Finished blades await shipment (below), while new ones are already in the making (right). Here, huge molds are being removed (center) from raw blades (left).

Catching the Wind

Siemens Wind Power is more than just the global market leader for offshore wind turbines. In Denmark, in a unique, one-shot process, the company produces rotor blades that are up to 52 meters in length. It also manufactures the world's largest serially-produced wind turbine, which has an output of 3.6 megawatts.

Low black clouds and bone-chilling wind are blowing in over the whitecaps on the North Sea. By most people's standards this is anything but great weather. But for Claus Burchardt, head of blades research and development at Siemens Power Generation's (PG) Wind Power division, nothing could be better. "For us, good weather means a stiff wind," he says. "Without that, we would be struggling to find customers."

Rather than standing at the beach, Burchardt is sitting in a small office on the outskirts of Aalborg, Denmark's third largest city. Together with 3,200 fellow employees of Siemens Wind Power, Burchardt builds huge wind power plants, each of which can generate enough electricity to boil a bath full of ice-cold water within 30 seconds. In fact, the individual components of such a wind turbine are so large that, for logistical reasons, some are built far from Denmark. One such location is Fort Madison, Iowa, where a new rotor blade factory opened in September, 2007. Local infrastructure also plays an important role in choosing locations. Thus, Aalborg, for example, was selected because of its proximity to a harbor with quays capable of handling rotor blades, some of which are over 50 meters in length.

"The big challenge in Aalborg," says Burchardt, "is to ensure that all of the rotor blades we produce, some of which weigh 16 metric tons, are manufactured to such a high level of precision that they perform exactly as required without any need to upgrade or adjust them for 20 years." To achieve this, the rotor blades — despite their huge size and strength — must have an optimal aerodynamic shape right down to the smallest angle and, most crucially, they must be very robust. This is because many of them are destined for offshore wind farms, where repair and replacement costs are extremely high. "The cost to the manufacturer of carrying out a repair on the open sea is around ten times as high as that for an onshore installation," says Burchardt. "On the large turbines an everyday wind speed of 10 meters per second forces 100 tons of air through the rotor every second. That requires a robust blade!"

Extreme quality requirements such as these have caused many manufacturers to pull out of the offshore sector. In the meantime, Siemens has not only become the most experienced, but also the largest supplier of offshore wind turbines.

> In a patented process, wind mill blades are baked as a single piece — without any seams.

Blade Baking. In the Aalborg facility's production hall, which is some 250 meters in length, there are huge blade-shaped molds like cake pans, stretching out along the floor and even hanging upside down from the ceiling. There's not a hint of chemical smell and most workers don't have to wear special protective clothing. "A few years ago we developed a method of manufacturing the blades as a single, all-in-one piece," says Burchardt. "Using this integral blade process — or one-shot technique, as we also call it — we've been able to do away with adhesives. As a result, the workforce is not exposed to toxic vapors. At the same time there are no individual components to clutter up the hall, and we end up with a rotor blade that is produced in a single casting and therefore without any seams whatsoever, which makes it considerably stronger than other blades."

At the far end of the hall, Burchardt halts at one of the blade molds, which an employee is lining with what look like lengths of white fabric. The material has the appearance of a finely woven carpet but feels like plastic. "Fiberglass," explains Burchardt, "and once it has been injected with epoxy resin it turns into a fiber-reinforced plastic composite. Unlike products from rival manufacturers, our rotor blades don't contain any polyvinyl chloride, which has been associated with dioxin. This means they're not a problem to dispose of at the end of their 20 year service life, because they are primarily made of recyclable fiberglass."

How can such a length of fabric give a rotor blade its enormous strength? "The mold is initially lined with many layers of fiberglass. In fact there are seven metric tons of this material in a 45-meter blade, and 12 tons in a 52-meter blade. To enhance stiffness, a layer of wood is placed between the fiberglass layers," says Burchardt. He indicates the different layers of fiberglass and the wooden mat carefully embedded in the midst of the multilayered structure. "The other side of the blade is made up of the same ingredients and then joined with its mate. But instead of fixing the two sides together with an adhesive, we fill the interior with bags of air and then inject several tons of liquid epoxy resin inside, which finds a smooth course between the pockets and the fiberglass and thus evenly joins the two sides of the blade. Finally, we bake the whole thing for eight hours at a temperature of 70 degrees Celsius."

As Burchardt speaks, a mold is lowered from the ceiling and seamlessly encloses the two sides of a blade. It is only now that the shape of the huge units on the backs of the molds becomes evident. In their closed state, the molds act as a huge cake pan with an integrated oven, and once the epoxy resin has been injected, they are heated to bake the blade into a solid whole. The bags inside the blade defy the heat and prevent the blade from collapsing during production. "With this method it only takes 48 hours from the first step to a completed blade, instead of several days," says Burchardt with evident pride. "That's one day to place all the fiberglass, and another to inject and bake. After that the blade is adjusted and painted white — it's a mixture of high-tech and skilled handicraft." Once completed, the rotor blades are delivered by truck or ship to customers worldwide, including destinations as far away as the U.S. and Japan.

