RWE Power

power:perspectives 2005

Innovations to prevent climate change
in fossil-fired power plant engineering

Preventive climate protection at RWE Power: Innovations in practical applications

Greater efficiency in power plants and in the deployment of plant and equipment, sparing use of resources – today already, RWE Power is harmonizing economic efficiency, security of supplies and environmental compatibility. The point of the photos in this publication is to document this with examples and to spotlight components used by the Company in various areas and closely related to climate and environmental protection.

Cover photo

Environmental protection, thanks to improved power generation technology: The lignite-fired power station with optimized plant engineering (BoA) at Niederaussem has an efficiency of 43.2%. It is the most modern plant of its kind worldwide. With the same power output, BoA emits up to three million tonnes of carbon dioxide less per year than old lignite-based systems. The photo shows two staffers examining one of the two flue gas ducts between the desulphurization system and the cooling tower during an inspection.

Photo: Klaus Görgen

At a glance

power:perspectives – Join us and take a look ahead

Opportunities, forecasts, visions. What is within easy reach and what is not. A company like RWE Power must keep an eye on any ball in play if it is to secure a successful future. These power:perspectives are a sort of radar screen designed to show you where and how work is being done today on important energy issues. The focus of this première edition is on innovations in fossil-fired power plant engineering to prevent climate change, a subject of special concern not only for the experts at RWE Power. An army of specialists at component suppliers' as well as scientists at research institutes and universities are working on ever better technological solutions for merging the concerns of secure energy supplies with those of the environment. We have asked some of these specialists to contribute to this publication.

Dear Readers,

With the exception of the British power plants, all of the RWE Group's upstream activities have been combined under the RWE Power banner since 1 October 2003. We now generate electricity and extract coal, gas and oil. This bundling makes RWE Power no. 2 in Europe and the market leader in Germany when it comes to providing energy and generating electricity.

We must face ever-changing underlying conditions

More systematically than ever before, RWE's core business is geared to the needs of the market and our customers. Being a company with a full bandwidth of energy sources at its disposal and able to reap synergies, RWE can act much more flexibly and successfully on the energy market. On a market that has changed dramatically in recent years and will go on changing. A market that expects operators to display a great willingness to embrace changes and innovations. RWE Power, too, must constantly face new underlying conditions. Thanks to comprehensive cost-cutting and efficiency-boosting programmes, we have created a sound basis for our economic success.

It is just as important to keep an eye on the future. These power:perspectives are intended to make a contribution here. With this publication, we are turning the spotlight on what we regard as an especially important subject: "Innovations to prevent climate change in fossil-fired power plant engineering". In response to these complex terms of reference, our thinking, research and planning move in many directions. In collaboration with renowned specialist authors, for whose support we wish to convey our sincere thanks, we have produced an overview of what is happening in this field and how the various activities are to be assessed. An outline is given of some projects and schemes where it is not even clear as yet whether and by whom they will be implemented. For us, as an enterprise, however, it is indispensable that we actively support such "perspectives". This is the only way for us to join together and find answers to major challenges in the future.

For us, the focus is on both the economics and the ecology

RWE Power is actively engaged in numerous research projects at both German and European level, cooperating with partners from science and industry. For us, this investment is aimed, on the one hand, at doing justice to our market position and, on the other, at underpinning our competitive footprint. In this respect, our focus is on both the economics and the ecology.

These power:perspectives also offer an overview of the power generation market in Germany and in an extended European Union. After all, we cannot take decisions about a future course of action that are detached from the political and economic environment. And much is happening here. We need only think of the consequences for the energy sector of the accession of 10 countries to the EU. Or of the increasing number of energy- and environmental-policy stipulations coming from Brussels that member states must implement. In Germany, we are having to cope with legislative processes that will have a serious impact on both our day-to-day business and on our corporate strategy. By way of example, we may cite the country's Energy Industry Act (EnWG), the Renewable Energy Sources Act (EEG) or the trade in emissions. This is where the scene has been, and is being set for the energy supply in the years and decades to come.

On these issues as well, power:perspectives will provide an overview. Last but not least, we wish in all brevity to present our still-fledgling company in this formation – RWE Power. "With all our power" is our self-set goal with which we are tackling our remit: secure energy supplies, economic efficiency and environmental compatibility.

RWE Power AG

Essen/Cologne, March 2005

RWE Power –
With all our power

Focus on the core business areas of electricity, gas, water

At the start of the 21st century, the RWE Group is caught up in a process of truly rapid change. The focus on the core business areas of electricity, gas and water has been expanded by the acquisition of the British power plant operator npower, the UK's Thames Water, the transatlantic American Water and the merger with VEW. RWE Power has an important role to play in this constellation.

Photo pages 4/5

Efficiency up, costs down: at our Frechen factory, trials are under way involving a system for fluidized-bed drying with internal waste heat utilization (WTA). The WTA fine grain drying of raw lignite is an important module in the BoA-Plus power plant concept, i.e. the combination of the pre-drying stage and a lignite-fired power station with optimized plant technology: the next BoA generation. The aim is to generate power from lignite in an even more environmentally friendly manner and at lower cost thanks to separate, energetically efficient pre-drying. Efficiency is expected to increase by a further 4% points with a corresponding reduction in CO_2 emissions, but with comparable investment costs. The photo shows the raw lignite feeder in the plant's drier being set.

