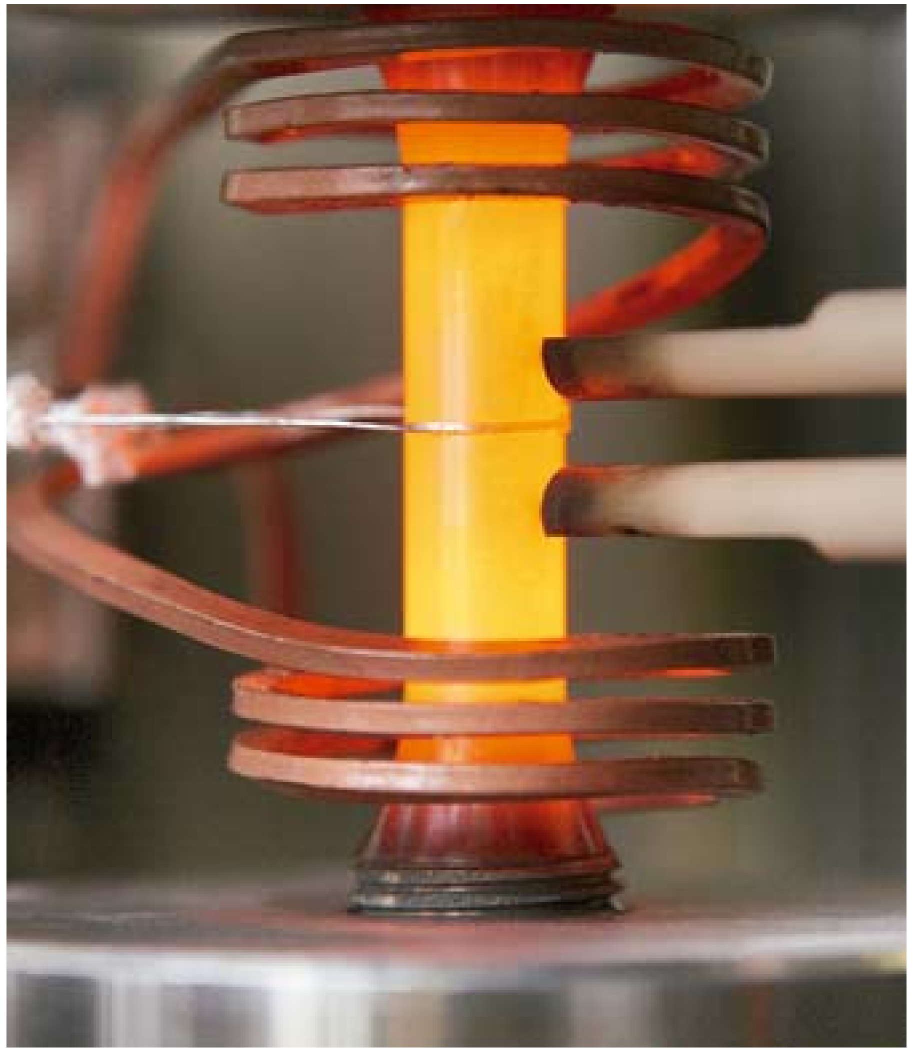
Preparing for a Fiery Future

To achieve 50 percent efficiency and cut environmental impact, tomorrow's coal-fired power plants will use hotter steam. Testing turbine materials at hellish temperatures and centrifugal forces is part of the picture.



In a materials lab at Siemens' Fossil Power Generation Division in Mülheim an der Ruhr, Germany, metals die a slow death. Weights drag relentlessly at rods made of new alloys, while material fatigue and corrosion race at time-lapse speeds. Materials specialist Hans Hanswillemenke indicates a test behind a plexiglass sheet, where a pencil-thin metal rod clamped at each end glows a dull red. "That will break in a few days," he says. The experiment is relentless — and that's as it should be. After all, it's better if the metals fail in the lab than later, after they've been forged to form steam turbine shafts a meter or more in diameter and are enduring enormous centrifugal forces and temperatures of 700 degrees Celsius.

