# Wind Turbine - Materials and Manufacturing Fact Sheet

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Recognition of the value of wind energy as a low cost, clean source for electricity is creating major new business opportunities for manufacturing and materials innovation. Worldwide growth in wind generation since 1994 has been 30% or higher annually. The cost of energy from large wind power plants has declined to less than $0.05/kWh at good wind sites. By the end of 2000, the global capacity had passed 17,600 megawatts (MW) [See reference 1], and in the United States alone, more than 1,800 MW of new installations should be completed this year [2, 3].

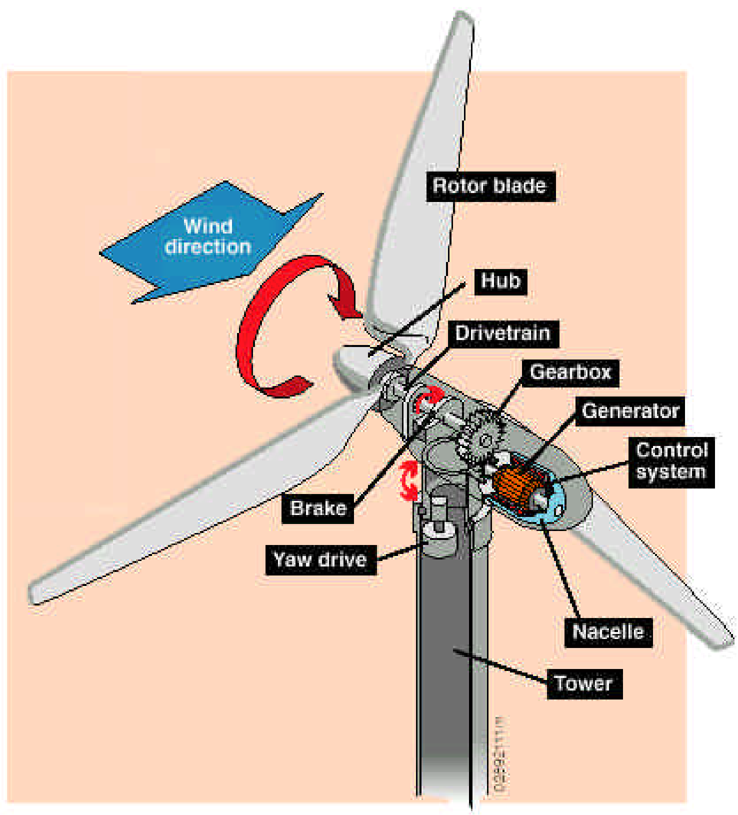
The combined sales of large wind power plants and small turbines for distributed generation is now $4-5 billion annually worldwide and growing. Small turbines (less than 100 kW each) are being produced for the growing distributed generation and off-grid markets. Grid-connected wind power plants typically employ hundreds of 1 to 2 MW turbines today and larger, 3 to 5 MW machines, with 100-meter (m) (110 yards - longer than a football field) or greater rotors are being developed. The wind turbine manufacturing business has grown from a "cottage industry," with hand-built subsystems, to sales warranting large-scale production operations.

### Parts of a Wind Turbine

Wind turbines come in many sizes and configurations and are built from wide range of materials. In simple terms, a wind turbine consists of a **rotor** that has wing shaped **blades** attached to a **hub**; a **nacelle** that houses a drivetrain consisting of a **gearbox,** connecting shafts, support bearings, the **generator**, plus other machinery; a **tower**; and ground-mounted electrical equipment.

The wing shaped blades on the rotor actually harvest the energy in the wind stream. The rotor converts the kinetic energy in the wind to rotational energy transmitted through the drivetrain to the generator. Generated electricity can be connected directly to the load or feed to the utility grid [4].

The weight and cost of the turbine is the key to making wind energy




**Wind Turbine Nomenclature**

competitive with other power sources, because research programs have significantly improved the efficiency of the rotor and maximized the energy capture of the machine. The real opportunity today is through better, low cost materials and though high volume production, while ensuring the reliability is maintained. The typical weight and cost of the primary turbine components today are shown in Table 1. In addition there are foundations and conventional ground-mounted systems, including transformers, switching and other power equipment.

