Knowing what happens inside a turbine

Generating electricity from carbon-neutral fuels – is it a feasible alternative?

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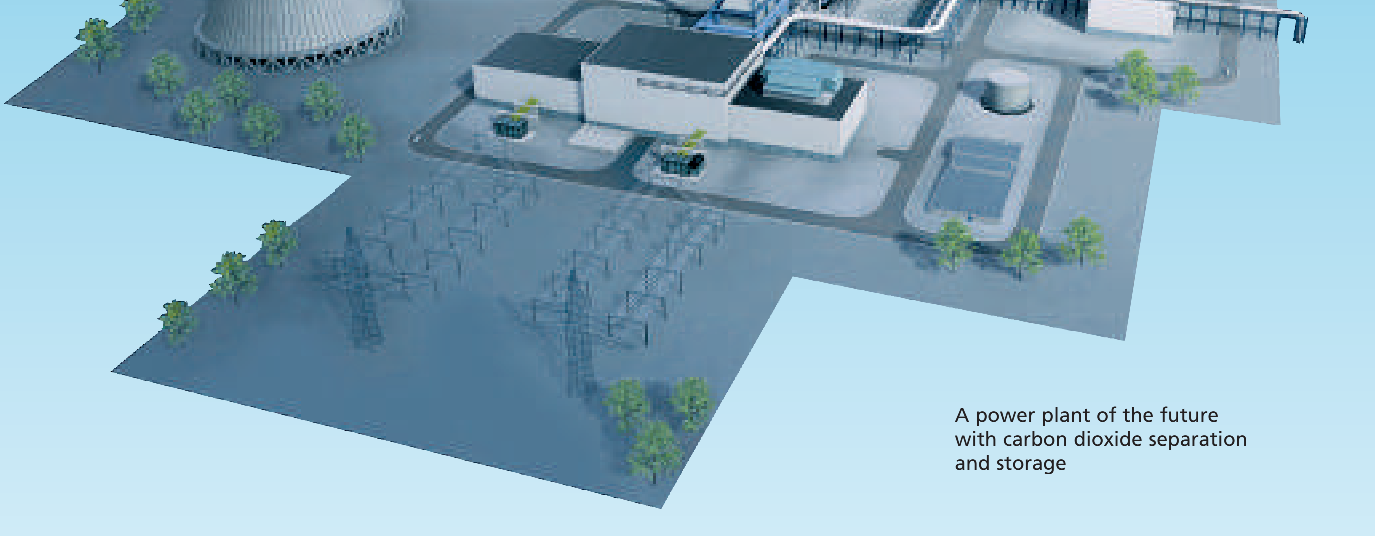
Hawaii, an island paradise in the Pacific, dream destination of countless holiday-makers around the world. But not many people know that Hawaii is also home to the Mauna Loa observatory. Located 3,500 metres above sea level, this is the world's oldest testing station for atmospheric carbon dioxide. The measurement curve produced by the station provides shocking evidence of global pollution: between the beginnings of industrialisation in 1800 and today, the level of CO_2 in our atmosphere has risen by almost 40 percent. As science has now proved, the concentration of CO_2 remained at a consistently low level in the 1,000 years before that. Currently, the annual amount of CO_2 emissions caused by humans is equal to around one percent of the total amount of CO_2 in the atmosphere. If these emissions are not reduced, the atmospheric CO_2 levels will rise by at least another 30 percent by 2050. The release of greenhouse gases, such as carbon dioxide, is regarded as the main cause of global warming; it is vital that our environmental agenda focuses on effective ways to lower these emissions.

Electricity generation in a modern power plant. This combined-cycle power plant with an integrated coal gasification system developed by Siemens is located in Puertollano, Spain.

In Germany, around 40 percent of the primary energy produced in power plants is used for electricity. If the country's ever-growing demand for electricity is to be met in an efficient yet environmentally sound manner, the CO_2 emissions caused by power plants will have to be reduced. Technologies based on renewable energies, such as wind power, hydropower and solar power, have matured into viable alternatives and are already being used in many countries around the world. DLR's research into concentrated solar power has made a significant contribution in this field. However, renewable energies cannot cover the full range of our energy needs; the amount of generated renewable energy frequently depends on weather conditions, and only specific supply conditions can be met. As a result, the generation of electricity will continue to rely on conventional technologies for some time to come. The hot topic in industrial research at the moment is alternative fuels, which are regarded as a very promising approach to sustainable energy production.