Photo: Klaus Görgen

Broad-based energy mix secures RWE Power a top slot among European utilities

Lignite and nuclear energy in the base load, hard coal and gas in the intermediate to peak loads, renewables as supplementing pillar in the long term: with this broad-based energy mix, RWE Power ensures a secure, low-cost and environmentally-friendly supply of electricity.

Since the merger of the companies RWE Rheinbraun and RWE Power on 1 October 2003, all upstream activities of the RWE Group in continental Europe have been bundled under one banner. In the RWE Group, the new RWE Power is responsible for building and operating power plants, providing energy and generating electricity. The electricity is distributed by the sister companies RWE Energy and RWE Trading or is traded at the exchange.

No. 1 in Germany, no. 2 in Europe

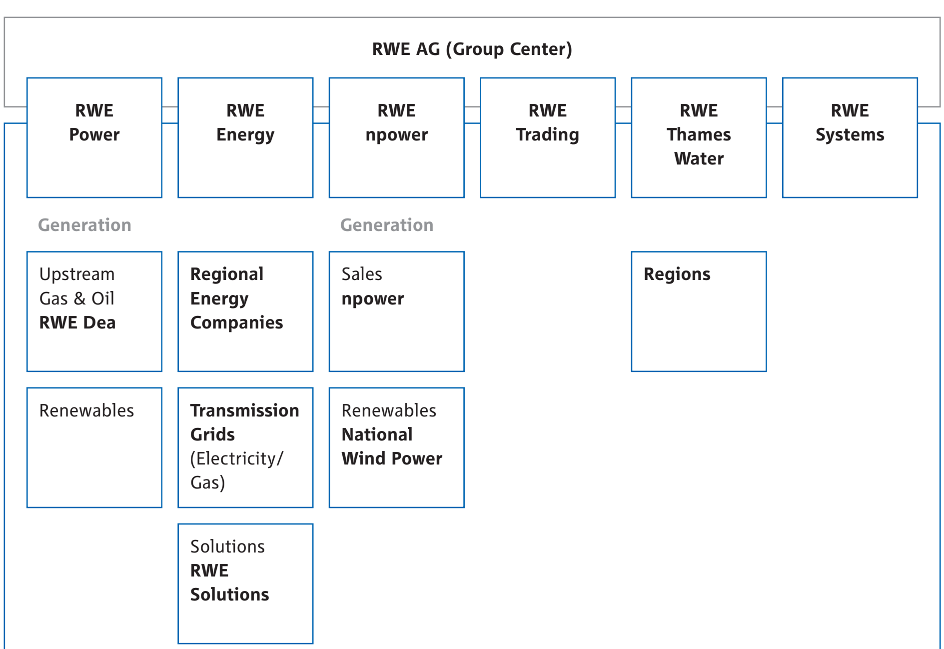
RWE Power's power plant fleet, including its participations, consists of 24 major stations and numerous smaller generation systems. Its installed capacity is over 34,000 megawatt (MW). Including the purchase of third-party electricity, the Company produces an annual total of some 200 billion (bn) kilowatt hours (kWh) of power. This is equivalent to the needs of more than 45 million (mill.) households. In the generating sector, this makes RWE Power no. 1 in Germany and no. 2 in Europe. In addition, the Company exports technical, economic and ecological know-how in mining, recultivation, power generation and lignite upgrading to over 40 countries around the globe.

To secure its competitive position, the Company pursues two main strategic goals:

- maintaining cost leadership, i.e. continuing to produce at lower cost than the competition;
- earning by itself the investment needed for new power plants, i.e. tackling modernization schemes under our own steam.

Our core business is meaningfully supplemented by RWE Dea AG and Harpen AG, both managed by RWE Power. RWE Dea is one of Germany's leading exploration and production companies for natural gas and oil, while Harpen has specialized on renewables-based and distributed power generation. RWE Power also has a majority share in the Hungarian mining and power plant company Mátra. The firm operates a lignite-fired power plant with a capacity of 800 MW that is supplied by two opencast mines. The company is Hungary's second largest power producer.

Integration of RWE Power as important management company into the RWE Group



Innovation driver in projects and programmes

RWE Power views climate protection as an integral task. In the first place, the Company is involved at many levels in the development of climate-sparing power plant technologies. Second, what matters is that we systematically raise energy-saving potentials in our own auxiliary power requirements, e.g. in the opencast mines.

Every kilowatt hour not consumed in the production and extraction process is not only cost-relevant, but also spares the environment. This is as true both of the use of smaller, lower-cost pumps to raise the groundwater level and of the energy-saving conveyor belts used in opencast lignite mining, as it is of the optimization of specific power plant components.