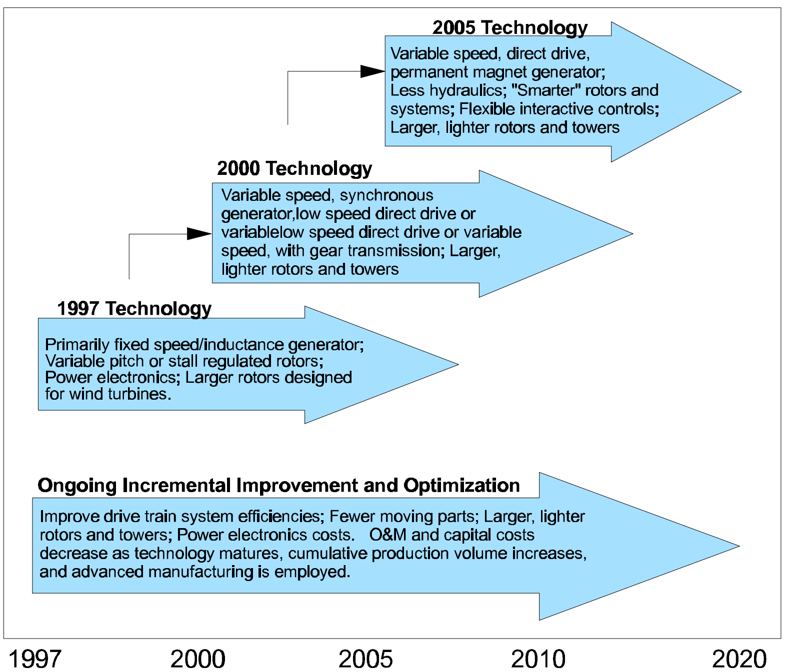
There appear to be several areas where technological progress and cost reduction are needed. Turbine subsystem costs are generally evenly split between rotor, nacelle, drivetrain power systems, and the tower. There is no single component that dominates turbine cost. The rotor is the highest cost item on most machines and must be the most reliable. Towers are normally the heaviest component and could benefit from weight reduction, but lightening the rotor or tower-top weight has a multiplier effect throughout the system including the foundation.

**Table 1. Turbine Component Weight and Cost**

| Component | % of Machine Weight | % of Machine Cost [5] |
|---|---|---|
| Rotor | 10-14 | 20-30 |
| Nacelle and machinery, less | 25-40 | 25 |
| Gearbox and drivetrain | 5-15 | 10-15 |
| Generator systems | 2-6 | 5-15 |
| Weight on Top of Tower | 35-50 | N/A |
| Tower | 30-65 | 10-25 |

## Expected Technology Evolution

The components of turbines are changing as the technology improves and evolves. There is a trend toward lighter weight systems. Light weight, low cost materials are especially important in blades and towers for several reasons. First the weight of the blades and rotor is multiplied through out the machine. The tower weight is key because it is typically 60% of the weight of the turbine above the foundation, due to the fact that sophisticated light-weight, high-strength materials are often too costly to justify their use.




Source: Renewable Energy Technology Charecterizations, Electric Power Research Institute, EPRI TR-I09496, December 1997

**Wind Turbine Technology Evolution**

Another technology shift is occurring in the drive train. In some cases the gearbox is being eliminated by employing variable speed generators and solid state electronic converters that produce utility quality alternating current (AC) power. This trend began in small machines and is now being incorporated in turbine sizes from 100 kW to 3 MW. Other trends in wind turbine technology are discussed in detail in the Renewable Energy Technology Characterizations published by the Electric Power Research Institute (EPRI) [5] with DOE support.

## Market and Turbine Component Materials Data

To estimate the quantities and types of materials used in wind turbines, a database was compiled from a variety of industrial, DOE laboratory and existing PERI sources. Much of the wind turbine and component characteristics and weight data came from the DOE, Wind Partnerships for Advanced Technologies (WindPACT) program database through NREL and their subcontractors, as well as directly from turbine manufacturers, their web sites and marketing materials. Twenty-eight types and models of turbines were analyzed in this report, ranging from small models for direct current (DC) battery charging (e.g. the 0.4 kW Southwest Windpower turbine), to large grid connected alternating current (AC) machines currently commercially available (e.g. the Enron 1.5 MW) and being employed in 100-200 MW wind power plants. Very large multi-megawatt machines being designed for future wind farm applications, both on- and off-shore (e.g. the 5 MW NREL concept turbine), were also included in expected future markets after 2005. The specific models, type and size, that were assumed for each manufacturer as the basis for estimating current and future market share in our model is shown in Table 2. The actual unit production and sales data incorporated in the market share database is considered proprietary by the manufacturers. This data was used in estimating weights of materials shown in Table 3.