This metallic martyrdom is helping engineers prepare for the coal-fired power station of the future, which should be much more efficient and use as little fuel as possible in order to keep atmospheric emissions to a minimum. The need for action is urgent. On average, the world's coal-fired power plants consume 480 grams of coal to produce a kilowatt-hour of electricity. In doing so, they release between 1,000 and 1,200 grams of CO_2 into the air, or some eight billion tons a year. One of the most efficient coal-fired power plants in the world, the Block Waigaoqiao III in China, for which Siemens delivered two 1,000-megawatt turbines, burns only 320 grams of coal per kilowatt-hour, and thus emits only 761 grams of CO_2.

In a project led by Trianel Power-Projektgesellschaft, Siemens is building a comparable power plant for a consortium of 27 city utilities on a site at Lünen in northern Germany. The plant is scheduled to go into operation by 2012. However, with an efficiency of around 46 percent, these power plants are not good enough for Siemens Fossil Power Generation Division and the power plant operators. Their aim is to achieve 50 percent efficiency by 2015. Such an efficient power plant would consume only 288 grams of coal per kilowatt-hour, and thus produce only 669 grams of CO_2. Such a step would have significant consequences because each percentage point in improved efficiency — if applied to all coal burning power plants — translates into 260 million tons less CO_2 each year .

Ordeal by Fire. To achieve this ambitious goal, turbine materials will have to be able to survive extraordinary stresses. A glance at any physics book reveals the principle behind the heat engine — and that's exactly what a fossil-fuel-fired power plant is. It turns out that the useful energy produced by such plants is determined by the difference between the temperature source and the temperature sink. In other words, the steam entering the turbine should be as hot as possible and the steam leaving it as cool as possible. The blades then have the maximum available energy to convert into rotational energy, which is fed into the generator. As a result, the steam temperature needs to be increased from the level currently found in the best power plants (around 600 degrees Celsius) to 700 degrees Celsius — the temperature to which the metals are being subjected in the Mülheim laboratory. Only then will it become possible to achieve 50 percent efficiency. "Temperature is the key factor," says Ernst-Wilhelm Pfitzinger, the project manager in charge of developing the 700-degree turbine in Mülheim. But as Werner-Holger Heine, head of Product Line Management for Steam Turbines, is only too aware, the situation is complex. For a steam turbine, customers demand a working lifetime of at least 200,000 hours, he says. That's equivalent to a service life of more than 25 years. "We are confident that we can achieve this goal with 700 degrees," he says. "However, we still have to prove it."

In a Siemens factory in Mülheim an der Ruhr, scientists prepare turbine materials for ultra-high temperatures (left). Gigantic steam turbines will one day have to withstand over 700 degrees Celsius.

There are good practical reasons why designers are determined to leap from 600 to 700 degrees and 285 to 350 bar pressure. "Above 600 degrees, we have to use new materials anyway; traditional metals just wouldn't be able to withstand the temperatures," says Pfitzinger. "And we want to make as much use as possible of these materials, so we're going to go straight to 700 degrees." The higher pressure is necessary to optimize efficiency. The objective is to increase efficiency by four percentage points over that achieved at 600 degrees, and to cut coal consumption by six to seven percent, thus also reducing CO_2 emissions.

Exotic Mix. By new materials, Pfitzinger means nickel alloys, which are a sophisticated mix of high-strength metals like nickel and chromium, with only a pinch of iron. Such alloys are expensive. After processing — a painstaking process — they cost five to ten times as much as the chromium steel used today. That's not exactly peanuts in a turbine requiring some 200 tons of the metal alloys.

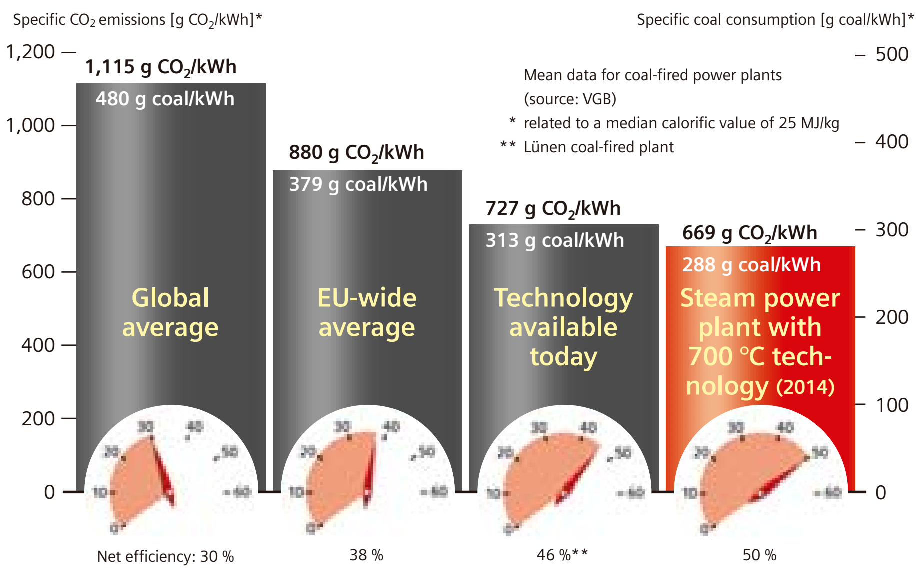
To reduce material costs, the turbine need not be made entirely of nickel alloy, but instead can be composed of different alloys depending on the temperatures different areas are subjected to. For example, the inner and outer housings are to be thermally separated by a layer of cooler steam, so that normal steel will be adequate for the outside, which will have to withstand a temperature of 550 degrees. In addition, the meter-thick shaft can be forged in several pieces, with the nickel alloy only being employed in the hottest area.