Much greater effects can be obtained with new plants. A prime example here is the lignite-fired power station with optimized plant engineering (BoA) at Niederaussem, which has been on stream since 2003. Generating the same amount of power, it emits up to 3 mill. t less CO_2 every year than old lignite-based systems. In developing a hard coal-fired power plant of the latest generation, too, RWE Power is playing an active role. Along with partners from science and industry, the Company has been involved in a study commissioned by the State of North-Rhine Westphalia on a reference power plant. The result: such a plant can achieve an efficiency rate of 46 %. The worldwide average is 30 %.

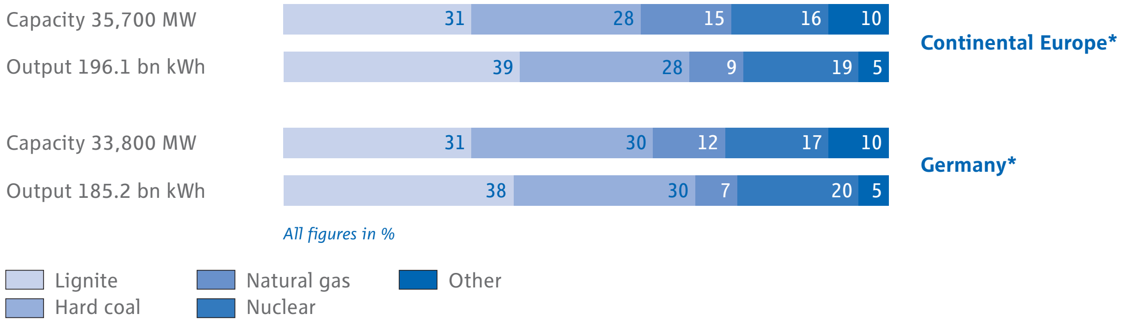
Another focus is on further developments to increase efficiency, e.g. lignite pre-drying/BoA-Plus. A trial system for fluidized-bed drying with internal waste heat utilization (WTA) is located at RWE Power's Frechen factory. By 2007, a 1:1 prototype is to be erected at Niederaussem. Using this technology, the aim is to generate power from lignite on a much more environmentally sound basis, this being achieved thanks to separate, energetically efficient pre-drying. For each kWh of electricity, some 10 % less coal would then be required, with correspondingly less CO_2 being emitted.

Other research schemes in which the Company is taking part:

- COMTES 700: construction of a component-testing plant in Scholven to develop materials that withstand extreme temperatures. An important step toward the next-generation plant with much improved temperature and, hence, efficiency levels: the 700-degree power plant.
- The COORETEC (**CO_2 re**duction **tec**hnologies) programme mounted by the Federal Economics Ministry to implement low-emission and zero-CO_2 fossil-fired power plants: studies on the combustion of coal with oxygen and on coal gasification, each with CO_2 capture. The OXYCOAL project has already been launched at the technical university RWTH Aachen.
- 6th EU framework programme: three more development projects to capture CO_2 promoted by the EU.

The budget for the above projects is several hundred million euros borne by all the partners involved – industry, the Federal government and the European Union. This is an investment that must pay off and will require both dependable political conditions and internationally harmonized cooperation.

RWE Power backing a broad-based energy mix (position: 2003)



* incl power plants not owned by RWE, though at the Company's free disposal via long-term agreements (2003)
Source: RWE AG

Investment to underpin market position

Tough competition, rising prices of gas and imported hard coal, subsidies for renewables, spare capacities down, and growing demand for balancing energy – these factors characterize the current market situation. It is in this environment, which is marked by very different developments, that RWE Power must hold its own.

The Company has set itself ambitious goals: remaining cost leader, limiting CO_2 emissions, responsible handling of existing energy sources. To achieve these goals, RWE Power is backing a sparing use of resources by renewing its power plants.

Owing to their age structure, the Company has to successively renew its plants. The central project: a new lignite-fired power station with optimized plant engineering (BoA) for which a request for approval was submitted in May 2004. The investment volume for the planned twin-unit plant with twice 1,050 MW net capacity and an efficiency of more than 43 % amounts to € 2.1 bn. Depending on how long the approval procedure and construction take, the new power plant can go on stream in about 2010.

Further investment running into millions

For the cornerstone of sparing use of resources, too, specific examples can be found:

- Up to 10 % of the valuable hard coal can be saved by using solid recovered fuels (SRFs) from treated industrial and household waste. SRFs are co-combusted in the Gersteinwerk plant at Werne and in the Westfalen power plant, Hamm. There, the ConTherm plant also carbonizes special refined waste and uses the resulting process gas and coke to fire the power plant.
- At the Weisweiler plant, two 190-MW topping gas turbines are being erected and installed upstream of the existing 600-MW lignite units. The effect is a 12.5 % increase in output and a boost to the efficiency of the entire plant from 36 to 40 %. The costs are around € 150 mill.; commissioning is scheduled for 2006.
- In unit A of the Westfalen power plant, the boiler, water-steam cycle, generator and turbine have been overhauled; also, safety-relevant components have been checked, retrofitted and renewed where necessary. The unit can now go on operating until 2010.

