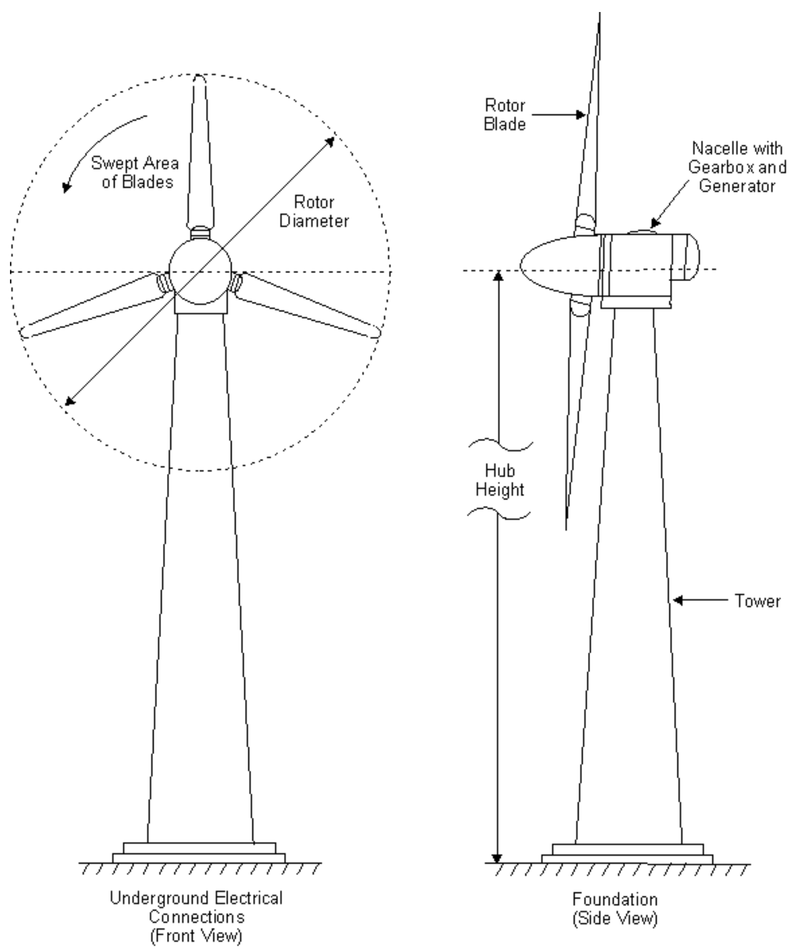


Figure 1.1 - Wind Turbine Major Components

Sub-Components

In order to better understand each of the four major component groups, the nacelle, rotor, tower, and balance of system can be broken down into a list of major subcomponents. Figure 1.2 provides a schematic view of a wind turbine's major components.

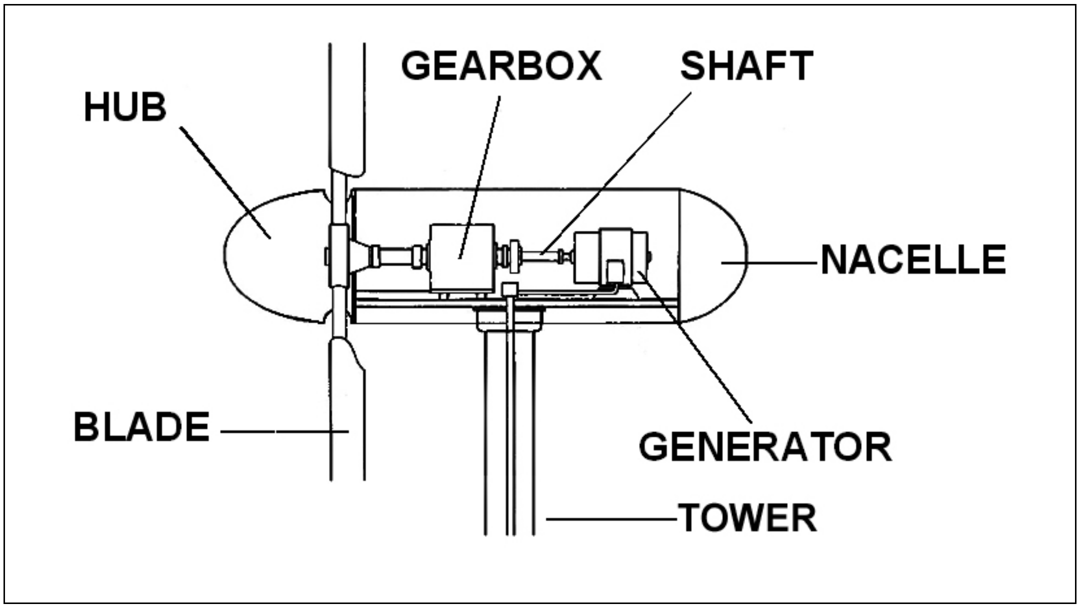


Figure 1.2 - Schematic of Wind Turbine Major Subcomponents

The nacelle includes:

- An outer frame protecting machinery from the external environment
- An internal frame supporting and distributing weight of machinery
- A power train to transmit energy and to increase shaft speeds
- A generator to convert mechanical energy into electricity
- A yaw drive to rotate (slew) the nacelle on the tower
- Electronics to control and monitor operation

Table 1.1 - Description of Nacelle Components

Subcomponent	Description
Low Speed Shaft and High Speed Shaft	Transmits rotational work from the rotor hub to the gearbox and from the gearbox to the generator.
Gearbox	Converts low-speed rotation from the input shaft of the rotor to high-speed rotation, which drives the high-speed shaft of the generator assembly. Wind turbine gearboxes typically use a planetary gear system.
Coupling	Attaches the gearbox to the generator. Flexible couplings may be used to reduce oscillating loads that could otherwise cause component damage.
Bearings	A number of bearings are required for the shafts, gearbox, yaw mechanism, generator, and other rotating parts.
Mechanical Brakes	A mechanical friction brake and its hydraulic system halt the turbine blades during maintenance and overhaul. A hydraulic disc brake on the yaw mechanism maintains nacelle position when nacelle is stationary.

Electrical Generator	Converts high-speed shaft work into electrical energy
Power Electronics	Couples the generator output to the step-up transformer input, typically with an IGBT bridge, allowing the generator to run at variable speed while still outputting 50 or 60 Hz AC to the grid. Also makes reactive power possible.
Cooling Unit	A large fan drives air to convectively cool the generator and gearbox and exhausts waste heat from the nacelle assembly. Ducting directs cool air to the generator.
Yaw Mechanism and Four-Point Bearing	Rotates the turbine directly into the wind in order to generate maximum power. Typically, four yaw sensors monitor the wind direction and activate the yaw motors to face the prevailing wind. A four-point bearing connects the nacelle to the tower. The yaw mechanism turns the blades 90 degrees from prevailing winds under high winds to reduce stress on internal components and avoid over-speed conditions.
Electronic Controller(s)	(a) A base controller, located at the base of the tower, utilizes PC's and fiber optics to monitor and record performance data, as well as to facilitate communication between both sub-controllers and external parties. (b) A nacelle controller monitors activity within the nacelle assembly. (c) A hub controller, being used in more recent models, communicates directly with the nacelle controller to more precisely monitor rotor activity
Sensors	(a) An anemometer, located on the tower, measures wind velocity and relays data to the yaw mechanism. (b) A wind vane measures wind direction and relays data to the yaw mechanism. (c) A cable twist counter monitors cables within the tower to determine if the turbine has been yawing in one direction for an extended period of time. (d) A thermocouple senses temperature within the nacelle assembly.

The rotor includes:

- Blades, which are generally made of glass-reinforced fiber up to 50m in length. Lighter and stronger carbon fibers are being used in the larger blades.
- Extenders attach the blades to the central hub
- Pitch drives to control the angle of the blades
- The rotor typically has three blades because that number provides the best balance of high rotation speed, load balancing, and simplicity.

Table 1.2 - Description of Rotor Components

Subcomponent	**Description**
Rotor Blades	Blades utilize the principles of lift to convert the energy of the wind into mechanical energy. Stall-regulated blades limit lift, or momentum, when wind speeds are too great to avoid damaging the machine. Variable-pitch blades rotate to minimize their surface area and thereby regulate rotational speed.
Pitch Drive	This system controls the pitch of the blades to achieve the optimum angle for the wind speed and desired rotation speed. At lower wind speeds a perpendicular pitch increases the energy harnessed by the blades, and at high wind speeds, a parallel pitch minimizes blade surface area and slows the rotor. Typically one motor is used to control each blade. Power is either electric or provided by hydraulics in the nacelle, and supplemented by a hydraulic accumulator in the event of system failure.
Extenders	These steel components serve as a means to support the rotor blades and secure them to the hub
Hub	The hub serves as a base for the rotor blades and extenders, as well as a means of housing the control systems for the pitch drive. It rotates freely and attaches to the nacelle using a shaft and bearing assembly.

The tower includes:

- Rolled steel tubes connected in series
- Flanges and bolts joining each section
- A concrete base serving as a stable foundation for the turbine assembly
- Concrete segmented towers and hybrid steel/concrete towers may also be used for large turbines in cases where steel tower section transportation is difficult.

Table 1.3 - Description of Tower Components

Subcomponent	**Description**
Tower	This component is typically made of rolled, tubular steel, and built and shipped in sections because of its size and weight. Common tubular towers incorporate a ladder within the hollow structure to provide maintenance access. Utility-scale towers range in height from 60-100m and weigh between 200-400 tons.
Base	The base supports the tower and transfers the loads to the foundation soil or bedrock. The foundation size and type depends on the foundation conditions but is typically constructed with steel-reinforced concrete.
Flanges and Bolts	These items join tower segments.

The balance of station includes:

- Electrical collection system: transformer, switchgear, underground and overhead high voltage cable, and interconnecting substation
- Control system: control cable, data collection, and wind farm control station
- Roadway, parking, crane pads and other civil works

Table 1.4 - Description of Balance of System Components

Subcomponent	**Description**
Electrical Collection System	(a) Transformers step up voltage transmission in the collector line to convert energy generated by the turbine into usable electricity for utility grids. (b) Underground cables are used to connect the power lines until a standard 25kV overhead collector line may be used. (c) Reclosers and risers act as circuit breakers and isolate a section of the line should there be a power fault. (d) Power substations raise the voltage for standard long-distance transmission.
Communications System	The communications subsystem allows the wind turbines to monitor themselves and report performance to a control station. Data collection equipment and fiber optic cables allow the turbine to monitor and report performance. A control station consolidates data and routes information to the local utility.
Civil Works	Crane pads enable the safe operation of cranes during construction of the turbine and roads provide access during construction and maintenance activities. Maintenance buildings house workers during construction and overhauls.

U.S. Manufacturing Census

The U.S. Census Bureau conducts an Economic Census every 5 years that profiles the US economy, from the national to the local level. The Census data is reported by economic sector. Data from the Manufacturing Sector report can potentially be used to geographically track the manufacturing and economic activity associated with wind turbines and their subcomponents.

SIC Codes

Manufacturing activity has historically been tracked by Standard Industrial Classification (SIC) codes. The four-digit SIC code was developed in the 1930's to classify businesses by the type of activity in which they are primarily engaged and to promote the comparability of business data to describe various aspects of the U.S. economy. In 1997 the SIC was replaced by the North American Industry Classification System (NAICS). [1] This six digit code constitutes a major revision in economic activity tracking, and uses a production-oriented, or supply-based, conceptual framework to group together producing units that use identical or similar production processes so that their economic activity can be tracked in a consistent manner over time and across industries.

NAICS Codes

A typical NAICS code ranges from two to ten digits, where a two digit code indicates the economic sector, a three digit code specifies a sub-sector, a four-digit code indicates the industry group, the six-digit code specifies the U.S. industry sector, and additional digits indicate increasing specificities within the sub-sector. As an example, the three-digit NAICS code 333 signifies “Machinery Manufacturing”, whereas the ten digit NAICS code 3336127438 pertains to “Enclosed Concentric and Parallel Shaft Speed Reducers and Motor-Reducers, Center Distance Greater than 6 inches.”

Table 1.5 - North American Industry Classification System (NAICS) Hierarchy

	Example 1		Example 2	
NAICS Level	**NAICS Code**	**Description**	**NAICS Code**	**Description**
Sector	31-33	Manufacturing	51	Information
Subsector	334	Computer and electronic manufacturing	513	Broadcasting and telecommunications
Industry Group	3346	Manufacturing and reproduction of magnetic and optical media	5133	Telecommunications
Industry	33461	Manufacturing and reproduction of magnetic and optical media	51332	Wireless telecommunications carriers, except satellite
U.S. Industry	334611	Reproduction of software	513321	Paging

Source: U.S. Census Bureau

Using Census Data

By isolating the individual components of wind turbines and using NAICS codes to track their economic and geographic information, one can assess the labor and economic impacts of wind power on a state, and potentially county, level. However, Census confidentiality and disclosure rules often limit the release of data at the county, and sometimes state level. As a first step, REPP has identified the NAICS codes associated with wind turbine components and subcomponents, shown in Table 1.6 below. In a larger study following this one, data will be gathered for each applicable NAICS code, and results will be tabulated for each component and reported on a geographic basis.

