A coal gasification plant in Vresová, Czech Republic. The resulting synthesis gas can be used to produce fuel, chemicals and electricity — including CO_2-free power generation.

Zero-Emission Power Plants

The zero-emission power plant is no longer a fantasy. Filters are becoming increasingly sophisticated, removing dust and other harmful substances from exhaust gases. And in the future, new power generation technologies should prevent emissions of carbon dioxide getting into the atmosphere. Enhanced measurement methods and more efficient power distribution are also helping to ensure cleaner air.

Back in the 19th century, towering factory chimneys belching black smoke may have been a popular motif for artists seeking to capture the dynamism of the industrial revolution. Today, however, smokestacks are indelibly associated with a dirty age of pollution and increasingly stringent controls. In the process, governments have tended to allow the state of technology to dictate what limits can be set.

A good example is dust. As a rule, today's power plants are equipped not only with fabric filters, but also with electrostatic filters the size of small apartment buildings. Connected in series, several such units can capture more than 99 percent of the dust produced. Electrostatic filters have wires running along the middle of steel channels. When a voltage of 40 to 100 kilovolts is applied between the wire and the wall of the channel, a plasma of electrons and positively charged ions is generated. The former give the dust particles a negative charge, which deflects them to the wall, to which they adhere. The filter is shaken from time to time, causing the dust to fall below, where it is loaded into rail cars and removed for disposal.

State-of-the-art filters are produced by Wheelabrator, a Siemens company since October 2005. Based in Pittsburgh, Pennsylvania, Wheelabrator has over 90 years of experience in filtering exhaust emissions. It supplies systems to power plants, paper mills, cement factories and other industrial facilities. Wheelabrator also manufactures equipment for processing harmful substances other than dust, such as nitrogen oxides. These systems utilize a process called "selective catalytic reduction," whereby urea is used to convert nitrogen oxides into harmless nitrogen. In the 1990s, Siemens developed the SINOx catalyst, which employs this process to clean exhaust gases from district heating plants and reduce nitrogen oxides emitted by diesel trucks.

Yet future limits on dust emissions will be too demanding for today's filter technology. That's why Dr. Werner Hartmann of Siemens Corporate Technology (CT) in Erlangen has been working to refine the plasma process, with the aim of capturing an additional 20 percent of the minuscule amount of dust not screened by today's filters. Ultra-short pulses of high voltage are superimposed on the direct voltage every few milliseconds, which improves filtering while also radically boosting efficiency. "Energy consumption is cut by half," says Hartmann in the wake of successful pilot tests at steel mills and power plants. And that's an important factor because a large power plant's filters can consume as much as a megawatt of power.

The plasma also can capture other harmful substances — a fact that did not go unnoticed by Werner von Siemens exactly 150 years ago. Back in 1857, the Siemens founder invented the first device to use a high voltage to produce ozone for the purification of drinking water. A highly reactive molecule comprising three oxygen atoms, ozone readily oxidizes harmful substances such as nitrogen monoxide, sulfur dioxide and mercury to produce compounds that can then be more easily separated out. The new plasma processes from Siemens offer a high level of efficiency at a lower cost than previous methods. "The power plant sector is very conservative; anything new is scrutinized with a critical eye," says Dr. Thomas Hammer of CT, who is nonetheless confident that Siemens' plasma technology will establish itself, not least because future legislation will introduce increasingly stringent emission controls.

Environmental legislation calls for using increasingly sophisticated measurement methods. Today, operators of power plants, waste-incineration plants and other combustion-based facilities must take exact readings and keep a full record of them. For common pollutants such as sulfur dioxide, nitrogen oxides and dust, measurements are taken as often as once every 200 seconds. At waste-incineration plants, substances such as mercury and dioxins also need to be monitored for daily average values or subjected to spot checks.