Further projects include the new efficiency-enhancing flue gas desulphurization (FGD) unit which RWE Power is building for the STEAG plant at Voerde, as well as the new burner technology at the Neurath power station. This prevents the soiling of the heating surfaces and maintains the heat transmission in the boiler at an unvarying high level, even if the coal's ash content is constantly changing.

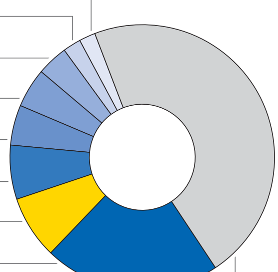
Competent partner to science and industry

Our know-how in the development and deployment of efficient and climate-sparing power plant technologies also makes RWE Power a competent partner to science and industry.

No. 2 in Europe, no. 1 in Germany in power generation

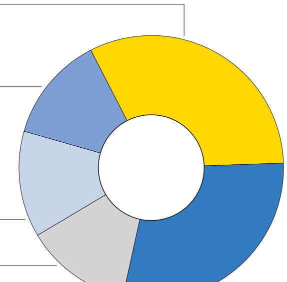
EU-25 (2003)*: approx. 3,000 TWh

CEZ	2.0 %
Iberdrola	2.2 %
Endesa	3.8 %
Vattenfall	4.8 %
ENEL	4.9 %
E.ON	6.6 %
RWE**	7.7 %
EdF (incl EnBW)	21.5 %
Other	46.5 %



Germany (2003)*: approx. 597 TWh

RWE Power	**31 %**
Vattenfall	13 %
EnBW	13 %
Other	14 %
E.ON	29 %



* accession countries´ figures based on 2002
** of which RWE Power 6 %; RWE npower 1.7 %; basis: annual reports 2003; Eurelectric 2002; estimates

Source: RWE AG (2)

Power generation
in the European Union

EU enlargement means new challenges for the energy market

2004 was a historic year for the European Union. With the accession of 10 states on 1 May, the economic area grew to include 450 mill. people. This is equivalent to 7 % of the world population. The event will have serious implications for the energy market in particular.

Photo pages 10/11

€ 80 mill. for climate-sparing and reliable power generation from hard coal. Thanks to the adaptation of the new FGD system at the Voerde location to the capacity of the steam generators and thanks to the retrofitting of the turbines, electric output was increased by 50 MW per unit. In addition, the net efficiency of the entire system has been boosted from 38.2 to 38.7 % by improved plant engineering and by lower auxiliary power requirements. The motif shows the 228-m high chimney of the hard coal-fired power plant.

Photo: André Laaks/STEAG

Shares of the various energy sources marked by considerable bandwidths in the 25 member states

In the EU, now extended to 25 states (EU-25), gross power generation in 2003 stood at 3,000 bn kWh. Of this, one third was accounted for by coal and nuclear energy, 18 % by natural gas, 5 % by oil, and 12 % by renewables. The EU had a share of just under one quarter of world electricity consumption. Power plant capacity totalled nearly 700,000 MW.

The shares of the various energy sources in power generation are marked by considerable bandwidths in the 25 member states: in the case of coal, for instance, they range from 1 % in Latvia to as much as to 90 % in Poland and, in natural gas, from 1 % in Estonia to almost 60 % in The Netherlands.

Nuclear energy

Nuclear energy, at 971 bn kWh, had a crucial share in Europe's power generation, making the European Union no. 1 in world power production from nuclear energy today. With 160 reactors, this is true of both the absolute figures and the percentage share. No other region in the world covers a larger share of its electricity needs from nuclear energy. Within the EU, the picture is very differentiated: Lithuania and France generate up to 80 % of their power from nuclear energy. By contrast, 12 countries make no use at all of this option.

Coal

Nearly one third of the EU's power supplies is covered by coal. Expressed in numbers: in the EU-25, some 980 bn kWh was produced on the basis of coal (630 bn kWh from hard coal, 350 bn kWh from lignite). Power plant capacities are distributed accordingly: while the installed capacity at hard coal-fired power plants amounted to 177,000 MW, there was 48,000 MW available at lignite-based power stations. Domestic coal deposits play a special role in power generation: in the accession countries, they cover about 60 % of electricity production. The EU also has an efficient infrastructure enabling it to benefit from worldwide coal deposits.

Coal defines a central price benchmark in the electricity sector. It is an important macro-economic element in relations with non-European energy suppliers. This restricts the leeway for increasing prices by external owners of resources.

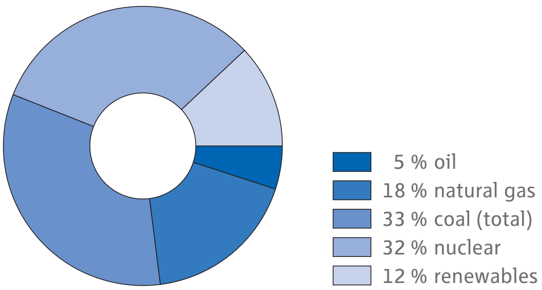
Natural gas

In Western Europe, the upward trend in deploying gas has continued. Total demand for natural gas, at approx. 415 bn cubic metres (cbm), reached a new all-time high in 2003. In Central and Eastern Europe, a good 70 bn cbm was consumed, roughly 6 % more than in 2002. Crucial for the increase were the higher number of gas customers in all consumption sectors and a significant rise in the deployment of gas in power plants. In 2003, 552 bn kWh of electricity was generated on a gas basis.