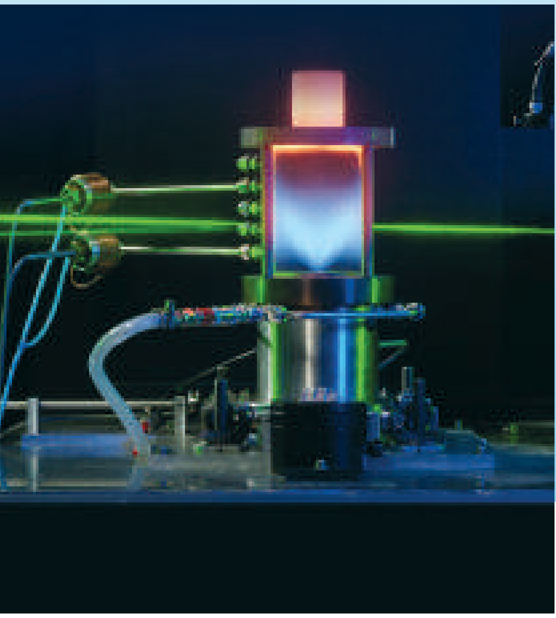
The alternative fuels being considered are "carbon neutral", i.e. they release no more carbon dioxide during their combustion than they have absorbed over their lifespan. Solid fuels can be used to power steam turbines directly, or they can be chemically converted into gaseous fuels (syngases) or liquid fuels – the latter can also be used directly (motor fuel). Alternative fuel types include solid fuels such as wood or biogenic waste products, liquid fuels such as bioalcohol obtained from BTL processes (biomass-to-liquid), and gaseous fuels such as biogenic methane or syngas. Methane can be obtained from fermenting plant matter, syngas from the gasification of biomass, and hydrogen from water using a CO_2-free solar power process.

Through the process of gasification, virtually any type of fuel (wood, biogenic waste products, coal, even wet matter) can be turned into syngas. The product gas is a combustible gas mixture that largely consists of hydrogen and carbon monoxide (CO). Alongside syngases' traditional uses in chemical processing, they can also be employed for generating electricity. The gasification technology is particularly interesting when processing fossil or wet substances, because the carbon dioxide can be separated out before the combustion stage. This creates a gas mixture that is very rich in hydrogen. If this product gas is used e.g. in a power-generating gas turbine, the high degree of fuel flexibility is coupled with the high efficiency of the gas/ steam turbine cycle – while



A power plant of the future with carbon dioxide separation and storage

Laser spectroscopic measurements on a model combustion chamber of a gas turbine



Visualisation of a flame fed from syngas.

Right: Characterising the ignition behaviour of syngas in a shock wave tube

simultaneously reducing carbon dioxide emissions. Research is currently focusing on the modification of gas turbines to suit syngas, and on optimising the gasification cycle.

One way to reduce CO_2 emissions in the medium term is to separate out the carbon dioxide released during combustion and store it away permanently in suitable repositories. This separation, or sequestration, is part of the CSS cycle (carbon dioxide capture and storage) and enables low-carbon use of fossil fuels such as coal. However, a considerable amount of energy is needed to make this technology work. Because of this, there have been renewed efforts to further develop and optimise the existing technologies.

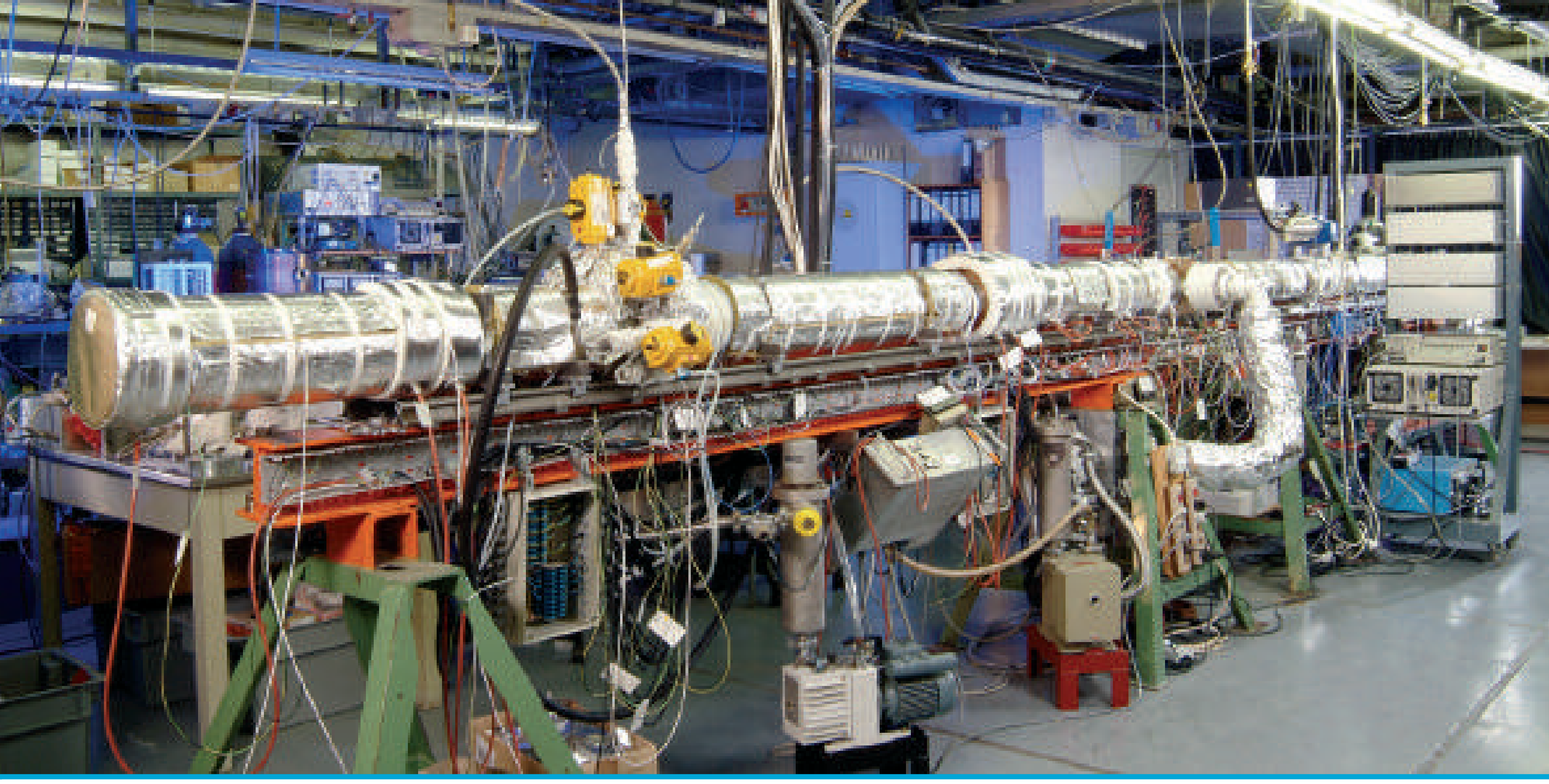
There are three main carbon capturing procedures:

