Wind Turbine Development: Location of Manufacturing Activity

REPP

Renewable Energy Policy Project

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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.

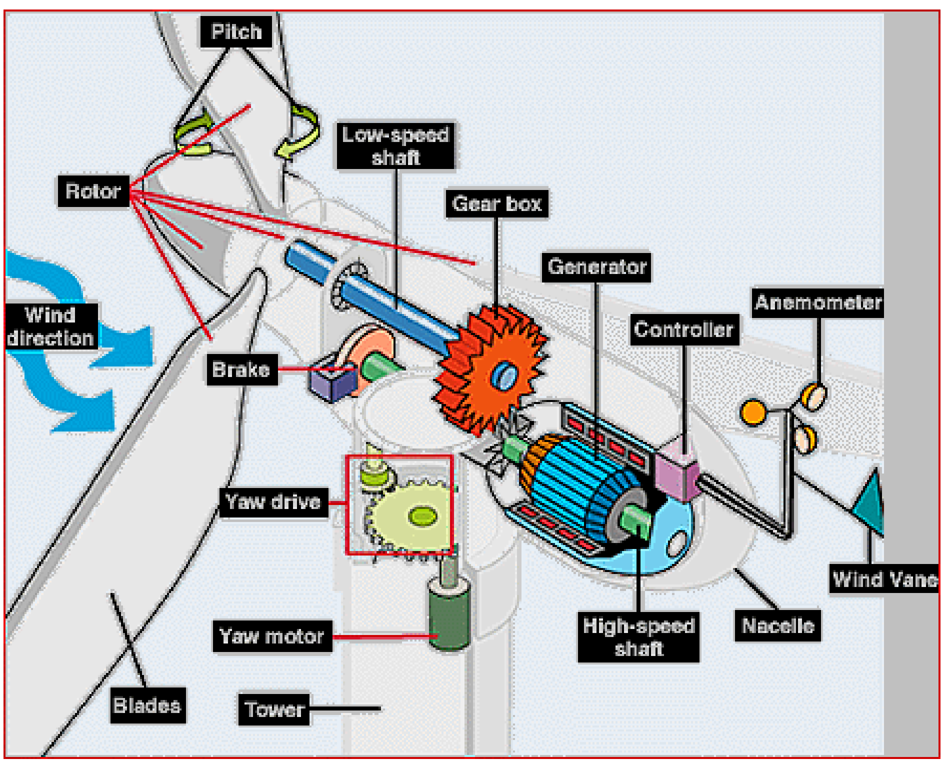

Figure 1 - Wind Turbine Major Components

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.

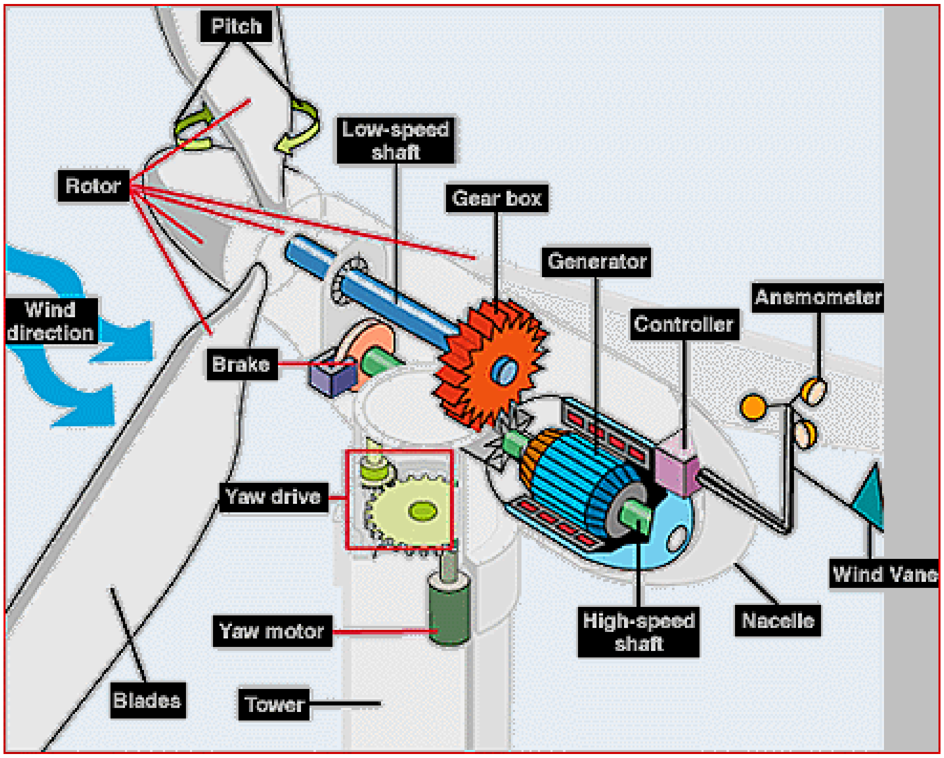

Figure 2 - Schematic of Wind Turbine Major Subcomponents

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.