But even this concept creates new challenges, including how to deal with different heat expansion coefficients. In addition, the necessary casting, forging, milling, and testing methods for manufacturing and processing the heat-resistant material have yet to be developed — at least for steam turbine components weighing several tons.

The production process used for gas turbines, where the use of nickel alloys has long been standard, doesn't help here. "We can't simply copy the process," says Pfitzinger. Gas turbines are delicate in comparison to coal turbines and can be built using completely different techniques. What's more, although at over 1,400 degrees their temperatures are very high, their pressures are comparatively low, at around 20 bar.

To jump from 600 to 700 degrees is no small achievement. In fact, no individual manufacturer could handle this task alone — which is why producers, plant manufacturers, and energy suppliers have formed a number of consortia, within which they are developing the 700-degree technology. These include:

CO_2 Emissions in Coal-Fired Power Plants



As efficiency increases, coal consumption drops and carbon dioxide emissions decline.

→ COMTES700. A "Component Test Facility for a 700°C Power Plant" is supported by the European Union. The European Association of Power and Heat Generators (VGB Power Tech) is coordinating a dozen international project partners, including Siemens. Since 2005, the 30-year-old F Block at the E.ON coal-fired Scholven power plant in Gelsenkirchen, Germany has been in operation using components that could one day be used in a 700-degree power plant. These include a test boiler, main steam lines, and other components currently operating at temperatures of 700 degrees Celsius, including a nickel alloy turbine valve made by Siemens. The old turbine is not affected by any of this. After passing through the test section, the steam is cooled to 520 degrees Celsius to avoid potential damage. Says Siemens turbine expert Dr. Holger Kirchner, "A recent inspection of the valve was very positive." The test is due to continue until 2009.

The first 700-degree power plant will cost around €1 billion, but will cut CO_2 emissions significantly.

→ NRWPP700. The "North Rhine-Westphalia 700°C Power Plant" is a pre-engineering study by ten European energy suppliers, in which nothing is being built or tested. Instead, the focus is on technical design concepts for the boiler, pipe work, and other components of a 500-megawatt power plant. The feasibility of their transfer to commercial coal and lignite-fired plants of the 1,000-megawatt-class is also being evaluated.

→ 50plus. Based on the results of preliminary projects, E.ON wants to put the first "real" 700-degree power plant into operation in Wilhelmshaven in 2014. To achieve at least 50 percent efficiency, E.ON plans to preheat the combustion air and use seawater, which cools more effectively, for cooling — hence the location of the plant in a coastal city. Construction of the 500-megawatt block is expected to start in 2010.

But 700-degree power plants are not yet an economical proposition. Today, a power plant in the 600-degree Celsius/800-megawatt class costs over €1,700 per kilowatt. 50plus will cost €1 billion, which will drive costs up to €2,000 per installed kilowatt. 50plus has therefore been essentially designed as a demonstration plant for future series-produced power stations. "When things get uneconomical, customers are no longer interested," says Heine. But considering the increasing costs of raw materials and CO_2 levies, savings will be possible due to the plant's improved efficiency, even allowing for the 10 to 15 percent higher costs of a series-produced 700-degree power plant.