In the "post-combustion" process, in which the carbon dioxide contained in the exhaust gas is separated out after the combustion stage. The advantage of this process is that practically every existing power plant can be retrofitted with the necessary technology; the disadvantage is that it is very expensive.

In the "Oxy-fuel" process, the fuel is combusted in an atmosphere of pure oxygen instead of normal air. This creates a very clean mixture of CO_2 and water vapour with virtually no nitrogen oxides. The water vapour condenses very easily, leaving behind pure CO_2. A pilot plant with a power output of 30 megawatts $_{(thermal)}$ is planned to commence operation at the Schwarze Pumpe industrial park in late 2008. The disadvantage of the Oxy-fuel procedure is that the oxygen needs to be obtained through the separation of air, which in itself requires a lot of energy. More efficient methods – for example, separating air through semi-permeable membranes – are currently in development.

In the "pre-combustion" process, the CO_2 is sequestrated immediately after gasification, i.e. before the product gas is used for combustion. As the volume of the product gas is significantly lower than that of the exhaust gas, the separation cycle is also cheaper here than for post-combustion.

DLR's Institute of Combustion Technology addresses experimental and numerical problems pertaining to the use of alternative fuels such as biogenic gasification gases, or syngases with high concentrations of hydrogen. Pollutant formation and combustion stability are of particular interest, as detailed knowledge of processes such as autoignition, heat release and flame extinction is vital to the use of alternative fuels in modern gas turbines. The institute is therefore conducting systematic validation experiments involving many different parameters (including air to fuel ratio, preheat temperature, fuel



gas composition, pressure). With the experimental data gained, reaction mechanisms for syngases and biogenic gas mixtures can be validated and optimised.

This facilitates a reliable and comprehensive numerical simulation of real-world combustion systems with complex geometries, with special consideration given to the interplay between chemistry and turbulent flows.

Such research, which is largely conducted for industrial clients and EU projects, permits better and more reliable operating predictions for combustors and gas turbines, and provides useful findings for the design of low-emission, reliable combustion chambers that use alternative fuels. As part of one EU project, for example, the institute investigated how low caloric syngases with high hydrogen concentrations can be used in modern gas turbines. The institute created a validated reaction mechanism designed for commercial CFD codes that describes syngas combustion at high temperatures and pressure levels. Today's gas turbines are not yet able to combust undiluted hydrogen. The institute is presently collaborating with industrial partners to develop innovative combustion concepts that can then be adopted by gas turbine manufacturers.

The use of Oxy-fuel combustion in gas turbines is of particular interest, as many of the cycles required by the other CO_2 capture methods are eliminated. To date, there has been very little research in this area. DLR is currently conducting fundamental research to determine whether it is feasible and viable to operate gas turbines using the Oxy-fuel cycle.

The energy supply of the future will rely on a mixture of energy sources. The research activities of the DLR's Institute of Combustion Technology are directed towards a reliable energy and electricity generation concept that is based on a multiplicity of deployable fuels, and utilises process cycles with reduced or no CO_2 emissions. With any luck, these efforts may soon be reflected in the measurements of the Mauna Loa observatory in Hawaii…

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