**Table 2. Turbine Models Used in Current and Future Materials Usage Estimates**

| Turbine Make | Rated Power (kW) |
|---|---|
| Southwest Windpower | 0.4, 1.0 |
| Bergey | 1.5, 10 |
| Atlantic Orient Corp. | 50 |
| Northern Power Systems | 100 |
| Enercon | 500, 850 |
| Micon | 600, 900 |
| Bonus | 600, 1000 |
| Vestas | 660, 850, 1650, 2000 |
| Nordex | 1000 |
| Mitsubishi | 600, 1000 |
| Enron | 750, 1500 |
| NREL (Concept) | 2500, 3500, 5000 |

## Future Market Projections

The surge in growth in wind turbine installations in the United States and around the world is expected to continue and actually accelerate. In a study conducted by the World Energy Council (WEC) projected worldwide wind capacity of 13 gigawatts (GW) by 2000 (actual installed capacity was 13.6 GW by the end of 1999), increasing to 72 GW by 2010 and 180 GW by 2020. WEC also considered an “environmentally driven scenario” that has much faster growth if national policies were adjusted. That scenario projected 470 GW of wind power by 2020.

In the United States, the American Wind Energy Association (AWEA) supports the DOE projections for wind power.

- Provide at least 5% of the nation's electricity by 2020 with 10 GW online by 2010 and 80 GW by 2020.
- Double the number of states with more than 20 MW installed to 16 by 2005 and to 24 by 2010.
- Provide 5% of the electricity used by the federal government (the largest single consumer of electricity) by 2010 with 1,000 MW online.

The members of the European Wind Energy Association (EWEA) have increased their estimates for wind installations in that region. Since 1993, the market for new turbines has grown at over 40 % per year. During 1999 was a record year with over 3000 MW installed in that year, resulting in a total installed capacity of 9,500 MW. This is well above the EWEA's old target for 2000 of 8000 MW. With support from the European Commission, studies show and the wind industry believes that the target of 40 GW will also be passed sooner, so the target for 2010 has been raised to 50 GW, of which 5 GW are expected to be offshore capacity. Similarly, a new target of 150 GW was agreed to by EWEA for 2020, of which 50 GW will be offshore.

The future markets for wind turbines in the United States and Europe are large but the biggest potential is expected to be in Asia, Latin America, the Former Soviet Union and Africa. These are the markets where demand for electricity is growing the fastest and the need for sustainable development with reliance on domestic energy resources are the greatest [6]. Growth in these markets could surpass both Europe and the U.S. by 2020.

**Materials Usage in Current Wind Turbines**

A wide range of materials are used in wind turbines. There are substantial differences between small and large machines and there are projected changes in designs that will accommodate the introduction of new material technologies and manufacturing methods. The estimated materials use in small and large turbines is shown in Table 3. To arrive at a total, the material usage is weighted by the estimated market share of the various manufacturers and machines types.

**Table 3. Percentage of Materials Used in Current Wind Turbine Component**

| Component/ Material (% by weight) | Large Turbines and *(Small Turbines[1])* Permanent Magnetic Materials | Pre-stressed Concrete | Steel | Aluminum | Copper | Glass Reinforced Plastic [4] | Wood Epoxy [4] | Carbon Filament Reinforced Plastic [4] |
|---|---|---|---|---|---|---|---|---|
| **Rotor** | | | | | | | | |
| **Hub** | | | *(95)* - 100 | *(5)* | | | | |
| **Blades** | | | 5 | | | 95 | *(95)* | *(95)* |
| | | | | | | | | |
| **Nacelle [2]** | *(17)* | | *(65)* - 80 | 3 - 4 | 14 | 1 - *(2)* | | |
| **Gearbox [3]** | | | 98 -*(100)* | *(0)* - 2 | *(<1)* - 2 | | | |
| **Generator** | *(50)* | | *(20)* - 65 | | *(30)* - 35 | | | |
| **Frame, Machinery & Shell** | | | 85 - *(74)* | 9 - *(50)* | 4 - *(12)* | 3 - *(5)* | | |
| | | | | | | | | |
| **Tower** | | 2 | 98 | *(2)* | | | | |