Good Vibrations. Before delivery, samples of the rotor blades have to go through a variety of static and dynamic tests. First of all, they are subjected to 1.3 times the maximum operating load. To simulate 20 years of material fatigue, the blades are then mounted on special test beds and made to vibrate around two million times, before the endurance of the material is again tested with a final static test.

In Brande, a town of 6,000 inhabitants located some 150 kilometers south of Aalborg, 2,000 Siemens employees manufacture the heart of every wind power plant: its turbines' nacelles (housing). During a trip through the Danish countryside, past its fields and farms and some of the country's 3,500 wind turbines, I ask why the biggest manufacturers of wind power plants are in Denmark.

"There are historical reasons," says Henrik Stiesdal, Chief Technology Officer at Siemens in Brande. "It all began with the energy crisis of 1973/1974. In a move to reduce its dependence on oil, Denmark looked at the possibility of building nuclear power plants. In response, talented engineers designed the first wind turbines. In the mid-1980s, a number of countries

Before installation at sea (bottom), Henrik Stiesdal (right) makes sure that everything is perfect — including turbine assembly (center), and a final endurance test (left).

introduced tax incentives for wind power, making it a lucrative business. As the only country with the know-how to build fully functional wind turbines, Denmark experienced a boom that has continued to this day."

Although it's good weather outside — in the Danish sense — Stiesdal is evidently content to remain in his cosy office. From a drawer he produces a chronology of wind power technology and places it on his desk. "The first wind turbines we built in the early '80s had an output of only 22 kilowatts. Since then output has doubled around once every four years. At 2.3 and 3.6 megawatts, our modern plants produce more than a hundred times as much power. At least for now, the smaller plants still account for around 80 percent of our business."

Stiesdal points to a large map of Europe. "We just completed installation of the Burbo Windfarm — our first offshore facility based on the new 3.6-megawatt turbine. The farm is located off Liverpool in the UK and has a total output of 90 megawatts. We needed just one and a half months to do the job. By the end of 2007, the facility will be supplying over 80,000 households. Next year we have another project with 54 turbines for what will be the world's largest offshore wind farm, on the east coast of England. And as the only company able to supply wind turbines of this size, we have already received other orders for our flagship product."

Stiesdal's eyes shine with enthusiasm. "This year we will be building wind turbines with a total output of 1,500 megawatts. That's enough to produce four billion kilowatt-hours a year — around 12 percent of Denmark's electricity requirements. Our 165 MW Nysted offshore wind farm, off the southern coast of Lolland, generates enough energy to supply my home town of Odense and its 185,000 inhabitants, including households, industry, street lighting and everything," he says, before entering a giant hall where turbines are produced.

500-ton Giants. Here, massive metal nacelles, each containing a 2.3-megawatt machine, are lined up. We approach one of the rounded structures, whose top is folded up at either side, offering a view of the interior. "We're standing at the front of the drive shaft. That's where the rotor and its three blades will be mounted from the outside. For an offshore turbine this is a job that takes place on the open sea. The towers are assembled on land. A specially designed ship, complete with crane, is used to transport them along with the nacelles and rotor blades to an offshore site. It then takes less than half a day to install a single turbine weighing 500 tons. Once the rotor begins turning, its motion is transmitted via the drive shaft to the gear unit. This, in turn, transfers the torque, which varies depending on wind strength, to the generator. The result is electrical energy."

The first wind turbines produced 22 kilowatts — that's less than one hundredth of today's output.

Stiesdal, a hobby sailor, points out that a system of this order of magnitude requires much more than just mechanical parts. "Today a 2.3-megawatt turbine like this contains many levels of processors and electronics. It might look simple and easy to understand, but the closer you look at it, the more complicated it becomes." This applies all the more so to the top-of-the-range, 3.6-megawatt turbine. On our way to inspect this giant, we cross the storage area. As if in a child's toy box, all the components for the wind turbines are neatly stacked, awaiting installation. On the left are the huge steel nose caps, which will later adorn the turbine housing, in the middle the machine nacelles, and on the right the gigantic rotor hubs, each of which weighs around 35 tons. The blades from Aalborg are delivered straight to the site of installation. The various components for the towers, which are up to 120 meters in height, come from external suppliers in Denmark, Germany, the U.S. and Korea, depending on the wind farm's location.

Once in the hall, the white nacelle of the 3.6-megawatt turbine is unmistakable. Unlike its smaller relative, it is angular in shape. Measuring some 13 meters in length, four meters in width, and four meters in height, it is also bigger. The innards of the turbine are reached via a ladder. Various systems are spread over two stories, as if it were a small house. "Everything's bigger in this turbine," says Stiesdal with typical understatement. "But we're already working on even bigger ones. In fact, before long the rotor blades on our turbines may be longer than 60 meters." *Sebastian Webel*