Renewables

In 2003, the EU countries generated 12 % of power from renewable energies, equivalent to 363 bn kWh. The traditional energy source, hydropower, accounted for the largest share by far, at over 9 % (277 bn kWh). A mere 3 % of power generation in an EU average stemmed from wind, biomass, waste and solar energy. The front runners in the generation from renewables, in absolute figures, were France, Spain and Sweden, followed by Germany occupying slot 4. However, if we use as basis the percentage share of renewables in national power generation, Latvia, Austria and Sweden took the lead. In this statistic, France ranks 11 and Germany 12.

Generation structures in EU-25 (2003): 3,000 TWh



Source: European Commission, European Energy and Transport Trends to 2030; Eurelectric 2004

Extensive legislative package on liberalization

In the past legislative period, the EU Commission, the EU Parliament and the EU Council of Ministers initiated and resolved a legislative package that is unique around the world in a move to create an internal market for electricity.

On 26 June 2003, the Council and the Parliament of the EU passed the Acceleration Directive for the Internal Market in electricity and natural gas. Energy suppliers are obliged to unbundle their companies' generation, procurement and distribution activities, the idea being to boost liberalization. The rule affects all transmission, combined and distribution system operators; the latter refers to independent companies with more than 100,000 customers. Also defined are the detailed requirements to be met in the unbundling and transparency of accounting and internal structures. The legislative package passed in 2003 to complete the liberalization of national energy markets is an important step toward a single European market in electricity and gas. With the implementation of the regulations as of 1 July 2004 and 1 July 2007 resp., approximately the same competitive conditions are now being created in all member states, ensuring the greatest possible entrepreneurial freedom of action in the light of the goals of the Lisbon process.

The complete opening of markets, unitary arrangements for system access, unbundling, regulators' duties, cross-border exchanges in electricity and bottleneck management will help ensure that free trade grows and – with increasing openness – market liquidity as well. The cross-border unfolding of market forces will strengthen competition in the member states and ensure a balanced energy mix, security of supplies and investment. Also, competition will counteract any sudden price hikes. This is a process that will evolve over several years.

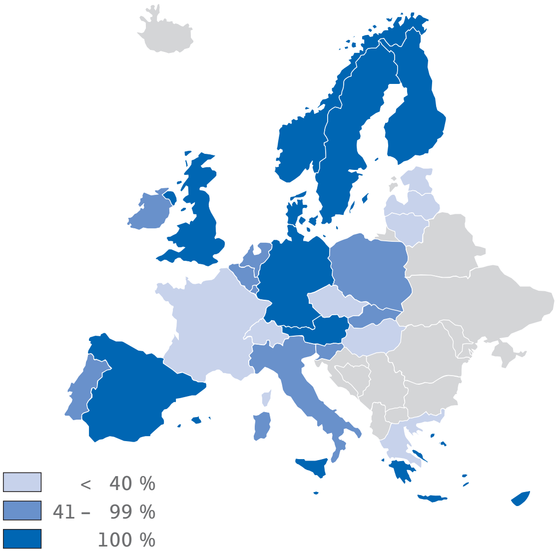
In view of the fact that the liberalization measures have not yet been fully translated into national law in many member states, it would be rushing things to intervene again with new schemes. Any (re-)regulation would provide market players with false signals as regards legal certainty and the long-term dependability of the underlying regulatory framework. Instead, the market forces should be given the time and space to prove and unfold their full capability under the new conditions.

The national implementation of the most recent liberalization package ought to be prioritized. Within the scope of the Florence and Madrid process, regulations should be sought that support cross-border trade in electricity and gas and a more efficient use of existing capacities. Drawing conclusions or doing rush jobs involving further regulatory measures would jeopardize the confidence of market players in the dependability of regulations.

Combined Heat and Power Generation Directive (CHP Directive)

The EU Directive to support combined heat and power generation entered into force at the end of February 2004. Member states have been given two years to implement it. The Parliament's wish that special support be given to micro-CHP systems (up to 50 kW) has been met to the extent that certified values can be used in calculating the CHP electricity.

Status of the opening of electricity markets, 2004



Source: RWE Power

For very small and small systems (up to 500 and 1,000 kW resp.), national lawmakers are able to make system access easier. Still, the demand for a binding share of min. 18 % CHP electricity in the energy mix by 2010 has been rejected.

The use of CHP is especially meaningful in energy terms wherever there are appropriate heat customers. Rigid extension targets or even quotas may be counter-productive if they cannot be squared with the existing infrastructure. What is more, any quota arrangements would contradict the thinking behind an internal market. The object of the current EU Directive is to harmonize the underlying conditions for supporting CHP.