Table 1.6 - Wind Component NAICS Codes

Component	Sub component	NAICS 6-digit	Code description	NAICS 10-digit	Code description
Rotor	Blade	326199	All other Plastics Products	A141	Other fabricated fiberglass and reinforced products
	Blade Extender	331511	Iron Foundries	1116	Ductile iron fittings 14 in. or more
	Hub	331511	Iron Foundries	3221	Other ductile iron casting for all other uses
	Pitch Drive	335312	Motors and Generators	30	Integral horsepower motors and generators other than for land transportation equip. (746 watts or more)
Nacelle and Controls	Anemometer	334519	Measuring and Controlling Devices	7025	Other meteorological instruments and parts
	Brakes	333613	Power Transmission Equip.	3111	Friction-type Clutches and Brakes
	Controller	334418	Printed circuits and electronics assemblies	A015	Industrial process control board assemblies
	Cooling Fan	333412	Industrial and Commercial fans and blowers	04	Axial fans
	Nacelle Case	326199	All other Plastics Products	A141	Other fabricated fiberglass and reinforced products
	Nacelle Frame	331511	Iron Foundries	3221	Other ductile iron casting for all other uses
	Sensors	334519	Measuring and Controlling Devices	7	Commercial, Meteorological, Geophysical, and General Purpose Instruments
	Yaw Drive	335312	Motors and Generators	30	Integral horsepower motors and generators other than for land transportation equip. (746 watts or more)
Gearbox and Drive Train	Bearings	332991	Ball and Roller Bearings	3032	Tapered roller bearings (including cups and cones), unmounted
				1023	Complete ball bearings, unmounted, annular, including self~aligning, ground or precision, angular contact, precision
	Coupling	333613	Power Transmission Equip.	3329	Non-gear-type flexible couplings
	Gearbox	333612	Speed Change, Industrial	7438	Enclosed concentric and parallel (Planetary) center distance 6 in. or more
	High and low speed shafts	333613	Power Transmission Equip.	3792	Mechanical power transmission equipment, NEC, except parts
Generator and Power Electronics	Generator	333611	Turbines, and Turbine Generators, and Turbine Generator Sets	0871	Turbine generators
	Power Electronics	335999	Electronic Equipment and Components, NEC	3219	Other rectifying(power conversion) apparatus, except for electronic circuitry
Tower	Tower	332312	Fabricated Structural Metal	5106	Fabricated structural iron and steel for transmission towers, radio antenna, and supporting structures
	Tower Flange	331511	Iron Foundries	116	Ductile iron fittings 14 in. or more

Anemometer

NAICS Codes:	NAICS Descriptions:
Industry Subsector Code: 334	Computer and Electronic Product Manufacturing
National Industry Code: 334519	Measuring and Controlling Devices
Detailed Product Code: 3345197025	Other meteorological instruments and parts

Photo:

Source: National Renewable Energy Laboratory www.nrel.gov/wind/ wind_pubs.html

Description Of Subcomponent: An anemometer, located on the tower, measures wind velocity and informs the yaw mechanism.

Currently, laser anemometers, which more accurately measure wind velocity and digitally assist in maximizing pitch and yaw angles, are in development.

U.S. Manufacturers of This Sub Component:

Texas Electronics Inc	Dallas	TX	NRG Systems Inc	Hinesburg	VT
GE Wind	Tehachapi	CA	Second Wind Incorporated	Somerville	MA
Mitsubishi Power Systems Incorp	Newport Beach	CA			

Bearings

NAICS Codes:	NAICS Descriptions:	Photo:
Industry Subsector Code: 332	Fabricated Metal Product Manufacturing	
National Industry Code: 332991	Ball and Roller Bearings	
Detailed Product Code: 3329915025	Other roller bearings, spherical roller bearings, including hourglass and barrel, double row	Source: http://www.timken.com/products/bearings /products/sphericals/

Description Of Subcomponent: A number of bearings are required for the shafts, gearbox, yaw mechanism, generator, and other rotating parts.

A four-point contact ball bearing joins the nacelle and the tower, allowing the nacelle to slew about in order to face upwind and extract the maximum amount of energy from the wind. The main shaft rotates on large tapered roller bearings.

U.S. Manufacturers of This Sub Component:

GE Wind	Tehachapi	CA	TRI Transmission and Bearing C	Lionville	PA

Blade Extender

NAICS Codes:	NAICS Descriptions:	Photo:
Industry Subsector Code: 331	Primary Metal Manufacturing	
National Industry Code: 331511	Iron Foundries	
Detailed Product Code: 3315111116	Ductile iron fittings 14 in. or more	Source: http://www.state.sd.us/puc/2000/Wind/Wind%20Word%20Pics.html

Description Of Subcomponent: These steel components serve as a means to support the rotor blades and secure them to the hub.

Typically weighing over a ton, each blade extender is mounted to a four-point ball bearing, which is then mounted to the hub. The structure of the extenders allows each blade maximize rotation while connected to the pitch mechanism.

U.S. Manufacturers of This Sub Component:

CAB Incorporated	Oakwood	GA	K & M Machine Fabricating Inc.	Cassopolis	MI
GE Wind	Tehachapi	CA	The Dyson Corporation	Painesville	OH
Hodge Foundry, Inc.	Greenville	PA			

Brakes

NAICS Codes:	NAICS Descriptions:	Photo:
Industry Subsector Code: 333	Machinery Manufacturing	
National Industry Code: 333613	Power Transmission Equip.	
Detailed Product Code: 3336133111	Friction-type Clutches and Brakes	Source: http://www.windpower.org/en/tour/wtrb/safety.htm

Description Of Subcomponent: Mechanical brakes are used as auxiliary devices to insure that the rotors, gears and generator have stopped during maintenance of periods of inclement weather.

The yaw mechanism typically halts any blade rotation by turning the rotors perpendicular to the wind direction. Should the rotors continue to turn, many turbines are equipped with either hydraulic or spring activated brake systems to prevent undesired rotation or fatigue on the turbine.

U.S. Manufacturers of This Sub Component:

Parker	Cleveland	OH	Hilliard Corporation	Elmire	NY
GE Wind	Tehachapi	CA	Mitsubishi Power Systems Incorp	Newport Beach	CA

Cooling System

NAICS Codes:	NAICS Descriptions:	Photo:
Industry Subsector 333	Machinery Manufacturing	
National Industry 333412	Industrial and Commercial fans and blowers	
Detailed Product Code: 33341204	Axial fans	Source: http://www.continentalfan.com/product.htm

Description of Subcomponent: A large fan drives air to convectively cool the generator and gearbox and exhausts waste heat from the nacelle assembly. Ducting directs cool air to the generator.

Most wind turbines have cooling and dehumidifying units set to maintain conditions within the nacelle at levels such that rust and corrosion is largely prevented.

U.S. Manufacturers of This Sub Component:

Afab Tech LLC	Mansfield	OH

Coupling

NAICS Codes:	NAICS Descriptions:	Photo:
Industry Subsector Code: 333	Machinery Manufacturing	
National Industry Code: 333613	Power Transmission Equip.	
Detailed Product Code: 3336133329	Non-gear-type flexible couplings	Source: http://www.mayr.de/english/p_old/sh_coupl/roba_ds/roba_ds.htm

Description Of Subcomponent:	The flexible coupling attaches to the high speed shaft and dampens out oscillating loads introduced by the gearbox. The reduction of these loads improves the quality of the electricity produced by the generator.

Modern couplings make use of composite materials for increased strength and flexibility. Use of these materials will increase and lighten the weight in a typical wind turbine.

U.S. Manufacturers of This Sub Component:

GE Wind	Tehachapi	CA

Electronic Controller

NAICS Codes:	NAICS Descriptions:	Photo:
Industry Subsector Code: 334	Computer and Electronic Product Manufacturing	
National Industry Code: 334418	Printed circuits and electronics assemblies	
Detailed Product Code: 334418A015	Industrial process control board assemblies	Source: www.newenergy.org.cn/english/guide/control.htm

Description Of Subcomponent: The communications subsystem allows the wind turbines to monitor themselves and report performance to a control station. Data collection equipment and fiber optic cables allow the turbine to monitor and report performance

Although there are typically controllers at the top and bottom of a tower, the increased data transfer capabilities of fiber optic wiring have provided the opportunity for a third controller to be placed in the hub of the rotor. The additional controller usually communicates with the nacelle unit using serial communications through a cable connected with slip rings and brushes on the main shaft

U.S. Manufacturers of This Sub Component:

Enerpro Inc.	Goleta	CA	GE Wind	Tehachapi	CA
Second Wind Incorporated	Somerville	MA	Northern Power Systems	Waitsfield	VT

Gear Boxes

NAICS Codes:	NAICS Descriptions:	Photo:
Industry Subsector Code: 333	Machinery Manufacturing	
National Industry Code: 333612	Speed Changer, Industrial	
Detailed Product Code: 3336127438	Enclosed concentric and parallel (Planetary) center distance 6 in. or more	Source: http://www.machinedesign.com/ASP/viewSelectedArticle.asp?strArticleId=56562

Description Of Subcomponent: The gearbox employs a planetary gear system to convert low-speed rotation of the input shaft from the rotor to high-speed rotation which drives the high-speed shaft of the generator assembly

According to NREL, the recent trend toward large wind turbines has led to very expensive gearboxes that hinder their feasibility. The gearboxes for these wind turbines are more expensive per kilowatt (kW) of rated power than for smaller turbines because the torque increases more quickly than the power when increasing the rotor diameter. Multiple-generator drivetrain configurations can reduce the drivetrain cost for large wind turbines while increasing the energy capture and reliability.

U.S. Manufacturers of This Sub Component:

Cleveland Gear Company	Cleveland	OH	NEG Micon USA Inc	Rolling Meadows	IL
Michael Byrne Manufacturing Co	Mansfield	OH	GE Wind	Tehachapi	CA
Metso Drives	Portland	OR	K & M Machine Fabricating Inc.	Cassopolis	MI
Lindquist Machine Corporation	Green Bay	WI	Casting Service	La Porte	IN
Canton Drop Forge	Canton	OH	The Cincinnati Gear Company	Cincinnati	OH
Peerless Winsmith Inc	Springville	NY	Hodge Foundry, Inc.	Greenville	PA
Mitsubishi Power Systems Incorp	Newport Beach	CA	Winergy AG (Flender Service)	Elgin	IL

Generators

NAICS Codes:	NAICS Descriptions:
Industry Subsector Code: 333	Machinery Manufacturing
National Industry Code: 333611	Turbines, and Turbine Generators, and Turbine Generator Sets
Detailed Product Code: 3336110871	Turbine generators

Photo:

Source: http://seattlepi.nwsource.com/photos/photo.asp?PhotoID=27489

Description Of Subcomponent:	This system converts high-speed shaft work into electrical energy by spinning the rotor around the magnetic stator and using the electromagnetism to produce AC electricity.

Generators will likely move towards direct-drive format and eliminate the need for a gearbox to step down rotational speeds. This would reduce a large part of the weight and cost of a wind turbine system. However, direct-drive generators are not yet commercially feasible.

U.S. Manufacturers of This Sub Component:

Northern Power Systems	Waitsfield	VT	Mitsubishi Power Systems Incorp	Newport Beach	CA
Hitachi America Ltd.	Tarrytown	NY	Motors and Controls Internationa	Hazelton	PA
GE Wind	Tehachapi	CA			

Hub

NAICS Codes:	NAICS Descriptions:	Photo:
Industry Subsector Code: 331	Primary Metal Manufacturing	
National Industry Code: 331511	Iron Foundries	
Detailed Product Code: 3315113221	Other ductile iron casting for all other uses	Source: http://www.richter-ag.de/english/highlights/windkraftanlage.

Description Of Subcomponent:

The hub serves as a base for the rotor blades and extenders, as well as a means of housing the control systems for the pitch drive. It rotates freely and attaches to the nacelle using a shaft and bearing assembly.

In wind turbines with two blades, the hub is mounted with trunion pins so the blades can teeter into and out of the plane of rotation. The Renewable Energy Research Laboratory is preparing a series of tests that will help to better understand and characterize the turbine's response to varying pin angles. With optimal hub geometry, two bladed wind turbines could potentially be more cost effective than the traditional three blade turbines.

U.S. Manufacturers of This Sub Component:

GE Wind	Tehachapi	CA	CAB Incorporated	Oakwood	GA
K & M Machine Fabricating Inc.	Cassopolis	MI	Casting Service	La Porte	IN

Nacelle Case

NAICS Codes:	NAICS Descriptions:	Photo:
Industry Subsector Code: 326	Plastics and Rubber Products Manufacturing	
National Industry Code: 326199	All other Plastics Products	
Detailed Product Code: 326199A141	Other fabricated fiberglass and reinforced products	Source: http://www.middelgrunden.dk/MG_UK/project_info/turbine.htm

Description Of Subcomponent: The nacelle case encloses all of the major mechanical components of the wind turbine.

The nacelle casing is composed of glass fiber-reinforced plastic with steel reinforcements. Through rubber dampers, the casing is mounted to the main frame with steel supports.

U.S. Manufacturers of This Sub Component:

NEG Micon USA Inc	Rolling Meadows	IL	Molded Fiber Glass Companies-	Adelanto	CA
GE Wind	Tehachapi	CA	Molded Fiber Glass Companies-	Gainesville	TX
TPI Composites Inc.	Warren	RI	Vectorply Corporation	Jamestown	RI
Mitsubishi Power Systems Incorp	Newport Beach	CA	DIAB Inc.	DeSoto	TX
Hitco Carbon Composites Inc	Gardena	CA			

Nacelle Frame

NAICS Codes:	NAICS Descriptions:	Photo:
Industry Subsector Code: 331	Primary Metal Manufacturing	
National Industry Code: 331511	Iron Foundries	
Detailed Product Code: 3315113221	Other ductile iron casting for all other uses	Source: www.cabinc.com/tgal.htm

Description Of Subcomponent: The inner casing of the nacelle which encloses the core components of the wind turbine.