Competing Concepts. The new 700° technology will compete with other technologies, such as IGCC power plants, in which coal and other fuels, such as oil and asphalt, are converted into syngas and fed into a gas and steam-turbine power plant (*Pictures of the Future*, Spring 2007, p.91). "Today, with modern gas turbines, we achieve efficiency levels of up to 46 percent," says Lothar Balling, head of the Steam Power Plants and Emerging Plant Solutions unit at Siemens' Fossil Power Generation Division in Erlangen. "By 2020 improvements will enable efficiencies of up to 51 percent without CO_2 separation with our H-class gas turbines."

Several IGCC plants are already in operation, including coal gasification plants in refineries, which produce hydrogen-rich syngas for chemical processes. Economically speaking, the IGCC power plants that Siemens is developing for power generation purposes are still at a disadvantage compared with conventional coal-fired power plants. IGCC can, however, become really competitive if CO_2 is made to play an economic role, for example through the introduction of a CO_2 tax or use of the gas in old oil fields to further improve their yield. The technology of CO_2 separation from syngas downstream of a gasification unit already exists and is used in the petrochemicals industry. This technology allows CO_2 emissions to be reduced by over 85 percent to under 100 grams per kilowatt-hour. Together with E.ON, Siemens is also developing a process for the separation of CO_2 downstream from conventional power plants. In the future, it will be possible to fit existing and new power plants with this technology. The development of more efficient coal-fired power plants could thus become an exciting race between different concepts. In any event, Siemens will be part of it.

And what does the future hold in store? "That depends not only on technological developments, but also on political decisions and legislation," says Balling. "That's because the development and realization of innovative CO_2 concepts need support."

Twice as big as an Airbus A380 turbine, the steam-turbine rotor being manufactured in Siemens' Mülheim an der Ruhr factory is the biggest and heaviest in the world.

The problem of naming such power plants will certainly be easier than developing their technologies. Because water converts directly into steam at pressures of over 221 bar, designers characterized modern power plants as "over-critical" in line with this physical phenomenon. That not only sounds unnecessarily threatening; it also requires some mental acrobatics in terms of finding names.

At temperatures from 600 to 620 degrees Celsius engineers refer to "ultra-supercritical." For the 700-degree class, there is no designation yet — let alone for anything beyond that. But Heine isn't interested in the next name combination of "hyper," "ultra" or "super." "At present, plants with temperatures of 760 or even 800 degrees are in the realm of fantasy," he says. *Bernd Müller*

Turbines that Dwarf other Engines

You might think that the new Airbus A380 is relatively large. Take its engine, for example, which has a rotor diameter of almost three meters and is 4.5 meters in length, making it the biggest in the world. But at Siemens' steam turbine and generator factory in Mülheim an der Ruhr, you would scarcely notice the mighty A380 engines. Housings belonging to steam turbines twice that size are awaiting assembly here. Close by is a giant wheel that might look like the compressor blades of an airplane engine but is disproportionately larger. Covering 30 square meters, the turbine blade has a diameter of 6.7 meters. At 320 tons total weight, the complete rotor is the largest and heaviest in the world (picture above on this page). The finished steam-turbine set is destined for power generation in a European pressurized water reactor (EPR) that is being built by Areva NP, a company in which Siemens has a minority share of 34 percent, in Olkiluoto, Finland. The project consortium also includes the Siemens Energy Fossil Division (for conventional plant components). The complete steam-turbine set tips the scales at over 5,000 tons and boasts a world-record output of 1,600 megawatts. Demands on heat resistance, however, are not as high as in 600-degree or 700-degree power plants. That's because at temperatures of no more than 300 degrees Celsius the saturated steam from an EPR is much cooler than the steam in a coal-fired power plant, while, at 70 bar, the pressure is much lower too. However, the centrifugal force at the 340 kg blades reaches around 1,500 tons at 1,500 rpm. Combined-cycle plants, in which the exhaust heat from a gas turbine generates steam for several other turbines, are not far behind. Siemens is currently building the largest combined-cycle power plant in the world in Irsching in Upper Bavaria. With an efficiency of over 60 percent, it is also the most efficient (*Pictures of the Future*, Fall 2007, p. 54). The steam in the plant's low-pressure turbine cools down to under 30 degrees Celsius and in doing so takes up such a large volume that the last two rows of blades, which are made of titanium, need to have a cross-sectional area of 16 square meters each (above). That too is a world record for so-called high-speed steam turbine sets, which turn at the remarkable speed of 3,000 rpm.