Renewable energies

The EU has set itself ambitious goals for expanding renewable energies. By 2010, their shares in gross domestic energy consumption is expected to rise to 12 %, and that in gross power generation to 22 %. The member states have agreed on indicative targets, so that progress in different countries varies correspondingly. This is due to their having different promotion systems (supply fees, quotas, bidding procedures), but also to differences in natural circumstances.

The expansion of renewables is an important component. All the same, advancing them must not be an end-in-itself and must not lead to distortions in competition. Renewable energies must be used above all wherever this is possible in ecological and economic terms. Further, a holistic account must be taken of the consequences for the infrastructure, security of supplies and the additional costs for balancing energy and for system extensions, also as regards the impact on jobs. In implementing the EU's Water Framework Directive, it must be ensured that no extra competition-distorting burdens or extensive operational restrictions emerge. Hydropower is still the crucial renewable energy source in the European Union.

Nuclear package

Nuclear safety in Europe, in addition to climate protection and liberalization, is the most important subject for the energy sector and political institutions. In quite a few countries, e.g., Lithuania, the EU Commission has ensured that the new member states become "EU-compatible" in this respect. For this purpose, it has made available generous financial aid, and is still doing so. The EU – above all the Commission – wishes to strengthen citizens'confidence in this technology. What matters specifically in this respect – for reasons of security of supplies and environmental protection – is the retention of a low-cost and environmentally friendly technology. In view of its still-necessary contribution to Europe's power generation mix, measures for further development and research in the area of nuclear energy should be stepped up again.

To enhance the safety of nuclear energy, the EU Commission in its most recent legislative period opted for legally binding instruments in the form of directives. It intends to stick to these. However, these directives set no new standards, especially as regards safety that go beyond internationally recognized and applied norms (IAEA, Nuclear Safety Convention). The result: the Council resolved in June 2004 not to discuss binding instruments again until existing tools have been exhausted. A Council debate in September 2004, too, showed that opinions have not changed.

Security of supplies and infrastructure directive

State interference in investment and any abandoning of the market-economy approach of the Acceleration Directive could have drastic consequences for the security of supplies if this were to rob investors in power plants and grids of long-term planning certainty. The same assessment applies to the draft directive on measures to underpin the security of the electricity supply and infrastructural investment (SoSI). Member states are to be obliged to monitor guaranteed security of supplies and to support companies in measures taken to achieve this goal. In this respect, while being bound by the objectives of the Directive, companies must be given the greatest possible leeway in choosing their measures. Also, to maintain system security in view of the specific features of national generation systems, member states must be allowed sufficient room for implementation.

Energy-policy goals balanced, taking a long view

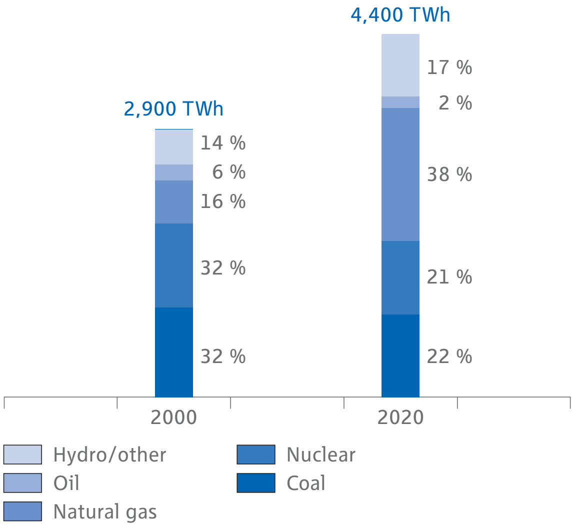
The major energy-policy goals – security of supplies, economic efficiency and environmental protection – must be balanced and take account of the long haul. This is an ambitious task for an extended EU, which becomes clear when we take a glance at the near future of the energy sector in the EU.

Investment in security of supplies requires dependable underlying conditions

Europe's energy sector will have to face considerable challenges if it is to ensure security of supplies and invest in necessary replacement power plants and new plants, transmission and distribution systems. This calls for a market-economy based legal framework and for a regulatory environment that is conducive to competition and provides companies with the necessary market-price signals and incentives for their investment decisions. If investors are deprived of long-term planning certainty due to state interference in investment and an abandonment of market-economy approaches, this could have serious consequences for the security of supplies.

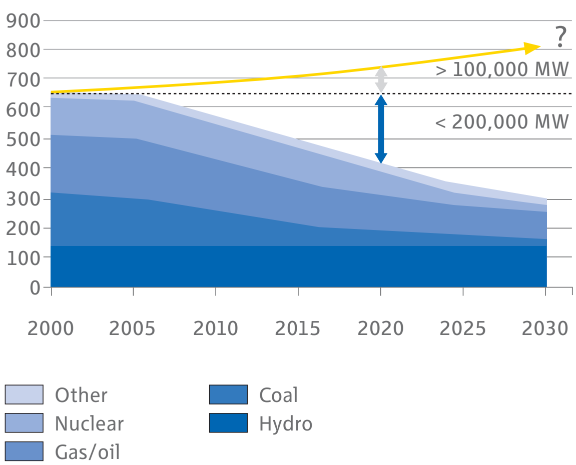
The challenges are tremendous. By 2020, EU-25 will need to replace some 200,000 MW of power plant capacity for age reasons and install an extra 100,000 MW to meet growing demand. In the EU alone, estimates put the need for investment in power plants and grids at € 900 bn over the next 25 years. Such sums can only be mobilized by capital markets if the underlying conditions give investors the requisite certainty in their returns and planning. In selecting possible technologies, account must be taken of the marginal conditions of climate protection, economical provision of power and security of supplies. To meet this spectrum of requirements in the best possible way, all technical options for power generation must be exploited and further developed.