Numerous holes are drilled into the frame of the nacelle for stability reasons. While the largest hole allows maintenance entry through the bottom of the nacelle, the other holes are precisely placed in order to ensure that the frame will not vibrate in step with the other components of the turbine.

U.S. Manufacturers of This Sub Component:

GE Wind	Tehachapi	CA	Hodge Foundry, Inc.	Greenville	PA
K & M Machine Fabricating Inc.	Cassopolis	MI	CAB Incorporated	Oakwood	GA
Trinity Structural Towers Inc	Dallas	TX	NEG Micon USA Inc	Rolling Meadows	IL

Pitch Drive

NAICS Codes:	NAICS Descriptions:	Photo:
Industry Subsector Code: 335	Electrical Equipment, Appliance, and Component Manufacturing	
National Industry Code: 335312	Motors and Generators	
Detailed Product Code: 33531230	Integral horsepower motors and generators other than for land transportation equip. (746 watts or more)	Source: http://www.boschrexroth.com/BoschRexroth/business_units/brm/en/branches/wind

Description Of Subcomponent: This system controls the pitch of the blades to achieve the optimum angle for the wind speed and desired rotation speed.

For variable-pitch wind turbines, a drive system is used to change the pitch of the blades to vary power output, and at high wind speeds to divert excess energy, thus reducing stress on the blades and keeping rotational speeds within design specifications. There are typically three motors used to perform this function, one for each blade. A hydraulic power package in the nacelle provides the power, and in case of power failure, a hydraulic accumulator provides backup power for the system. Fully-electric pitch drives may also be employed.

U.S. Manufacturers of This Sub Component:

Parker	Cleveland	OH	SIPCO	Webster	TX
MLS Electrosystem	Houston	TX	GE Wind	Tehachapi	CA

Power Electronics

NAICS Codes:	NAICS Descriptions:	Photo:
Industry Subsector Code: 335	Electrical Equipment, Appliance, and Component Manufacturing	
National Industry Code: 335999	Electronic Equipment and Components, NEC	
Detailed Product Code: 3359993219	Other rectifying(power conversion) apparatus, except for electronic circuitry	Source: http://www.abb.com/global/abbzh/abbzh251.nsf!OpenDatabase&db=/global/seitp/s

Description Of Subcomponent:

U.S. Manufacturers of This Sub Component:

ABB Inc.	Raleigh	NC	Xantrex Technology, Inc.	Livermore	CA
Virtual Technologies Ltd	Post Falls	ID	Enerpro Inc.	Goleta	CA
Hitachi America Ltd.	Tarrytown	NY	Performance Energy Solutions, I	Austin	TX
GE Wind	Tehachapi	CA	Motors and Controls Internationa	Hazelton	PA
Princeton Power Systems Inc.	Princeton	NJ	1stPower.com	Mansfield	OH
American Superconductor	New Berlin	WI	Northern Power Systems	Waitsfield	VT
Magnetek Incorporated	Menomonee Falls	WI			

Rotor Blade

NAICS Codes:	NAICS Descriptions:
Industry Subsector Code: 326	Plastics and Rubber Products Manufacturing
National Industry Code: 326199	All other Plastics Products
Detailed Product Code: 326199A141	Other fabricated fiberglass and reinforced products

Photo:

Source: http://www.middelgrunden.dk/MG_UK/project_info/turbine.htm

Description Of Subcomponent: Rotor blades convert the energy of the wind to mechanical energy by harnessing the principles of lift. Blades can have a stall regulated or variable-pitch design

The trend in rotor blade development is toward lighter and stronger blades. Currently the majority of blades are made of glass fiber-reinforced plastic. However in the future there will be greater use of carbon fiber-reinforced plastic, used in combination with steel and existing glass fiber.

U.S. Manufacturers of This Sub Component:

EDO Fiber Science	Salt Lake City	UT	GE Wind	Tehachapi	CA
DIAB Inc.	DeSoto	TX	Owens Corning	Toledo	OH
Vectorply Corporation	Jamestown	RI	TPI Composites Inc.	Warren	RI
Hexcel Corporation	Dublin	CA	Hitco Carbon Composites Inc	Gardena	CA
Knight and Carver	National City	CA	LM Glasfiber ND	Grand Forks	ND
Mitsubishi Power Systems Incorp	Newport Beach	CA	Molded Fiber Glass Companies-	Gainesville	TX
Molded Fiber Glass Companies-	Adelanto	CA			

Sensors/Data Loggers

NAICS Codes:	NAICS Descriptions:	Photo:
Industry Subsector Code: 334	Computer and Electronic Product Manufacturing	
National Industry Code: 334519	Measuring and Controlling Devices	
Detailed Product Code: 3345197	Commercial, Meteorological, Geophysical, and General Purpose Instruments	Source: http://www.fraunhofer.de/german/press/pi/pi2003/09/md_fo2.html

Description Of Subcomponent: Sensors throughout turbines, including the anemometer array, relay information to the electronic controllers, which automatically adjust turbine components to address changing conditions.

As a wind vane measures wind direction and relays data to the yaw mechanism, a cable twist counter monitors cables within the tower to determine if the turbine has been yawing in one direction for an extended period of time. Additionally, a thermocouple senses temperature within the nacelle assembly.

U.S. Manufacturers of This Sub Component:

Swantech LLC	Fort Lauderdale	FL	Second Wind Incorporated	Somerville	MA
NRG Systems Inc	Hinesburg	VT	NEG Micon USA Inc	Rolling Meadows	IL
GE Wind	Tehachapi	CA			

Shafts

NAICS Codes:	NAICS Descriptions:	Photo:
Industry Subsector Code: 333	Machinery Manufacturing	
National Industry Code: 333613	Power Transmission Equip.	
Detailed Product Code: 3336133792	Mechanical power transmission equipment, NEC, except parts	Source: http://www.middelgrunden.dk/MG_UK/project_info/turbine.htm

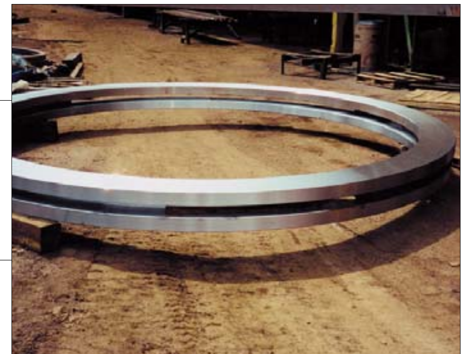
Description Of Subcomponent: Low and high speed shafts are the driving mechanisms converting low speed rotation from kinetic wind energy to high speed rotation creating electrical energy

The sizes of shafts have significantly decreased as component parts such as bearings have become smaller. Therefore, greater fatigue on smaller shafts has necessitated better handling of fatigue and possibly more regular maintenance.

U.S. Manufacturers of This Sub Component:

Logic Beach Incorporated	La Mesa	CA	GE Wind	Tehachapi	CA

Tower Flange and Bolts

NAICS Codes:	NAICS Descriptions:	Photo:
Industry Subsector Code: 331	Primary Metal Manufacturing	
National Industry Code: 331511	Iron Foundries	
Detailed Product Code: 3315111116	Ductile iron fittings 14 in. or more	Source: www.cabinc.com/tgal.htm
Description Of Subcomponent:	These components join tower segments	

A combination of bolting and welding is employed to join flanges and tower segments. To assure the stability of the tower welding seams, x-rays inspections are made of the adjoining segments.

U.S. Manufacturers of This Sub Component:

Thomas & Betts Corp.	Memphis	TN	CAB Incorporated	Oakwood	GA
The Dyson Corporation	Painesville	OH	Trinity Structural Towers Inc	Dallas	TX
GE Wind	Tehachapi	CA	SMI and Hydraulics	Porter	MN
Ameron International Corporatio	Rancho Cucamonga	CA	Bergen Southwest Steel	Canutillo	TX
Beaird Industries Inc.	Shreveport	LA	Valmont Industries Inc	Valley	NE
DMI Industries	West Fargo	ND			

Towers

NAICS Codes:	NAICS Descriptions:	Photo:
Industry Subsector Code: 332	Fabricated Metal Product Manufacturing	
National Industry Code: 332312	Fabricated Structural Metal	
Detailed Product Code: 3323125106	Fabricated structural iron and steel for transmission towers, radio antenna, and supporting structures	Source: http://www.middelgrunden.dk/MG_UK/project_info/turbine.htm

Description Of Subcomponent:

This large component of the turbine is made of rolled, tubular steel, and built in sections because of its size. For tubular towers, the most common type, a ladder is built in the hollow center to provide maintenance access.

Towers are an extremely heavy portion of the wind turbine system as they must support the nacelle and rotor. If carbon light-weight materials come down in cost, there is the possibility that towers will be made of other materials besides rolled steel. For the time being, steel will be used which is of great benefit to local steel producers and pressure vessel manufacturers.
Transportation logistics: According to NREL, " In the United States, the transportation system has unique rules, regulations, and oversized permit requirements for each state. A primary constraint on transportation is the oversize- load constraint. Of particular concern is the 4.83m (16 ft) height constraint. Shipments taller than 4.83m risk interference with overhead structures and utilities. Excessive heights can cause considerable expenses because local utilities are required to disconnect power, drop and protect the lines, and then reinstall the wires. Overweight permits can also be problematic. In addition to restrictions on the time of day that oversize loads can be moved, specific dates are also prohibited. The dates are state specific but tend to eliminate periods during the spring when the frozen ground is thawing.

Although studies show a steady increasing trend in cost for large machines, it is possible that technology improvements, such as self-erecting towers and lattice towers, may significantly alter this trend. For example, there are several possible approaches to overcoming the transportation problems associated with large-diameter tower bases, such as slip-formed concrete bases, onsite tower fabrication, and truss tower sections. In addition, recent developments in self-erecting tower technologies will likely mitigate the crane costs for large turbines."
Source: http://www.nrel.gov/wind/windpact/turbine_logistics.html

U.S. Manufacturers of This Sub Component:

Ameron International Corporatio	Rancho Cucamonga	CA	Bergen Southwest Steel	Canutillo	TX
Trinity Structural Towers Inc	Dallas	TX	Beaird Industries Inc.	Shreveport	LA
Valmont Industries Inc	Valley	NE	Thomas & Betts Corp.	Memphis	TN
Composite Technology Corporati	Irvine	CA	CWMF Inc	St. Cloud	MN
SMI and Hydraulics	Porter	MN	ROHN Industries	Peoria	IL
Newmark International	Birmingham (HQ onl	AL	Mitsubishi Power Systems Incorp	Newport Beach	CA
Innovative Metal Products	Kenoza Lake	NY	GE Wind	Tehachapi	CA
DMI Industries	West Fargo	ND			

Yaw Drive

NAICS Codes:	NAICS Descriptions:	Photo:
Industry Subsector Code: 335	Electrical Equipment, Appliance, and Component Manufacturing	
National Industry Code: 335312	Motors and Generators	
Detailed Product Code: 33531230	Integral horsepower motors and generators other than for land transportation equip. (746 watts or more)	Source: http://www.boschrexroth.com/BoschRexroth/business_units/brm/en/branches/wind

Description Of Subcomponent: Slews the turbine directly into the wind in order to generate maximum power. Typically, four yaw drives monitor the wind direction and active the yaw motors to face the prevailing wind.

When the wind blows over 60 mph the mechanism turns 90 degrees from prevailing winds to reduce stress on internal components and to prevent stalling due to over-speed conditions.

U.S. Manufacturers of This Sub Component:

GE Wind	Tehachapi	CA	SIPCO	Webster	TX
Parker	Cleveland	OH			

CHAPTER TWO – U.S. WIND MANUFACTURING INDUSTRY LOCATIONS

In order to quantify the current value and estimate the future value of the U.S. wind manufacturing industry, and to determine the current location of manufacturing activities, companies involved in manufacturing components of wind turbines on U.S. soil must first be identified. To this end, this report employs a phone survey of manufacturers belonging to the major U.S. wind power trade association, the American Wind Energy Association (AWEA). In addition the results of this survey are added to a compilation of the AWEA, James and James, and Energy Sources Guide databases. This report is an initial effort at such quantification, and as such is contacting a representative sample of U.S. wind industry manufacturers. As discussed in Chapter 4, below, a subsequent survey undertaken by REPP and funded by the U.S. Department of Energy will take a comprehensive look at all U.S. wind power-related manufacturing activity, and will employ additional direct manufacturer surveys, as well as acquisition and analysis of U.S. Manufacturing Census data.

US Census Regions

This report uses U.S. census regions to aggregate the results of the study. Census regions are also used to be consistent with future plans to use census data to further examine location of manufacturing. The U.S. census data is reported at a number of geographic scales, from sub-county to national. The largest sub-national reporting scales are the four census regions: Midwest, Northeast, South, and West. Nine multi-state divisions are defined within these regions, as shown in the map in Figure 2.1 below. From the information in the REPP database about location and types of manufacturing activity for each company, Table 2.1 below indicates the number of manufacturing activities occurring in each division. This gives an idea of the distribution of wind turbine manufacturing throughout the country.