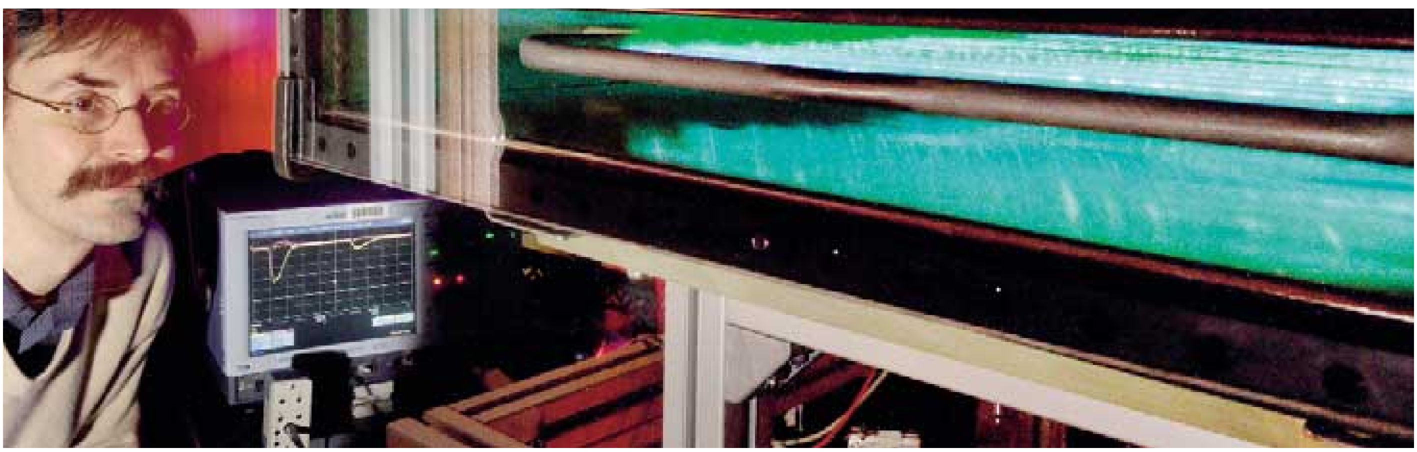
Cutting Costs. Siemens has developed a gas analysis device that measures the amount of infrared light absorbed by a power plant's exhaust gases and, on this basis, calculates pollutant levels in the gases. The device can measure up to three substances at once — usually carbon monoxide, sulfur dioxide and/or nitrogen oxides — plus oxygen as a reference value. The principle behind the device was first developed several decades ago, explains Dr. Michael Markus, product manager for exhaust gas measurement systems at Siemens Automation and Drives (A&D) in Karlsruhe. "The real innovation story behind our device is its constantly improving cost-performance ratio," he explains. For example, the Ultramat 23, which enables A&D to hold about a quarter of today's industrial gas chromatography market, only costs between 5,000 and 11,500 euros depending on specifications.

A&D has also begun offering measurement systems for waste-incineration plants. Alongside a device for analyzing the infrared absorption of exhaust gas constituents, the product line also includes systems for measuring hydrocarbons and oxygen, as well as a device that shines a laser through a chimney to measure levels of moisture, hydrogen chloride and ammonia. Markus says the use of separate devices for different pollutants will soon predominate, instead of all-in-one systems by rival manufacturers. "In addition to being less costly, it's also a safer investment in view of steadily tightening limits. And it won't put plant operation at risk if an individual device fails."

Meanwhile, Siemens has broken new ground in gas chromatography. Such devices can separate gaseous mixtures within a matter of minutes and measure their individual constituents with high precision. Long used to monitor and control processes in the chemicals and petrochemicals industries, the use of gas chromatography to measure emissions is just getting started, as the devices are still very expensive. The breakthrough here for Siemens came with a legislative initiative in the U.S. calling for measuring emissions produced by the oil industry in Texas. As a result, 90 percent of the 380 measuring points around Houston were fitted with the company's gas chromatographs in 2006 (*Pictures of the Future*, Fall 2006, p. 37).

While much has been done to cut pollutants in exhaust gases, a solution is still needed for the problem of greenhouse gases such as carbon dioxide. In addition to measures for boosting efficiency, saving energy and increasing the use of renewable energy sources, there is a pressing need for technologies that can dispose of carbon dioxide from fossil-fuel power plants.

However, the vision of a totally CO_2-free power plant is no longer a pipe dream. RWE, for example, plans to build a 450-megawatt power plant with zero CO_2 emissions by 2014. And the U.S. Department of Energy has scheduled construction of FutureGen, to be completed by around 2013. This 275-megawatt



Using ultra-short, high voltage pulses, Siemens researchers led by Werner Hartmann can remove the last remaining particles of dust from exhaust gases.

Efficient power transmission. Light-triggered thyristors (left) convert alternating current into direct current. Underground gas-insulated lines (right) are well suited for use in urban areas.

plant will not only produce electricity and hydrogen but also sequester its CO_2 emissions underground. A number of European countries are also working on concepts to store CO_2 in depleted salt domes or to pump it into oil and gas fields, including those under the North Sea. This would also increase pressure and thus improve yields.

But before CO_2 can be sequestered, it must be separated from exhaust gas. An efficient means is the "oxyfuel" process, where coal or natural gas is burned using pure oxygen (*Pictures of the Future*, Spring 2004, p. 49). This prevents large amounts of nitrogen, which makes up three quarters of the atmosphere's volume, from being needlessly added to the process and then forming nitrogen oxides during combustion. With the oxyfuel method, the exhaust gas is largely carbon dioxide and steam. When the latter is condensed by cooling, the CO_2 is left behind and can be pumped underground. Today, such oxyfuel power plants exist only on paper or in labs, but two 30-megawatt pilot facilities are set to begin operation in 2008, one in France and one in the German state of Brandenburg.

Burning Everything. Integrated Gasification Combined Cycle (IGCC) plants are already in operation. Here, a fuel such as coal is converted, with the addition of oxygen, into synthesis gas — mainly carbon monoxide and hydrogen. This gas is purified, processed and burnt in a gas turbine to generate electricity. The hot exhaust gas is used to generate steam. This drives a steam turbine, which also produces power.