Notes:
1. Small turbines with rated power less than 100 kW- (listed in italics where different)
2. Assumes nacelle is 1/3 gearbox, 1/3 generator and 1/3 frame & machinery
3. Approximately half of the small turbine market (measured in MW) is direct drive with no gearbox
4. Rotor blades are either glass reinforced plastic, wood-epoxy or injection molded plastic with carbon fibers

The trends in design and manufacturing differ between small and large turbines. Small machines tend to use lighter weight castings in an effort to reduce costs. Many parts are die cast aluminum in small turbines, while in large machines steel castings or forgings are needed to meet strength and structural fatigue requirements. The size of steel castings for large turbines, especially the blade hub units, is one of the manufacturing challenges.

Material fatigue properties are an important consideration in wind turbine design and materials selection. During the expected 30 year life of a wind turbine, many of the components will need to be able to endure $4 \times 10^8$ fatigue stress cycles. This high cycle fatigue resistance is even more severe than aircraft, automotive engines, bridges and most other man-made structures.

## Future Component Development Trends

There are new component developments underway now that will significantly change the materials usage patterns. Generally there are trends toward lighter weight materials, as long as the life-cycle cost is low. Specific development trends in turbine components are discussed below:

<u>Rotors</u> Most rotor blades in use today are built from glassfiber-reinforced-plastic (GRP). Other materials that have been tried include steel, various composites and carbon-filament-reinforced-plastic (CFRP). As the rotor size increases on larger machines, the trend will be toward high strength, fatigue resistant materials. As the turbine designs continually evolve, composites involving steel, GRP, CFRP and possibly other materials will likely come into use.

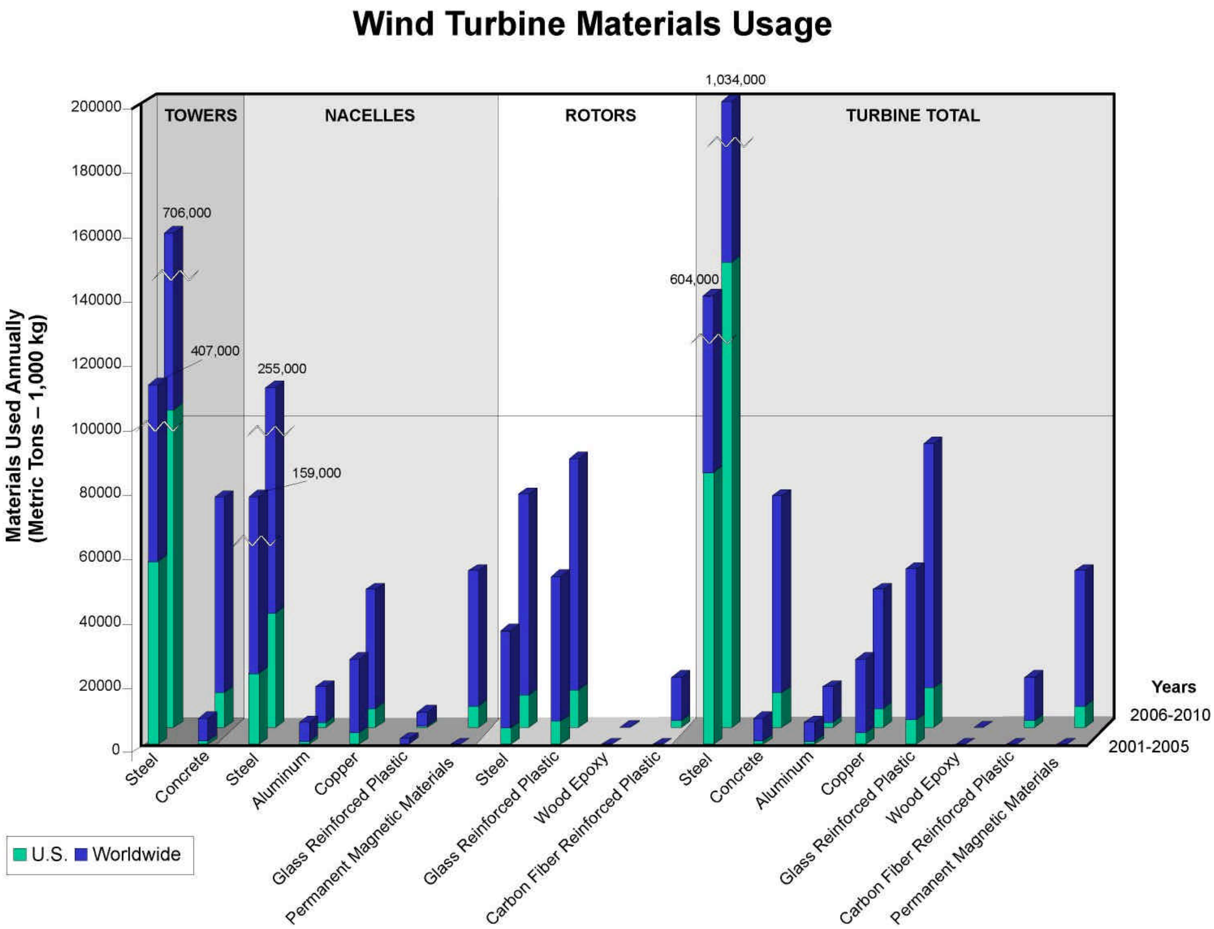
Gearboxes The step-up gearbox used on large turbines today is expected to be replaced in many future machines. Most small turbine designed for battery charging use a variable speed, permanent magnet, variable frequency generator connected to a rectifier. As high power solid state electronics are improved, larger and larger machines are likely to use AC-DC-AC cycloconverters. This is the case on turbines being developed by Northern Power Systems (100 kW), the ABB (3 MW), and in some commercial machines. This trend will increase the use of magnetic materials in future turbines. Large epicyclic gear boxes used in large ships, may continue to be the drive system for some large turbines.