Figure 2.1 - Census Regions and Divisions of the United States

Source: U.S. Census Bureau

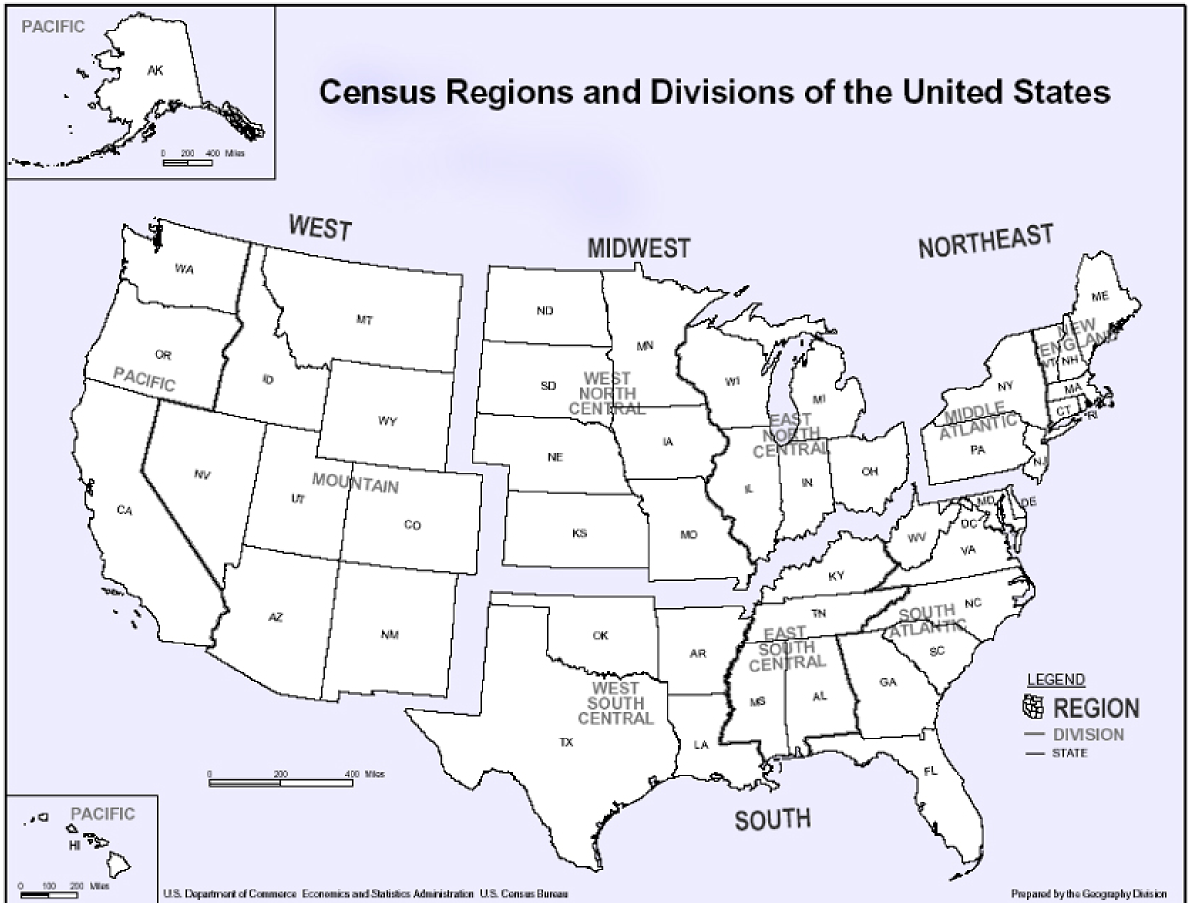


Table 2.1 - Location of U.S. Wind Turbine Component Manufacturers Providing Data By Census Region and Division

Region	Division	Rotor	Nacelle and Controls	Gearbox & Drive Train	Generator & Power Electronics	Tower	Division Total
Midwest	East North Central	6	5	8	1	2	22
	West North Central	1	0	1	1	8	11
Northeast	Middle Atlantic	3	4	4	5	1	17
	New England	0	6	0	2	0	8
South	East South Central	0	0	0	0	2	2
	South Atlantic	3	2	1	1	2	9
	West South Central	4	5	0	1	6	16
West	Mountain	1	0	0	1	0	2
	Pacific	5	4	2	4	4	19
	Component Total:	23	26	16	16	25	106

Phone Survey
The initial phone survey involved contacting current manufacturers of utility-scale wind systems as identified by AWEA. Survey questions focused on the company's level of involvement in wind turbine components, the number of jobs related to the manufacture of wind power-related components, and the production and total revenue resulting from these activities. At the time of this writing 81 companies were identified as being potential manufacturers of interest. Of these, 49 have been contacted, 33 have been interviewed, and 18 have provided quantitative data. Seventeen of the 81 companies have been eliminated from the survey as it turns out they are not manufacturers but distributors.

REPP Database
In order to identify a larger number of wind turbine component manufacturers than those contacted in the phone survey, REPP created a database from a combination of three major listings of wind manufacturers: the AWEA membership database, James & James, and the Energy Sources Guide. This compilation resulted in a list of more than 180 companies involved in the wind industry. However, many of these only do small wind projects, or are entirely distribution or project management firms. Through phone contacts and web inquiries to determine what each company actually does, the database was weeded to include only companies that directly manufacture components for utility scale wind turbines - utility scale being roughly defined as 750 kW turbines or greater. This weeding resulted in a smaller, yet more accurate, list of approximately 90 companies. This report examines actual manufacturing activity, and not just companies, therefore if a company makes several different components, each component is listed as a separate manufacturing activity. Hence, from these 90 companies there are approximately 106 different manufacturing activities. The current list of companies, their location, and the components they manufacture are included below in Table 2.2.

Table 2.2 - Manufacturers of Wind Components by State

State	City	Company	Manufactured Parts
AL	Birmingham (HQ onl	Newmark International	Towers
AR	Little Rock	Priority Wire and Cable In	Balance of System
AZ	Scottsdale	Firetrace International	Safety Equipment
CA	Rancho Cucamonga	Ameron International Corp	Towers Tower Flange and Bolts
CA	Irvine	Composite Technology Co	Balance of System Towers
CA	Santa Ana	Contech Construction Prod	Towers
CA	Goleta	Enerpro Inc.	Electronic Controller Power Electronics
CA	Tehachapi	GE Wind	Complete Wind Turbine Power Electronics Electronic Controller
CA	Dublin	Hexcel Corporation	Rotor Blade
CA	Gardena	Hitco Carbon Composites	Nacelle Case Rotor Blade
CA	National City	Knight and Carver	Rotor Blade
CA	Los Angeles	Lift It Manufacturing	Safety Equipment
CA	La Mesa	Logic Beach Incorporated	Shafts
CA	Newport Beach	Mitsubishi Power Systems	Rotor Blade Power Electronics
CA	Adelanto	Molded Fiber Glass Comp	Rotor Blade Nacelle Case
CA	Livermore	Xantrex Technology, Inc.	Power Electronics
CO	Fort Collins	REMTECH Inc.	Balance of System
CO	Boulder	Sustainable Automation L	Balance of System
FL	Pensacola	GE Wind	Rotor Blade

State	City	Company	Manufactured Parts
FL	Lake Mary	Mitsubishi Power Systems	Gear Boxes
FL	Fort Lauderdale	Swantech LLC	Sensors/Data Loggers
GA	Oakwood	CAB Incorporated	Blade Extender Hub Nacelle Frame Tower Flange and Bolts
IA	Harlan	Insul-8 Corporation	Balance of System
ID	Post Falls	Virtual Technologies Ltd	Power Electronics
IL	Blue Island	G&W Electric Co.	Balance of System
IL	North Chicago	King Wire Incorporated	Balance of System
IL	Rolling Meadows	NEG Micon USA Inc	Sensors/Data Loggers Nacelle Case Gear Boxes Complete Wind Turbine
IL	Peoria	ROHN Industries	Towers
IL	Elgin	Winergy AG (Flender Serv	Gear Boxes
IN	La Porte	Casting Service	Hub Gear Boxes
KY	Highland Heights	General Cable	Balance of System
KY	Owensboro	U.S. Wind Turbine	Complete Wind Turbine
LA	Shreveport	Beaird Industries Inc.	Tower Flange and Bolts Towers
MA	Somerville	Second Wind Incorporated	Anemometer Electronic Controller Sensors/Data Loggers
MI	Cassopolis	K & M Machine Fabricati	Blade Extender Nacelle Frame Gear Boxes Hub
MN	St. Cloud	CWMF Inc	Towers
MN	Warren	Nordic Fiberglass, Inc.	

State	City	Company	Manufactured Parts
			Balance of System
MN	Porter	SMI and Hydraulics	Tower Flange and Bolts Towers
NC	Raleigh	American Superconductor	Power Electronics Balance of System
ND	West Fargo	DMI Industries	Tower Flange and Bolts Towers
ND	Grand Forks	LM Glasfiber ND	Rotor Blade
ND	Fargo	Wanzek Construction Inc	Balance of System
NE	Valley	Valmont Industries Inc	Towers Tower Flange and Bolts
NJ	Somerville	Abacus Controls inc	Balance of System
NJ	Mahwah	Hytorc- Division of Unex	Balance of System
NJ	Princeton	Princeton Power Systems I	Power Electronics
NY	Elmire	Hilliard Corporation	Brakes Complete Wind Turbine
NY	Tarrytown	Hitachi America Ltd.	Generators Power Electronics
NY	Kenoza Lake	Innovative Metal Products	Towers
NY	Springville	Peerless Winsmith Inc	Gear Boxes
NY	Floral Park	Telecom & Energy Cables	Balance of System
OH	Mansfield	Afab Tech LLC	Cooling System Power Electronics Safety Equipment
OH	Canton	Canton Drop Forge	Gear Boxes
OH	Cleveland	Cleveland Gear Company	Gear Boxes
OH	Solon	ERICO, Inc.	Balance of System
OH	Mansfield	Michael Byrne Manufactur	Gear Boxes

State	City	Company	Manufactured Parts
OH	Toledo	Owens Corning	Rotor Blade
OH	Cleveland	Parker	Brakes
			Pitch Drive
			Yaw Drive
OH	Cincinnati	The Cincinnati Gear Comp	Gear Boxes
OH	Painesville	The Dyson Corporation	Tower Flange and Bolts
			Blade Extender
OR	Portland	Metso Drives	Gear Boxes
PA	Erie	GE Wind	Gear Boxes
PA	Greenville	Hodge Foundry, Inc.	Nacelle Frame
			Gear Boxes
			Blade Extender
PA	Hazelton	Motors and Controls Intern	Generators
			Power Electronics
PA	Easton	TorcUp	Balance of System
PA	Lionville	TRI Transmission and Bea	Bearings
RI	Warren	TPI Composites Inc.	Rotor Blade
			Nacelle Case
RI	Jamestown	Vectorply Corporation	Rotor Blade
			Nacelle Case
SC	Columbia	Pirelli Power Cables & Sys	Balance of System
TN	Dyersburg	ERMCO	Balance of System
TN	Franklin	Flash Technology	Balance of System
TN	Memphis	Thomas & Betts Corp.	Towers
			Tower Flange and Bolts
TX	Cross Plains	Barr Fabrication, LLC	Balance of System
TX	Canutillo	Bergen Southwest Steel	Towers
			Tower Flange and Bolts
TX	DeSoto	DIAB Inc.	Rotor Blade

State	City	Company	Manufactured Parts
			Nacelle Case
TX	Arlington	Dywidag Systems Internati	Balance of System
TX	Pasadena	Hyrdatight Sweeney	Balance of System
TX	Houston	MLS Electrosystem	Pitch Drive
TX	Gainesville	Molded Fiber Glass Comp	Nacelle Case Rotor Blade
TX	Kingwood	Orga Aviation Lighting Inc	Safety Equipment
TX	Austin	Performance Energy Soluti	Power Electronics
TX	Webster	SIPCO	Yaw Drive Pitch Drive
TX	Dallas	Texas Electronics Inc	Anemometer
TX	Dallas	Trinity Structural Towers I	Towers Tower Flange and Bolts Nacelle Frame
UT	Salt Lake City	EDO Fiber Science	Rotor Blade
VA	Simi Valley	Honeywell Obstruction Lig	Balance of System
VT	Waitsfield	Northern Power Systems	Power Electronics Generators Electronic Controller
VT	Hinesburg	NRG Systems Inc	Anemometer Sensors/Data Loggers
WA	Seattle	CC Jensen	Balance of System
WI	New Berlin	American Superconductor	Towers
WI	Waukesha	Cooper Power Systems	Balance of System
WI	Green Bay	Lindquist Machine Corpor	Gear Boxes
WI	Menomonee Falls	Magnetek Incorporated	Power Electronics
WV	St. Marys	Innovative Technologies G	Balance of System

CHAPTER THREE – ECONOMIC IMPACT OF WIND POWER INVESTMENT

To fully measure the potential economic impact of wind power development, the economic stimulus related to the investment must be traced beyond the Installation and Operations and Maintenance phases back to the manufacturing activity related to the components that go into the turbines. If wind development is seen solely as an effort to put new turbines on-line, then the benefits of development will be seen as largely accruing to the communities and states that have good wind resources and can host the developments. For example, a federal Renewable Portfolio Standard will certainly benefit states and communities in the Upper Plains because these states have excellent wind resources and open spaces for project development. However, the benefits of a federal Renewable Portfolio Standard are not limited to the localities where the installations occur.