Power requirements of EU-25



Source: EU Commission, European Energy and Transport Trends to 2030, Brussels 2003

Power plant renewals in EU-25
Installed capacity (GW)



Source: VGB PowerTech

Coal-based supply remains backbone

Here, Europe must become too strongly dependent neither on natural gas nor on the hope of being able to cover most of the demand from renewable energies. Conventional power generation on the basis of nuclear energy, in particular, and, to an even greater extent, on the basis of hard coal and lignite will go on forming the backbone of Europe's electricity supply. In this mix, renewables must assume a steadily growing role in line with their further technical development and deployment options. This is also true of decentralized applications like fuel cells, CHPs and micro-gas turbines.

Power plant renewals: factoring in the strengths and potentials of all energy sources

The European market is one of the most important in the world, also and especially for electricity: the enlarged European Union now produces and needs an annual total of some 3,000 bn kWh of electricity, approx. 25 % of worldwide power generation. VGB PowerTech Executive Committee chairman and RWE Power Executive Vice President Dr Gerd Jäger highlights the developments and opportunities facing this market in the years to come.

To cover the EU's electricity needs, recent decades saw the erection of production capacities totalling nearly 700,000 MW on the basis of coal, nuclear energy, oil, gas and hydropower. They ensure economically efficient, secure and environmentally compatible supplies.

Need for renewals and additional demand

One of the future challenges facing us is the replacement of ageing power plants. Also, we will have to satisfy the growing demand that is caused, among others, by an equalization of living standards in the accession countries. Those standards are currently equivalent to only half the average per-capita power consumption in the "old" EU. EU-25-wide, over 200,000 MW must be built as replacements, along with more than 100,000 MW of new power plant capacity, by 2020 in order to cover the extra demand.

In the discussion surrounding future power generation, all of this is undisputed. Where views differ is on the question of which energy sources can and should be used in the further development of power generation. For some, this culminates in the exaggerated warning that Europe is facing the historic decision between managing the switchover to an era of renewable energies and energy saving and missing the boat for the future by backing coal, gas and nuclear energy.

Future power generation will need all energy sources

A reality check shows that this conflict need not exist. It is not true that renewables and energy saving alone can master the challenges facing us; nor will power be generated in future using only gas, coal and nuclear energy. Precisely the converse is the case: promoting new energies requires the use of conventional energies. The more they can be used at a high environmental level and with economic efficiency, the greater will be the leeway for developing and implementing renewable energy sources. The key to Europe's future power generation lies in a broad mix of all energy sources, so that supply risks can be minimized, low-cost power generation ensured, and further progress made in environmental protection. Efficient coal- and gas-fired power plants will play a crucial role here. Accounting for over 50 % of Europe's total energy supply, they will remain the main pillars in the decades to come. Moreover, power generation from coal and gas has an outstanding potential for increasing efficiencies, with a prospect of less fuel input and lower emissions, but with the same power generated. Further R&D activities to exploit the potentials of the energy source coal look promising. Alongside this, nuclear energy, too, standing at 30 % today, will remain a central pillar. At present, EU-25, with 1,000 TWh, is the world's no. 1 producer of power from nuclear energy – and that at high safety levels. Nuclear energy in Europe, too, offers great perspectives for safe, environmentally sound and low-cost power generation.

Promoting new energies requires the use of conventional sources

Throughout the EU, renewables are definitely set to grow. This huge challenge for technology and economic efficiency, especially in the case of wind, biomass and geothermal energy, can only be tackled if Europe as an economic area remains powerful, thus leaving enough space for the development of renewable energies.

The preconditions for successfully shaping the upcoming power plant renewals across the entire EU-25 are a facts-driven approach to the energy-policy debate and the inclusion and development of all energy sources according to their strengths and potentials.

The author: *Dr Gerd Jäger*

Executive Committee chairman of VGB PowerTech

Executive Vice President of RWE Power Nuclear power plants/renewables portfolio

Climate policy needs market-based tools

An ambitious climate policy and the launch of emissions trading are central challenges for Europe's energy sector.