Nacelles The nacelle contains an array of complex machinery including, yaw drives, blade pitch change mechanisms, drive brakes, shafts, bearings, oil pumps and coolers, controllers and more. These are areas where simplification and innovation can pay off.

Towers Low cost materials are especially important in towers, since towers can represent as much as 65% of the weight of the turbine. Prestressed concrete is a material that is starting to be used in greater amounts in European turbines, especially in off-shore or near-shore applications. Concrete in towers has the potential to lower cost, but may involve nearly as much steel in the reinforcing bars as a conventional steel tower.

**Material Usage Trends though 2010**

The component development trends described above are reflected in the following material use projections. The overall annual material usage trends are shown in the following figure for two periods, from now though 2005 and for 2006 though 2010. Introduction of much of the new technology discussed above is expected to be incorporated in commercial machines during the later period. Materials used in machines installed in the U.S. are included as part of the global totals.




The following observations are based on the results of the material usage analysis:

- Turbine material usage is and will continue to be dominated by steel, but opportunities exist for introducing aluminum or other light weight composites, provided strength and fatigue requirements can be met.
- Small turbine production volume is increasing rapidly which can be accommodated by manufacturing mechanization and innovation that will lower costs.
- Elimination of the gearbox by using variable speed generators will increase through use of permanent magnetic generators on larger turbines increasing the need for magnetic materials.
- New high power electronics will help reduce the need for gearboxes and also decrease losses occurred during transmission of wind power to distant load centers.
- Simplification of the nacelle machinery may not only reduce costs, but also increase reliability.
- Blades are primarily made of GRP, which is expected to continue. While use of CFRP may help to reduce weight and cost some, low cost and reliability are the primary drivers.
- Increasing the use of offshore applications may partially offset this trend in favor of the use of composites.

- Prestressed concrete towers are likely to be used more, but will need a substantial amount of steel for reinforcement.
- Wood epoxy, used in early blade production, is not expected to be a material of choice despite excellent fatigue properties.
- Wind turbine component and materials manufacturing are major and expanding business opportunities for at least the next 10 years.
- The largest market for wind turbine systems and materials in the future will be outside North America and Europe, but this market will be slower in development.

**References:**

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