A large wind development program will also stimulate manufacturing activity in communities distant from where the actual installations occur. This Chapter traces the potential boost a major wind development effort would provide to both investment and job creation stimulus in regions and specific states.

According to several recent REPP analyses, the job creation potential related to new wind developments looks something like a pyramid: 70% of the potential job creation is in manufacturing the components, 17% in the installation, and 13% in operations and maintenance. A national program could easily lead to the development over a period of years of 50,000 –77,000 MW or $50 - $77 billion in investments that would in turn drive new orders for manufacturing related to all the components that are required to build a new wind generator. A program of that magnitude creates the potential for 215,000 – 331,000 Full Time Equivalent job/years of employment: 150,000 – 231,000 in manufacturing, 35,000 – 54,000 in installation, and 30,000 – 46,200 in on-going operations and maintenance.

The wind industry in the United States is small compared to the European industry in part because the European Union countries have already committed to a major program of technology development and installation. For the United States the potential of wind development to stimulate a domestic manufacturing industry could be an important reason for developing the wind industry. Within this context, understanding the potential becomes important because it can support the very programs that will allow the potential to be captured.

In this section of the Report we analyze how an expanded program of wind development that produced $50 billion in new investment or 50,000 MW of installed capacity could flow to regions of the country and could lead to the creation of new jobs. The $50 billion or 50,000 MW estimate used is certainly aggressive and would require a much more focused effort to develop the resource than one could expect from any "business-as-usual" scenario. Nevertheless the 50,000MW estimate is supported by two compelling arguments.

Major wind development is most likely to result from a federal or national program such as a Renewable Portfolio Standard. According to a number of Energy Information

Analyses, a federal RPS calling for 20% renewable generation requirement would support roughly 77,000MW of wind. An RPS of 10% led to the development of 50,000 MW of wind according to the same EIA analysis.

An additional support for a major wind development program comes from a growing recognition of a looming shortage of natural gas for electricity generation and the increasing recognition of the ability of new wind generation to compete with that fuel. The projected annual natural gas shortfall from domestic supply in the United States is on the order of 3 to 5 trillion cubic feet (tcf). The nation as a whole faces a choice between increasing imports of Liquefied Natural Gas or developing additional wind resources. To meet this shortfall, the U.S. is looking to imported liquefied natural gas (LNG), which REPP estimates will cost approximately \$5.00 - \$6.00 per thousand cubic feet (MCF). The natural gas shortfall is driven largely by a need for the gas as a fuel to generate electricity. Every TCF of natural gas will provide fuel to generate kWh's that could alternatively be provided by roughly 40,000 MW of wind generation. The wind would be economic, avoid growing dependence on Middle Eastern fossil fuels, and improve the environmental footprint of electric sector.

For this initial Report, the analysis of the 50,000 MW development proceeds in three steps. First we determine how the total installed cost of the new wind development will flow into demand for the various components of the turbines. Second, we spread the total demand among the regions of the country by allocating the dollars according to the number of firms in each region. (For this initial Report we use firms identified as already active in manufacturing components. For future Reports we will add firms in closely related businesses as identified by the NAICS codes.) Third, we translate the regional dollar allocation by assuming that all component manufacturing has the same ratio of jobs/total investment of 3000/\$1 billion of investment.

First, the existing manufacturers of the components will benefit and it is therefore important to know where these firms are located. Beyond that, it is very likely that a major initiative involving demand for tens of thousands of MW will spill beyond these active firms to firms now operating in the same niche but not as yet directly supplying components. This latter potential can be determined by locating firms with closely related skills and experiences.

Geographic Distribution of Investment and Job Creation Potential

As the previous section of this initial report indicates, manufacturing of wind turbine components occurs in all regions of the country – hence the economic benefit of investing in wind is also distributed among a number of states. Combining this information with knowledge of the relative costs of each component, the table below shows an estimate of how the \$50 billion investment would divide into each census region. Furthermore, based on the REPP labor study for the Pennsylvania RPS, which found 3000 manufacturing jobs for every \$1 billion of investment in wind, the table estimates the employment benefits in each region.

Table 3.1 - Summary of Investment and Job Potential

Region	Average Investment (in Billions of $)	Manufacturing Jobs Created
Northeast	$16.9	50,552
Midwest	$10.2	30,639
South	$13.4	40,080
West	$9.6	28,729
Total	$50	150,000

This estimate is promising, and indicates the investment will be well distributed across the regions. Interestingly, the advantage the Midwest would likely hold in investment due to actual installations is compensated for in the manufacturing sector, where the above table indicates a greater portion of manufacturing investment goes to regions outside the Midwest.

Table 3.2 - Average Investment Per Division (Numbers are in billions of $)

		Rotor	Nacelle and Controls	Gearbox & Drive Train	Generator & Power Electronics	Tower	Total
Component Cost Fraction		**28.0%**	**21.7%**	**17.3%**	**7.0%**	**26.0%**	**100%**
Northeast	**Middle Atlantic**	**3.65**	**2.09**	**4.33**	**0.22**	**1.04**	**10.38**
	New England	**0.61**	**-**	**0.54**	**0.22**	**4.16**	**5.19**
Midwest	**East North Central**	**1.83**	**1.67**	**2.16**	**1.09**	**0.52**	**8.02**
	West North Central	**-**	**2.50**	**-**	**0.44**	**-**	**3.77**
South	**East South Central**	**-**	**-**	**-**	**-**	**1.04**	**0.94**
	South Atlantic	**1.83**	**0.83**	**0.54**	**0.22**	**1.04**	**4.25**
	West South Central	**2.43**	**2.09**	**-**	**0.22**	**3.12**	**7.55**
West	**Mountain**	**0.61**	**-**	**-**	**0.22**	**-**	**0.94**
	Pacific	**3.04**	**1.67**	**1.08**	**0.88**	**2.08**	**8.96**
Total							**50.00**

Many of the gaps in production activity in certain divisions are due to the limited nature of our initial survey. The upcoming broader survey to be performed by REPP will include a much larger number of manufacturers, and hence will likely close these gaps.

Table 3.3 - Created Manufacturing Jobs Per Division, by Component

	Division	Rotor	Nacelle and Controls	Gearbox and Drive Train	Generator and Power Electronics	Tower	Total
Component Cost Fraction		**28.0%**	**21.7%**	**17.3%**	**7.0%**	**26.0%**	**100%**
Northeast	**Middle Atlantic**	**10,957**	**6,260**	**12,975**	**656**	**3,120**	**33,967**
	New England	**1,826**	**-**	**1,622**	**656**	**12,480**	**16,584**
Midwest	**East North Central**	**5,478**	**5,008**	**6,488**	**3,281**	**1,560**	**21,815**
	West North Central	**-**	**7,512**	**-**	**1,313**	**-**	**8,824**
South	**East South Central**	**-**	**-**	**-**	**-**	**3,120**	**3,120**
	South Atlantic	**5,478**	**2,504**	**1,622**	**656**	**3,120**	**13,380**
	West South Central	**7,304**	**6,260**	**-**	**656**	**9,360**	**23,580**
West	**Mountain**	**1,826**	**-**	**-**	**656**	**-**	**2,482**
	Pacific	**9,130**	**5,008**	**3,244**	**2,625**	**6,240**	**26,247**
Total							**150,000**

Wind Installation Cost Breakdown

The allocation of investment among regions and states is based in part on the determination of how the capital cost of an installed project breaks down into the various cost categories. First, the component cost breakdown showing the percentage of total project cost attributable to each component is established. For this Report the cost breakdown comes from the WindPACT study, which will be described in further detail in the next section. The database of manufacturers described in Chapter 2 of this report provides information about what manufacturers are responsible for each of the relevant items and where they are located. That information allows the initial investment to be broken into the relevant categories, and for each category we have information on the number and location of the firms responsible for manufacturing each component.

To match the WindPACT study categories with the analysis we had for Chapter 2, individual components were aggregated in to component groups. Hence the Rotor consists of blades, blade extenders, hub, and pitch drive. The Nacelle and Controls group consists of the anemometer, brakes, cooling system, electronic controller, nacelle case, nacelle frame, sensors, and the yaw drive. The Gearbox and Drive Train group consists of the gear box, bearings, and shafts, the Generator and Power Electronics are grouped together, and the Tower consists of the tower sections and the tower flanges and bolts. Each product that a company makes in a particular group is added to the total. For example, if a company manufactures hubs and blade extenders, they are listed as making two products in the Rotors group.

The $50 billion or total investment is allocated among the component groups according to the relative cost of the component to the total cost. The cost allocated to each component group is then allocated to states and geographic regions according to the amount of manufacturing of components in each region. To illustrate this, the Rotor group accounts for 28% of the total cost of wind installation according to the WindPACT study. Of the $50 billion total investment, $14 billion is then allocated to rotors. According to our manufacturing analysis, rotor component manufacturing firms operate in every region of the country except for the East South Central. The $14 billion total for rotors is allocated to each region on the basis of the number of firms manufacturing components that go into the rotor component category in that region. Using this method, the West would receive $2.69 billion, the South $3.75 billion, the Midwest $2.86 billion, and the Northeast $4.73 billion.

Table 3.4 – Number of Manufacturing Activities by State

State	State Total	Rotor	Nacelle and Controls	Gearbox & Drive Train	Generator & Power Electronics	Tower	Number of FTE Jobs	Average Investment ($ Billions)
California	**18**	5	4	1	4	4	**24,625**	**8.21**
Texas	**14**	4	5	-	1	4	**20,460**	**6.82**
Ohio	**11**	3	2	4	1	1	**16,686**	**5.56**
Pennsylvania	**7**	1	1	3	2	-	**9,256**	**3.09**
Indiana	**5**	-	2	2	-	1	**7,308**	**2.44**
Vermont	**5**	-	3	-	2	-	**5,068**	**1.69**
New York	**5**	-	1	1	2	1	**5,746**	**1.92**
Rhode Island	**4**	2	2	-	-	-	**6,156**	**2.05**
Michigan	**4**	2	1	1	-	-	**6,526**	**2.18**
Georgia	**4**	2	1	-	-	1	**6,464**	**2.15**
Wisconsin	**3**	-	-	1	1	1	**3,838**	**1.28**
North Dakota	**3**	1	-	-	-	2	**4,946**	**1.65**
Minnesota	**3**	-	-	-	-	3	**4,680**	**1.56**
Massachusetts	**3**	-	3	-	-	-	**3,756**	**1.25**
Florida	**3**	1	1	1	-	-	**4,700**	**1.57**
Tennessee	**2**	-	-	-	-	2	**3,120**	**1.04**
Nebraska	**2**	-	-	-	-	2	**3,120**	**1.04**
Louisiana	**2**	-	-	-	-	2	**3,120**	**1.04**
Illinois	**2**	1	-	1	-	-	**3,448**	**1.15**
Utah	**1**	1	-	-	-	-	**1,826**	**0.61**
Oregon	**1**	-	-	1	-	-	**1,622**	**0.54**
New Jersey	**1**	-	-	-	1	-	**656**	**0.22**
North Carolina	**1**	-	-	-	1	-	**656**	**0.22**
Idaho	**1**	-	-	-	1	-	**656**	**0.22**
Alabama	**1**	-	-	-	-	1	**1,560**	**0.52**
Total	**106**	23	26	16	16	25	**150,000.00**	**50.00**

This method provides an initial estimate of how the $50 billion could diffuse through the states and regions of the country. However, it is important to understand its limitations. Because we have been unable to obtain data on the relative size of the current firms manufacturing rotor components, the method does not account for the fact that one company might manufacture a thousand hubs a year while another only makes 20. In this current model both of these companies count the same. These results show how a major increase in the demand for wind installations and the various components that go into the installations could be transferred to states and regions, and could result in an increase in demand for manufactured goods and in manufacturing employment. Again, this analysis is meant to highlight the potential in order to underline the possible benefits that could be captured. The analysis is intended to highlight what could happen, not provide an analysis of what will happen.

Wind Turbine Component Cost Studies

A multi-year study of advanced wind power developments undertaken by the National Renewable Energy Laboratory (NREL), in combination with extensive participation from the wind industry, lead to publication in 2003 of a series of reports that include detailed wind turbine cost breakdowns. The study was done under the Wind Partnerships for Advanced Component Technology (WindPACT), which started in 1999 to “assist industry in lowering the cost of energy by designing and testing innovative components, such as advanced blades and drive trains. These components are expected to be primary constituents of the low-wind-speed turbine. Researchers have also performed a range of systems studies as part of the WindPACT project in an effort to answer questions like how big should a wind turbine of the future be and to explore the impact of rotor configuration on turbine design and cost.” [2]

A 2001 study prepared for the U.S. DOE by Princeton Energy Resources International on current wind technology and opportunities for technical improvements published wind turbine cost breakdowns that agree with the subsequent WindPACT study. A comparison of these two studies is summarized in Table 6. A previous study was completed by DOE in 1997, [3] but is not included in Table 6 because cost estimates for the nacelle, gearbox and drive train were not disaggregated as they are in subsequent studies. The rotor, generator, and tower percent cost contributions published in the 1997 report agree with those published in the PERI (2001) and NREL (2003) reports.