In an IGCC plant, CO_2 can be separated during the synthesis gas preparation stage. However, separation compression and storage of the gas reduces the efficiency by about 12 percentage points. The large, CO_2-free power plant to be built by RWE will operate using this process. As true omnivores, IGCC plants can be fed biomass or wastes from the chemical industry such as asphalt and even car tires. They also use refinery residues as fuel to generate both power and heat or hydrogen for chemical processes.

That Siemens has high hopes for the IGCC process was clear in May 2006, when the company acquired the coal gasification and syngas business of the Swiss-based Sustec Group. The Siemens fuel gasifier, which can burn not only coal but also biomass, petroleum coke and refinery residues, offers high efficiency and long service life, and is easy to start up and control. The syngas produced by gasification with oxygen and steam can be used either in IGCC plants or in facilities for producing synthetic fuels or chemicals formerly derived from crude oil. In January 2007, Siemens won a major order from China to supply two 500-megawatt entrained-flow gasifiers capable of producing 830,000 tons of dimethyl ether a year.

At Siemens Power Generation, Dr. Georg Rosenbauer is responsible for business development relevant to climate change. Rosenbauer has studied the technical and economic feasibility of various CO_2 separation processes. He says it should be possible to push CO_2 avoid-

Trading Emissions & Cutting Costs

On January 1, 2005, the EU launched its emissions trading plan (*Pictures of the Future*, Spring 2004, p. 47). Since then, installations with high CO_2 emissions, such as power plants, steel mills and mineral processing facilities, may only produce as much CO_2 as is allocated in their certificates. If their emissions are higher, they must purchase additional certificates. Conversely, any plant that cuts CO_2 emissions below its allowance can sell its remaining credits. Once a year, about 1,850 companies in Germany must report their CO_2 emissions to the German Emissions Trading Authority (DEHSt) at the Federal Environment Agency. This is done via the Internet, with a document management system developed by Siemens IT Solutions and Services together with partners. In a multistage process, the emissions data from the plant operator is first collected online and then checked by an expert assessor. The report is then sent, complete with an electronic signature, to state authorities. After further checks, the latter forward the report, via a virtual mail room, to the DEHSt.

Whereas the report itself is obligatory, operators are at liberty to decide how best to manage and document their emissions. One option is Simeos, an emissions management software package from Siemens Industrial Solutions and Services in Aachen. Simeos combines data from measuring points, energy data management systems, financial accounting, and other company processes into a CO_2 account that helps to forecast and optimize emissions trading. The software also clearly classifies the flow of energy and materials according to specific products and different forms of energy, providing rapid and easy identification of potential savings in energy costs.

ance costs below 30 euros per ton by using the IGCC process with CO_2 separation before combustion. Similar figures are available for alternative methods, although these are uncertain from today's perspective. While this is still far from the current price of around 16 euros per ton of CO_2 in the emissions trading plan, the advent of stricter emissions targets, and thus higher avoidance costs, should drive the CO_2 price back above 30 euros in the long term, making it economically viable to separate and store carbon dioxide. "Until then, other incentives will be needed to make this technology marketable," says Rosenbauer.

Second Wind for DC. The power grid also has a key role to play in cutting emissions. To minimize energy loss, high-voltage transmission lines for alternating current shouldn't be longer than a few hundred kilometers. That might be feasible in Germany, but not in a vast country like China. To connect the huge hydroelectric plants in the interior with cities on the coast, high-voltage direct-current (HVDC) transmission is a better option (*Pictures of the Future*, Spring 2006, p. 20).

To date, Siemens has built four large HVDC transmission links in China, each carrying up to 2,000–3,000 megawatts with a minimal loss of power. The technology could also be interesting for Germany. "HVDC transmission links make sense for offshore wind farms more than 50 kilometers off the coast," says Dr. Hartmut Huang, Director of HVDC and FACTS Technologies at Siemens Power Transmission and Distribution in Erlangen.

FACTS (Flexible Alternating Current Transmission Systems) have converter valves that optimize current-flow stability. This means that high-voltage overhead lines with a nominal rating of 400 kilovolts can be operated close to the maximum permitted limit of 420 kilovolts, which cuts transmission losses. Gas insulated lines (GILs) can handle even higher voltages. Made of aluminum and copper enclosed in a rigid metal sheath containing an insulating mixture of nitrogen and sulfur hexafluoride (SF_6), GILs are suitable for carrying DC and AC transmitted at up to 550 kilovolts. They can be laid overhead or underground, making them ideal for urban use.

Back in 2002 Siemens built a 550-kilovolt GIL in Bangkok, followed by a 220-kilovolt line in Cairo in 2004. Another advantage of GILs is that the metal sheath shields almost all the electromagnetic radiation emanating from the lines, so they can be used in densely populated metropolitan areas. "With gas-insulated lines," Huang explains, "you don't have any electrosmog." ■ *Bernd Müller*