Table 3.5 - Comparison of Wind Turbine Component Cost Studies

	% cost	
Component	**WindPACT (2003)**	**PERI (2001)**
Rotor (blades, hub, pitch drive)	28.0%	20-30%
Nacelle and Machinery, w/o drivetrain and generator	21.7%	25%
Gearbox and Drivetrain	17.3%	10-15%
Generator Systems	7.0%	5-15%
Tower and Foundation	26.0%	10-25%
Total	100%	100%

Sources: [1]Alternative Design Study Report: WindPACT Advanced Wind Turbine Drive Train Designs Study. November 1, 2000 – February 28, 2002. R. Poore and T. Lettenmaier, Global Energy Concepts, LLC. August 2003 • NREL/SR-500-33196. [2]Wind Turbine Materials and Manufacturing Fact Sheet. Prepared for the Office of Industrial Technologies, US Department of Energy. By Princeton Energy Resources International, LLC. Dan Ancona and Jim McVeigh. August 29, 2001.

The WindPACT detailed wind turbine component cost breakdown is given in Table 7. It is seen that three components, the blades, gearbox, and tower account for approximately 50% of the capital of the complete turbine. A further breakdown of gearbox subcomponents is provided by Table 8. Here, the gears, housing, and bearings account for almost two-thirds of the gearbox cost.

Table 3.6 - Wind Turbine Component Costs

Component	Component Cost (%)	Major Component Cost (%)
Rotor		28%
Blades (three)	16.6%	
Hub	7.2%	
Pitch mechanisms and bearings	4.0%	
Drivetrain and Nacelle		46%
Transmission system		
Gearbox	13.4%	
Mainshaft	2.3%	
Mainshaft bearing and block	1.3%	
Elastomeric mounting system	0.3%	
Generator isolation mounts	0.1%	
Support structure	3.8%	
Generator cooling system	0.3%	
Brake system, hydraulics	0.6%	
Coupling	0.3%	
Nacelle cover	1.9%	
Generator	6.7%	
Variable-speed electronics	6.9%	
Transformer	2.5%	
Cable	2.0%	
Switchgear	1.4%	
Yaw Drives and Bearings	1.8%	
Control and Safety System	0.8%	
Tower	20.6%	21%
Foundation	5.4%	5%
Total	100%	100%

Source: Alternative Design Study Report: WindPACT Advanced Wind Turbine Drive Train Designs Study.[4]

Table 3.7 - Gearbox Component Cost Breakdown

Component	% Cost
Gears	25.0%
Housings	23.6%
Bearings	16.0%
Other	9.1%
Labor	7.7%
Shafts	7.3%
Hubs	5.3%
Cooling	3.9%
Hydraulic	2.1%
Total	100%

Source: Alternative Design Study Report: WindPACT Advanced Wind Turbine Drive Train Designs Study. [5]

The balance-of-station summary includes other infrastructure-related costs that are significant to the operation of the turbine (see Table 9). The WindPACT Study mapped infrastructure costs for two theoretical 50MW projects, one composed of 750kW turbines, the other with 2.5 MW turbines. The greatest costs were in civil infrastructure due to the foundations of the large turbines.

Table 3.8 - Balance of Station Cost Summary

	Turbine Size	
Category	**750kW**	**2.5MW**
Infrastructure – Electrical	27.7%	24.8%
Infrastructure – Civil	53.9%	61.7%
Infrastructure - Miscellaneous	10.5%	5.4%
Land and Overhead	8.0%	8.0%
Total	100%	100%

Notes: These costs are based on a 50 MW wind farm. Categories are defined as: [1] Electrical Infrastructure includes transformers, cables, risers, power lines, and power substation. [2] Civil Infrastructure includes foundations, service roads, crane pads. [3] Miscellaneous Infrastructure includes tower lighting, meteorological towers, maintenance building. [4] Land and Project Overhead includes permitting, right-of way, engineering, surveying, inspection, administration, land for transmission lines, substation, and maintenance buildings.

CHAPTER FOUR – Location of Manufacturing Potential

If wind were to become a large industry, for example as the result of a federal renewable portfolio standard, the economic impact would spread far beyond the 90 active firms identified in the previous sections of this Report. Companies currently engaged in manufacturing processes similar to the manufacturing of wind turbine components could potentially transfer some of their capabilities to this new market. For example, a company that rolls steel for water towers could potentially begin rolling steel towers for wind turbines; a roller bearing company could begin making wind turbine main shaft bearings. In order to take a look at the size and location of this potential market, REPP uses an approach based on the North American Industrial Classification System, or NAICS, which the U.S. Census Bureau adopted in 1997. The results of this study indicate that 16,163 firms, located across all 50 states, operate in industries similar to the manufacturing of wind turbine components.

Using the NAICS to Locate Similar Manufacturing Companies

In the Economic Census conducted by the U.S. Census Bureau, every firm operating in North America reports one or more NAICS codes, indicating what types of products or services they provide. Companies reporting the same NAICS code are involved in similar activities, for example every company that reports 326199 manufactures some type of Ball or Roller Bearing. Using this system, REPP was able to tabulate the companies involved in activities similar to the manufacturing of wind turbine components.

The NAICS codes have several levels of detail, up to ten digits, with each digit indicating a higher level of detail. For example, a first digit of 3 indicates Manufacturing, 332 is Fabricated Metal Product Manufacturing, 332991 is Ball and Roller Bearings, and 3329913032 is “Tapered roller bearings (including cups and cones), unmounted.” This system replaced the older System of Industrial Classification, or SIC codes. Each wind turbine component can be matched with a 10-digit code, and hence also a 6-digit code, as shown in Table 4.1.

Table 4.1 - Wind Component NAICS Codes

Component	Sub component	NAICS 6-digit	Code description	NAICS 10-digit	Code description
Rotor	Blade	326199	All other Plastics Products	A141	Other fabricated fiberglass and reinforced products
	Blade Extender	331511	Iron Foundries	1116	Ductile iron fittings 14 in. or more
	Hub	331511	Iron Foundries	3221	Other ductile iron casting for all other uses
	Pitch Drive	335312	Motors and Generators	30	Integral horsepower motors and generators other than for land transportation equip. (746 watts or more)
Nacelle and Controls	Anemometer	334519	Measuring and Controlling Devices	7025	Other meteorological instruments and parts
	Brakes	333613	Power Transmission Equip.	3111	Friction-type Clutches and Brakes
	Controller	334418	Printed circuits and electronics assemblies	A015	Industrial process control board assemblies
	Cooling Fan	333412	Industrial and Commercial fans and blowers	04	Axial fans
	Nacelle Case	326199	All other Plastics Products	A141	Other fabricated fiberglass and reinforced products
	Nacelle Frame	331511	Iron Foundries	3221	Other ductile iron casting for all other uses
	Sensors	334519	Measuring and Controlling Devices	7	Commercial, Meteorological, Geophysical, and General Purpose Instruments
	Yaw Drive	335312	Motors and Generators	30	Integral horsepower motors and generators other than for land transportation equip. (746 watts or more)
Gearbox and Drive Train	Bearings	332991	Ball and Roller Bearings	3032	Tapered roller bearings (including cups and cones), unmounted
				1023	Complete ball bearings, unmounted, annular, including self~aligning, ground or precision, angular contact, precision
	Coupling	333613	Power Transmission Equip.	3329	Non-gear-type flexible couplings
	Gearbox	333612	Speed Change, Industrial	7438	Enclosed concentric and parallel (Planetary) center distance 6 in. or more
	High and low speed shafts	333613	Power Transmission Equip.	3792	Mechanical power transmission equipment, NEC, except parts
Generator and Power Electronics	Generator	333611	Turbines, and Turbine Generators, and Turbine Generator Sets	0871	Turbine generators
	Power Electronics	335999	Electronic Equipment and Components, NEC	3219	Other rectifying(power conversion) apparatus, except for electronic circuitry
Tower	Tower	332312	Fabricated Structural Metal	5106	Fabricated structural iron and steel for transmission towers, radio antenna, and supporting structures
	Tower Flange	331511	Iron Foundries	116	Ductile iron fittings 14 in. or more

Ideally, one could then search for other companies involved in the same 10-digit codes as those for wind turbines. However, for several reasons it was necessary to use the 6-digit codes instead of the 10-digit.

Advantages to Using the 6-digit Codes

The 6-digit NAICS codes replaced the 4-digit SIC codes, which were the highest level of detail available in the SIC. Hence the 6-digit NAICS are the standard level reported by all companies in North America, with the 10-digit codes providing additional detail. The U.S. Census Bureau itself provides data primarily at the 6-digit level, reporting 10-digits only at the request of a special study. Furthermore, for a given NAICS code and a given geographical area, such as a county, if there are less than 2 companies operating or if one company is dominant, disclosure rules require the Census to not report information for that particular code and for that area, to avoid disclosing private company information. The small number of companies reporting for a given 10-digit code would make it difficult to obtain information even at the state level. Additionally, the specificity of a 10-digit code could have excluded companies with good potential for entering the wind turbine market. To continue with the roller bearings example, the difference between 3329913032 and 3329913033 is whether or not the cup and cone assemblies are shipped separately – a company reporting one code versus the other is not less likely to enter the wind turbine market. Finally, parts that fall within the same 6-digit code are often made by a single company. For example, the blade extender, rotor hub, nacelle frame, and tower flange are all cast steel parts with the same 6-digit code, and it is indeed the case that in the 90 currently active companies identified by REPP, a single company often makes all of these parts.

Table 4.2 – NAICS 6-digit Codes Associated with Wind Turbine Components

NAICS 6-digit	Code Description	Components
326199	All other Plastics Products	Rotor Blade, Nacelle Case
331511	Iron Foundries	Blade Extender, Hub, Nacelle Frame, Tower Flange
332312	Fabricated Structural Metal	Tower
332991	Ball and Roller Bearings	Bearings
333412	Industrial and Commercial fans and blowers	Cooling System
333611	Turbines, and Turbine Generators, and Turbine Generator Sets	Generator
333612	Speed Changer, Industrial	Gear Box
333613	Power Transmission Equip.	Brakes, Coupling, Shafts
334418	Printed circuits and electronics assemblies	Electronic Controller
334519	Measuring and Controlling Devices	Anemometer, Sensors
335312	Motors and Generators	Pitch Drive, Yaw Drive
335999	Electronic Equipment and Components, NEC	Power Electronics

Caveat to Using the 6-digit Codes
The main thing to be aware of when interpreting the results of a 6-digit code search, is the potential broadness of companies included. The most notable example of this being a problem is in the case of the rotor blade, which is a complicated fiberglass product, requiring a very specialized manufacturing setup. Under the 6-digit NAICS, all fiberglass products are lumped together under "All other Plastics Products." A company that makes plastic swimming pool liners, for example, would be included, but in fact would require significant effort to begin making wind turbine blades. However, this is mostly a problem for this particular code, the other 11 NAICS codes used in this study, shown in Table 4.2, have much less variation of product type. Furthermore, even a company that makes swimming pool liners has some advantage over a company starting from scratch, as they have basic knowledge and capabilities for understanding and working with plastic resins, mold-making, etc.

Potential Wind Manufacturing, Throughout the United States
In the United States, there are more than 16,000 companies operating in the NAICS codes identified for wind turbine components. These companies employ over 1 million employees, with an annual payroll of more than $35 billion.

Table 4.3 – Manufacturing Activities Similar to Wind Turbine Components – Summary for Entire United States

NAICS code	Code Description	Total Employees*	Annual Payroll ($1000s)	Number of Companies
326199	All other Plastics Products	501,009	15,219,355	8,174
331511	Iron Foundries	75,053	3,099,509	747
332312	Fabricated Structural Metal	106,161	3,975,751	3,033
332991	Ball and Roller Bearings	33,416	1,353,832	198
333412	Industrial and Commercial fans and blowers	11,854	411,979	177
333611	Turbines, and Turbine Generators, and Turbine Generator Sets	17,721	1,080,891	110
333612	Speed Changer, Industrial	13,991	539,514	248
333613	Power Transmission Equip.	21,103	779,730	292
334418	Printed circuits and electronics assemblies	105,810	4,005,786	716
334519	Measuring and Controlling Devices	34,499	1,638,072	830
335312	Motors and Generators	62,164	2,005,414	659
335999	Electronic Equipment and Components, NEC	42,546	1,780,246	979
Total		**1,025,327**	**35,890,079**	**16,163**

* Number of Employees reported for the middle of March, 2001.

These 16,163 companies are well distributed throughout the United States, with every one of the 50 states involved in some manufacturing activity that is similar to the production of wind turbine components. A significant number of potential entrants to the wind turbine market are situated in each census division of the country, as shown in Table 4.4.

Table 4.4 – Distribution of Potential Manufacturing Activity, by Division

Region	Division	326199 All other Plastics Products	331511 Iron Foundries	332312 Fabricated Structural Metal	332991 Ball and Roller Bearings	333412 Industrial and Commercial fans and blowers	333611 Turbines, and Turbine Generators, and Turbine Generator Sets	333612 Speed Changer, Industrial	333613 Power Transmission Equip.	334418 Printed circuits and electronics assemblies	334519 Measuring and Controlling Devices	335312 Motors and Generators	335999 Electronic Equip. Components, NEC	Totals
Midwest	East North Central	1977	235	524	43	38	13	78	78	79	150	134	168	**3517**
	West North Central	916	109	292	15	26	9	47	42	58	52	90	63	**1719**
Northeast	Middle Atlantic	1236	108	382	46	26	25	45	42	109	136	88	179	**2422**
	New England	349	24	80	8	2	10	9	15	77	64	22	59	**719**
South	East South Central	327	29	186	15	6	1	2	14	17	23	47	22	**689**
	South Atlantic	1065	103	579	43	27	14	32	33	84	83	112	122	**2297**
	West South Central	747	53	420	12	23	21	12	28	64	92	78	112	**1662**
West	Mountain	325	21	161	3	4	6	1	4	36	47	24	48	**680**
	Pacific	1232	65	409	13	25	11	22	36	192	183	64	206	**2458**
	Component Total:	**8174**	**747**	**3033**	**198**	**177**	**110**	**248**	**292**	**716**	**830**	**659**	**979**	**16163**

Table 4.5 ranks the states in order of total number of firms operating in the state, in all 12 of the NAICS industries associated with wind. While looking at the number of firms gives a rough idea of the current size of an industry, it does not account for the size of the firms themselves. A firm with 1,000 employees entering the wind turbine market would likely have a larger financial impact than one with 10 employees. To get a more accurate picture of the size of each industry in the potential wind turbine market, Table 4.6 ranks the states by total number of employees.

This distribution clearly indicates that significant investment in wind power could benefit the entire country, not only those states with wind resources. The fact that 16,000 different manufacturing companies across the entire nation could potentially enter this market indicates the significant and complex manufacturing activity that goes into producing a modern wind turbine. 35 of the 50 states have more than 100 firms operating in one or more of these 12 NAICS industries.

A Note about Disclosure Rules and Employment Numbers

Federal disclosure rules prohibit census data from being released if there are too few companies in a given area, or if one company dominates such that a person looking at the information could determine information for a specific company. However, even in these cases the total number of establishments is still published, as well as the number of establishments in each size class (i.e. number of companies with 1-4 employees, 5-9 employees, and so on). These size class numbers can be used to calculate an average guess at the number of employees working in a given region. Numbers that are italicized in the employment tables indicate a case where this method was used. Numbers in regular type did not fall under the disclosure rules and are the number of employees reported for mid-March 2001 by the Census bureau. Slight variation in total employment stated for the entire U.S. and for the sum of the 50 states is due to use of this method.

Table 4.5 – Number of Establishments – by State

State	326199 All other Plastics Products	331511 Iron Foundries	332312 Fabricated Structural Metal	332991 Ball and Roller Bearings	333412 Industrial and Commercial fans and blowers	333611 Turbines, and Turbine Generators, and Turbine Generator Sets	333612 Speed Changer, Industrial	333613 Power Transmission Equip.	334418 Printed circuits and electronics assemblies	334519 Measuring and Controlling Devices	335312 Motors and Generators	335999 Electronic Equipme Components, NEC	Totals
California	983	47	263	12	18	9	20	26	164	140	55	181	**1,918**
Ohio	559	85	168	11	13	6	22	23	20	52	47	39	**1,045**
Michigan	584	63	121	8	8	2	17	22	21	54	23	34	**957**
Texas	430	27	227	5	10	11	10	22	42	64	33	71	**952**
Illinois	510	42	125	14	12	1	32	21	29	27	35	64	**912**
Pennsylvania	398	65	149	10	9	7	12	11	41	45	32	42	**821**
New York	370	21	115	15	10	10	17	15	33	40	27	57	**730**
Florida	325	16	124	4	6	5	8	4	29	34	24	55	**634**
Indiana	324	45	110	10	5	4	7	12	9	17	29	31	**603**
Wisconsin	282	45	68	3	5	3	19	23	16	14	41	19	**538**
Massachusetts	242	17	46	3	2	7	9	9	52	46	15	38	**486**
New Jersey	271	11	73	6	4	3	10	6	18	21	15	42	**480**
North Carolina	206	12	89	10	7	3	9	15	13	11	24	16	**415**
Minnesota	235	17	50	2	6	2	9	4	22	23	21	21	**412**
Tennessee	168	20	108	8	3	-	2	8	11	16	19	13	**376**
Georgia	164	16	81	10	5	-	4	5	7	4	12	8	**316**
Missouri	161	9	68	1	6	2	11	7	8	6	15	11	**305**
Connecticut	135	6	35	14	3	5	5	10	13	24	14	34	**298**
Washington	125	8	88	-	4	1	1	2	14	28	5	18	**294**
Colorado	122	3	51	-	2	-	-	2	21	27	6	22	**256**
Alabama	81	35	95	2	3	1	2	2	13	4	5	10	**253**
Arizona	129	2	43	-	1	4	1	-	13	12	6	20	**231**
Oregon	112	10	51	1	3	1	1	8	14	14	3	7	**225**
South Carolina	109	6	53	15	1	3	3	4	1	4	18	8	**225**
Virginia	78	11	77	2	3	1	3	1	11	10	16	11	**224**
Oklahoma	69	13	55	6	7	4	1	2	6	9	17	10	**199**
Kentucky	104	3	43	7	3	-	-	4	3	4	12	5	**188**
Iowa	88	21	36	3	2	1	4	2	2	5	5	2	**171**
Utah	76	8	54	2	1	1	-	1	7	5	3	9	**167**
Kansas	75	10	32	5	3	-	2	2	3	3	3	7	**145**
Arkansas	73	6	30	1	5	-	-	3	2	4	15	5	**144**
Maryland	68	3	26	-	2	1	1	2	8	15	6	10	**142**
Louisiana	46	5	65	-	-	2	-	1	1	3	7	6	**136**
New Hampshire	60	3	12	5	-	-	-	3	19	14	4	14	**134**
Mississippi	55	6	35	-	-	1	-	2	3	3	16	4	**125**
Rhode Island	62	5	10	1	-	-	1	-	4	6	-	4	**93**
Nevada	54	3	12	-	1	2	1	-	1	6	4	4	**88**
Nebraska	37	5	22	1	-	-	-	4	2	-	1	3	**75**
Idaho	35	4	16	-	-	2	-	1	5	2	5	3	**73**
West Virginia	20	4	28	-	-	-	2	-	2	1	6	2	**65**
Maine	23	3	18	-	-	2	-	2	2	1	3	2	**56**
New Mexico	19	-	14	-	-	-	-	-	-	5	4	7	**49**
Vermont	24	1	4	-	-	1	-	1	4	3	-	5	**43**
South Dakota	21	-	6	-	4	-	1	-	4	-	1	-	**37**
North Dakota	17	2	10	-	-	1	1	-	1	1	3	-	**36**
Montana	16	3	8	-	-	-	-	-	2	-	1	2	**32**
Delaware	14	-	6	-	-	-	-	-	-	-	1	2	**23**
Wyoming	3	-	6	1	-	1	-	-	-	2	1	1	**15**
Alaska	3	-	6	-	-	-	-	-	-	1	1	-	**11**
Hawaii	9	-	1	-	-	-	-	-	-	-	-	-	**10**
U.S. Total	8,174	747	3,033	198	177	110	248	292	716	830	659	979	**16,163**

Table 4.6 – Number of Employees – by State

State	326199 All other Plastics Products	331511 Iron Foundries	332312 Fabricated Structural Metal	332991 Ball and Roller Bearings	333412 Industrial and Commercial fans and blowers	333611 Turbines, and Turbine Generators, and Turbine Generator Sets	333612 Speed Changer, Industrial	333613 Power Transmission Equip.	334418 Printed circuits and electronics assemblies	334519 Measuring and Controlling Devices	335312 Motors and Generators	335999 Electronic Equipment Components, NEC	Totals
California	47,179	1,576	7,876	562	500	4,153	367	677	21,472	5,461	1,696	10,736	**102,255**
Ohio	45,925	10,650	4,171	4,588	1,140	177	807	1,448	1,382	2,447	4,581	3,195	**80,511**
Michigan	46,389	8,155	3,159	652	339	22	863	1,427	2,177	1,570	893	904	**66,550**
Texas	23,811	3,585	11,119	141	286	806	426	1,668	10,368	2,835	2,985	2,200	**60,229**
Illinois	34,764	3,175	3,653	2,125	1,156	175	1,920	2,213	1,956	1,136	2,063	2,968	**57,304**
Indiana	26,120	8,301	4,251	2,441	1,033	591	1,467	1,313	1,807	195	3,503	2,043	**53,064**
Pennsylvania	26,269	4,969	7,009	1,303	316	1,073	615	972	2,413	2,387	2,055	924	**50,304**
Wisconsin	19,614	9,207	2,387	244	92	156	2,130	2,134	4,522	498	6,769	411	**48,164**
New York	19,522	478	2,227	2,205	622	3,276	1,055	1,140	10,411	2,040	1,710	2,690	**47,375**
North Carolina	14,662	888	2,584	2,152	355	1,502	319	1,006	2,098	817	3,312	535	**30,229**
Tennessee	12,817	3,056	2,860	1,615	19	-	17	745	2,156	1,093	3,649	381	**28,407**
Massachusetts	12,758	484	936	96	82	505	237	489	6,785	2,088	670	2,826	**27,955**
Minnesota	12,484	1,142	1,202	17	300	49	522	258	4,149	1,814	3,101	1,093	**26,131**
Florida	9,628	335	4,413	15	303	197	208	47	5,423	1,402	312	1,726	**24,008**
Missouri	11,603	700	2,300	375	1,817	37	680	222	719	208	4,474	500	**23,634**
New Jersey	15,824	1,042	1,414	404	191	212	221	291	815	796	238	1,087	**22,535**
Alabama	6,329	6,401	3,774	784	142	375	22	182	2,223	254	483	246	**21,213**
Georgia	9,756	1,511	3,078	1,986	185	-	286	94	1,242	554	1,954	253	**20,898**
South Carolina	7,646	440	2,969	6,244	75	1,449	452	126	15	91	711	316	**20,532**
Virginia	9,600	2,323	3,440	1,124	392	3	424	3	463	406	1,461	564	**20,201**
Kentucky	11,423	412	1,232	601	84	-	-	1,104	537	15	2,428	97	**17,932**
Connecticut	6,797	220	760	1,401	144	525	33	543	706	863	2,083	2,007	**16,081**
Arizona	5,406	5	1,742	-	15	91	15	-	5,089	605	61	751	**13,778**
Arkansas	5,731	196	1,778	3	241	-	-	104	549	217	4,793	161	**13,771**
Iowa	6,786	1,927	1,278	456	89	175	346	752	77	117	345	29	**12,376**
New Hampshire	4,040	72	575	2,283	-	-	-	324	2,395	472	194	384	**10,736**
Washington	5,219	584	1,555	-	114	15	75	37	1,258	657	81	481	**10,075**
Mississippi	3,357	124	1,430	-	-	175	-	209	759	40	3,216	358	**9,666**
Colorado	3,775	40	1,157	-	109	-	-	177	3,202	440	96	386	**9,382**
Kansas	6,011	979	1,194	47	192	-	89	409	43	84	252	46	**9,345**
Oklahoma	3,490	810	1,700	308	462	106	15	29	266	215	1,092	296	**8,788**
Maryland	5,580	24	897	-	10	3	3	377	363	655	174	271	**8,355**
Oregon	4,020	186	1,639	3	389	3	3	233	1,332	230	56	238	**8,329**
Louisiana	1,179	152	5,080	-	-	109	-	15	3	112	98	179	**6,926**
Nebraska	3,089	441	937	75	-	-	-	279	37	-	750	1,243	**6,849**
Utah	2,164	514	2,169	37	15	3	-	7	210	221	62	359	**5,760**
Rhode Island	3,278	109	1,137	35	-	-	35	-	215	467	-	391	**5,665**
South Dakota	787	-	247	-	798	-	375	-	1,381	-	35	-	**3,622**
Vermont	1,612	3	538	-	-	3	-	175	151	791	-	233	**3,504**
Idaho	1,347	34	313	-	-	42	-	3	1,396	42	91	152	**3,417**
West Virginia	1,751	126	866	-	-	-	49	-	182	75	181	49	**3,278**
Nevada	1,860	92	604	-	75	5	75	-	35	150	51	182	**3,127**
Delaware	1,898	-	327	-	-	-	-	-	-	-	15	89	**2,329**
Maine	983	92	525	-	-	377	-	37	82	3	64	77	**2,238**
North Dakota	496	82	442	-	-	75	7	-	750	15	29	-	**1,893**
New Mexico	433	-	322	-	-	-	-	-	-	161	298	247	**1,461**
Montana	246	12	569	-	-	-	-	-	17	-	7	17	**867**
Wyoming	384	-	155	35	-	7	-	-	-	5	3	3	**590**
Hawaii	85	-	35	-	-	-	-	-	-	-	-	-	**119**
Alaska	24	-	56	-	-	-	-	-	-	3	3	-	**85**
U.S. Total	505,945	75,648	106,078	34,351	12,075	16,463	14,152	21,262	103,628	34,743	63,172	44,318	**1,031,832**

Impact of $50 Billion Investment in Wind

While the data presented above using the NAICS indicate the number and size of companies that could enter the wind turbine market, the number that actually enter would depend on the size of the market itself. However, it is reasonable to assume that the geographic distribution of companies actually entering the wind market would not widely vary from the distribution of companies identified using the NAICS codes. In other words, if a certain percentage of the potential manufacturers actually do enter the wind turbine market, this percentage would be similar across the country. Hence, the data from the NAICS industries can be used to investigate how a given investment in wind would propagate geographically throughout the country.

Chapter 3 of this Report investigates the impact 50,000MW of new wind capacity installation, and the resulting $50 billion investment in manufacturing activities, as well as 150,000 new FTE jobs. The results of that chapter were based on the geographic location of the 90 companies identified as currently active in wind turbine component manufacturing. However, a wind program as large as 50,000 MW will almost certainly spread beyond the current list of 90 active companies. A more balanced and comprehensive view of how this investment would be distributed can be obtained by examining the geographic location of potential entrants to the wind turbine market.

As in Chapter 3 for the currently active companies, first we determine how the total installed cost of the new wind development will flow into demand for each of the 20 separate components of the turbines (grouped into 5 categories). Second, we spread the total demand among the regions of the country by allocating the $50 billion investment according to the number of employees at firms identified by the NAICS codes. The number of employees is used rather than number of firms to account for the different impact of large vs. small companies, and hence to more accurately distribute the investment. This produces a "map" of manufacturing activity across the United States based on firms that have the technical potential to become active manufacturers of wind turbine components. Third, we translate the regional dollar allocation by assuming that all component manufacturing has the same ratio of jobs/total investment of 3000 FTE jobs/$1 billion of investment.

Table 4.7 – New Job and Investment Potential, based on Employment in NAICS Industries Associated with Wind Components

State	Employees at Potential Active Firms	Rotor	Nacelle and Controls	Gearbox & Drive Train	Generator & Power Electronics	Tower	Number of Jobs	Average Investment ($ Billions)
California	**102,255**	25,226	52,490	1,380	14,889	8,270	**12,717**	**4.24**
Ohio	**80,511**	30,578	33,367	6,360	3,372	6,834	**11,688**	**3.90**
Illinois	**57,304**	20,001	24,193	5,520	3,143	4,447	**8,530**	**2.84**
Texas	**60,229**	15,191	28,339	1,678	3,006	12,015	**8,943**	**2.98**
Michigan	**66,550**	27,719	30,241	2,466	926	5,198	**8,549**	**2.85**
Pennsylvania	**50,304**	16,647	20,844	2,565	1,997	8,251	**7,622**	**2.54**
New York	**47,375**	10,855	24,188	4,020	5,966	2,347	**6,549**	**2.18**
Indiana	**53,064**	18,962	20,359	4,783	2,633	6,326	**8,317**	**2.77**
Florida	**24,008**	5,138	12,197	254	1,923	4,497	**3,371**	**1.12**
Wisconsin	**48,164**	17,795	21,317	3,796	567	4,689	**6,956**	**2.32**
New Jersey	**22,535**	8,552	10,191	819	1,299	1,675	**2,920**	**0.97**
North Carolina	**30,229**	9,431	12,814	3,142	2,036	2,806	**4,661**	**1.55**
Massachusetts	**27,955**	6,956	15,952	659	3,331	1,057	**3,210**	**1.07**
Tennessee	**28,407**	9,761	12,513	2,128	381	3,624	**4,233**	**1.41**
Minnesota	**26,131**	8,364	14,427	711	1,142	1,488	**3,064**	**1.02**
Georgia	**20,898**	6,610	8,245	2,335	253	3,456	**3,532**	**1.18**
Connecticut	**16,081**	4,550	6,388	1,796	2,532	815	**2,479**	**0.83**
Missouri	**23,634**	8,389	11,031	1,202	537	2,475	**3,234**	**1.08**
South Carolina	**20,532**	4,398	4,510	6,780	1,765	3,079	**4,964**	**1.65**
Washington	**10,075**	2,942	4,837	99	496	1,701	**1,382**	**0.46**
Alabama	**21,213**	6,607	7,686	927	620	5,374	**3,571**	**1.19**
Virginia	**20,201**	6,692	7,372	1,549	567	4,021	**3,386**	**1.13**
Colorado	**9,382**	1,955	5,755	118	386	1,167	**1,141**	**0.38**
Oregon	**8,329**	2,131	4,112	160	240	1,685	**1,202**	**0.40**
Oklahoma	**8,788**	2,696	3,446	341	402	1,903	**1,399**	**0.47**
Arizona	**13,778**	2,736	8,443	15	842	1,743	**1,648**	**0.55**
Kentucky	**17,932**	7,131	8,032	1,337	97	1,335	**2,483**	**0.83**
Iowa	**12,376**	4,529	4,580	1,303	204	1,760	**2,037**	**0.68**
Utah	**5,760**	1,370	1,689	42	361	2,298	**1,094**	**0.36**
Kansas	**9,345**	3,621	3,831	409	46	1,439	**1,368**	**0.46**
Louisiana	**6,926**	715	795	10	288	5,118	**1,800**	**0.60**
Arkansas	**13,771**	5,360	6,352	72	161	1,827	**1,774**	**0.59**
New Hampshire	**10,736**	2,153	5,109	2,498	384	592	**1,927**	**0.64**
Maryland	**8,355**	2,889	4,036	254	274	903	**1,095**	**0.37**
Mississippi	**9,666**	3,348	4,185	139	533	1,461	**1,337**	**0.45**
Nebraska	**6,849**	2,139	2,159	261	1,243	1,047	**1,080**	**0.36**
Rhode Island	**5,665**	1,693	2,348	69	391	1,164	**846**	**0.28**
Nevada	**3,127**	1,001	1,237	75	187	627	**477**	**0.16**
West Virginia	**3,278**	1,029	1,253	49	49	898	**531**	**0.18**
Idaho	**3,417**	736	2,166	2	193	321	**383**	**0.13**
Maine	**2,238**	569	642	25	454	548	**379**	**0.13**
New Mexico	**1,461**	365	526	-	247	322	**228**	**0.08**
Vermont	**3,504**	807	1,806	116	236	539	**490**	**0.16**
North Dakota	**1,893**	303	1,046	7	75	462	**273**	**0.09**
South Dakota	**3,622**	411	2,590	375	-	247	**468**	**0.16**
Montana	**867**	132	146	-	17	572	**209**	**0.07**
Delaware	**2,329**	956	956	-	89	327	**310**	**0.10**
Wyoming	**590**	193	198	35	10	155	**103**	**0.03**
Alaska	**85**	13	16	-	-	56	**20**	**0.01**
Hawaii	**119**	42	42	-	-	35	**19**	**0.01**
Total	**1,031,832**	**322,382**	**461,003**	**62,677**	**60,781**	**124,990**	**150,000**	**50**

Table 4.7 shows how many of the 150,000 new jobs nationwide would be created in each state, and for which wind turbine component group. Again, the job creation is distributed throughout the entire country, with every state at least participating. In 35 out of the 50 states, more than 1,000 jobs would be created. 45 out of 50 would each receive at least $100 million of the total investment. This result is even more promising than if only the 90 currently active firms are considered, and indicates that the potential to benefit from a national investment in wind is widespread, not just in states with large wind resources.

Many of the 12 NAICS codes considered are associated with more than one component group. To maintain the integrity of the data, in this case the amount of manufacturing activity for a given code is divided evenly amongst the applicable component groups. For example, 326199 applies to both the Rotor group (blades) and the Nacelle and Controls group (nacelle case). Hence, for a given geographic region such as a state, half the companies would be counted in Rotor, and half in Nacelle and Controls. A code applying to 3 component groups would be divided in thirds.

Availability of County Level Data

Another advantage to examining potential manufacturing activity through the NAICS codes is the availability of information for every county in the U.S. This information makes it possible to determine how any local community would potentially benefit from a national investment in wind. The sheer volume of this information precludes publishing it as part of this report, however REPP plans to provide a browseable directory on the REPP website, where one can find information about potential wind turbine manufacturing activity for each county. Table 4.8 shows a sample of this information.

Table 4.8 – Number of Employees, Partial List of Ohio Counties

County	326199 All other Plastics Products	331511 Iron Foundries	332312 Fabricated Structural Metal	332991 Ball and Roller Bearings	333412 Industrial and Commercial fans and blowers	333611 Turbines, and Turbine Generators, and Turbine Generator Sets	333612 Speed Changer, Industrial	333613 Power Transmission Equip.	334418 Printed circuits and electronics assemblies	334519 Measuring and Controlling Devices	335312 Motors and Generators	335999 Electronic Equipment and Components, NEC	Totals
Adams, OH	15	-	-	-	-	-	-	-	-	-	-	-	15
Allen, OH	75	189	15	-	-	-	-	75	-	-	184	-	537
Ashland, OH	404	-	7	-	-	-	-	-	-	-	35	35	480
Ashtabula, OH	2,573	3	-	-	-	-	-	-	-	-	-	-	2,576
Athens, OH	35	-	-	-	-	-	-	-	-	-	-	-	35
Auglaize, OH	15	175	7	-	-	-	-	-	-	-	-	-	196
Belmont, OH	-	-	7	-	-	-	-	-	-	-	-	-	7
Brown, OH	-	-	-	-	-	-	-	-	-	-	3	-	3
Butler, OH	788	35	49	-	175	-	-	75	69	-	15	-	1,204
Carroll, OH	77	-	-	-	-	-	-	-	-	-	-	-	77
Champaign, OH	409	-	-	-	-	-	-	-	-	-	-	-	409
Clark, OH	347	-	7	-	-	-	-	-	-	15	35	7	410
Clermont, OH	236	-	175	-	-	-	-	-	-	15	-	-	425
Clinton, OH	284	35	35	-	-	-	7	-	-	-	-	-	360
Columbiana, OH	799	230	55	-	-	-	-	-	-	-	-	-	1,084
Coshocton, OH	-	375	3	-	-	-	-	-	-	-	-	-	377
Crawford, OH	375	-	3	750	-	-	-	-	-	-	-	-	1,127
Cuyahoga, OH	1,998	1,031	260	24	175	-	419	504	189	459	589	216	5,863
Darke, OH	859	-	-	-	-	-	-	-	-	-	35	3	896
Defiance, OH	-	1,003	175	-	-	-	-	-	-	-	7	-	1,184
Delaware, OH	37	284	15	-	-	-	-	-	-	-	-	-	335
Erie, OH	752	175	-	1,000	-	-	-	175	-	49	-	-	2,150

Using this county information, it is then further possible to consider how a given national investment in wind, for example the 50,000 MW considered above, would benefit a given county. The methodology is the same as at the state level, simply using the geographic location information for the county level. A sample of these results are shown in Table 4.9 – complete listings for every county in the U.S. will be available on REPP's website.

Table 4.8 – Number of Employees, Partial List of Ohio Counties

County	Employees at Potential Companies	Rotor	Nacelle and Controls	Gearbox & Drive Train	Generator & Power Electronics	Tower	Number of Jobs	Average Investment ($ Millions)
Adams, OH	**14**	7	7	-	-	-	**1**	**0.5**
Allen, OH	**537**	224	201	50	-	62	**83**	**27.7**
Ashland, OH	**480**	219	219	-	35	7	**52**	**17.4**
Ashtabula, OH	**2,576**	1,288	1,287	-	-	1	**259**	**86.3**
Athens, OH	**34**	17	17	-	-	-	**3**	**1.2**
Auglaize, OH	**197**	95	51	-	-	51	**32**	**10.6**
Belmont, OH	**7**	-	-	-	-	7	**2**	**0.7**
Brown, OH	**2**	1	1	-	-	-	**0**	**0.1**
Butler, OH	**1,205**	419	678	50	-	58	**141**	**47.0**
Carroll, OH	**78**	39	39	-	-	-	**8**	**2.6**
Champaign, OH	**410**	205	205	-	-	-	**41**	**13.7**
Clark, OH	**410**	191	205	-	7	7	**43**	**14.2**
Clermont, OH	**426**	118	133	-	-	175	**79**	**26.4**
Clinton, OH	**360**	159	151	7	-	43	**48**	**15.9**
Columbiana, OH	**1,084**	514	457	-	-	113	**134**	**44.8**
Coshocton, OH	**377**	187	94	-	-	96	**61**	**20.3**
Crawford, OH	**1,127**	187	187	750	-	3	**349**	**116.2**
Cuyahoga, OH	**5,864**	1,809	2,542	779	216	518	**936**	**312.2**
Darke, OH	**897**	447	447	-	3	-	**90**	**30.0**
Defiance, OH	**1,184**	505	254	-	-	425	**216**	**72.1**
Delaware, OH	**334**	160	89	-	-	85	**54**	**17.9**
Erie, OH	**2,150**	463	527	1,116	-	44	**573**	**191.1**

NOTES

[1] U.S. Bureau of Census. 1997 Economic Census. http://www.census.gov/epcd/www/econ97.html
[2] NREL. Wind Partnerships for Advanced Component Technology (WindPACT). http://www.nrel.gov/wind/windpact/. Accessed April 15, 2004.
[3] Advanced Horizontal Axis Wind Turbines in Windfarms. Renewable Energy Technology Characterizations. DOE Office of Power Technology Topical Report. December 1997 • TR-109496. http://www.eere.energy.gov/power/pdfs/turbines.pdf
[4] O&M Worksheets: Baseline 1.5 MW wind turbine, 70m rotor, 84m hub height - Unscheduled Maintenance Costs. NREL.
[5] November 1, 2000 – February 28, 2002. Appendix D: Gearbox Bill of Materials and Mechanical Cost Estimates. R. Poore and T. Lettenmaier, Global Energy Concepts, LLC. August 2003 • NREL/SR-500-33196.