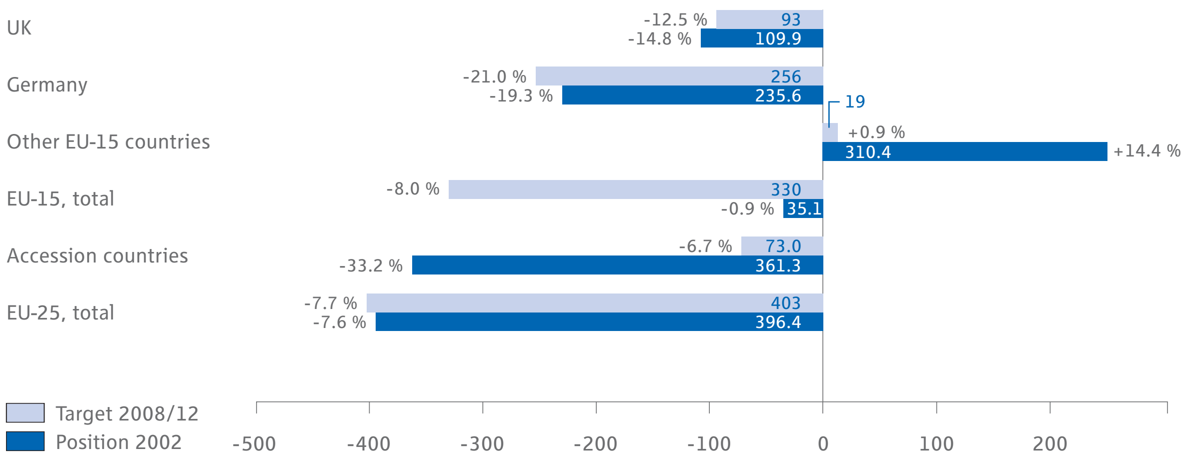
The EU has assumed a leading role in the measures being taken to prevent climate change. In the Kyoto Protocol, the EU-15 assumed an obligation to obtain an 8 % reduction in its greenhouse-gas emissions by 2008/12 relative to 1990. Of the big emitter countries, the UK and Germany in particular have realistic chances of fulfilling their commitments within the scope of the EU's burden-sharing scheme, whereas other EU member states still have a long way to go to meet their targets.

Huge R&D efforts

Any future climate policy must keep all energy options open, as well as CO_2 avoidance options, like carbon capture and sequestration, but also nuclear energy. In this respect, the EU, along with the member states, wishes to promote R&D investment in particular to support suitable solutions and innovations. In addition, all sectors are to do their bit in climate protection.

In any processes adopted, whether avoidance or adaptation measures, preference must be given to market-based tools to ensure target achievement at the lowest possible cost. Any devaluation of the existing infrastructure, specifically in energy-intensive industries and in the power sector, by an overly-ambitious or solely Europe-focused climate policy would massively impair economic growth and, hence, the aims of the Lisbon strategy.

EU-25 climate balance statement, 1990 to 2002
in mill. t of CO_2 equivalent



Source: European Environment Agency (EEA)

Focus

Combating climate change is a global task. Ambitious climate-protection targets set by the EU alone will not suffice to ensure cost-efficient prevention of climate change. In the coming years, the biggest growth in energy consumption and GHG emissions will be noted in developing countries and in countries in transition. After 2010, total emissions in these countries will exceed those in industrialized nations. Only if these countries are included in the post-Kyoto process for the long haul will we see an effective and cost-geared climate policy being pursued worldwide.

To achieve its Kyoto target, the EU is, above all, backing the tool of emissions trading. According to the EU Directive, which came into force on 13 October 2003, Europe's emissions-trading system will initially be confined to CO_2, only one of the six GHGs in the Kyoto Protocol.

Allocation plans with far-reaching consequences

At the core of the Europe-wide implementation of the Emissions Trading Directive are the National Allocation Plans (NAPs). These apportion the CO_2 emissions admissible in future to the various economic sectors (macro-allocation) and to the plants included in emissions trading (micro-allocation). These plans must be approved by the EU Commission and will leave their mark on the longer-term structures of industry and the energy supply in the various member states.

The trade in emissions will have a profound impact on Europe's future energy supply. In this respect, the EU Commission must advocate economically defensible solutions that ensure stability and sustainability. Emissions trading can evolve into a key tool for reducing greenhouse gas emissions. Still, Brussels and the member states will have to realize that the arrangements in place hitherto permit a mere kick-off into emissions trading. The system now launched must be further developed and harmonized in the long term.

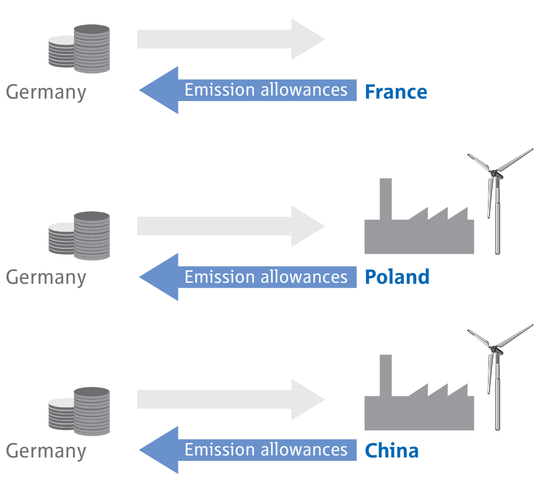
The CO_2-trading system according to Kyoto
JI and CDM projects may be implemented by states and private companies

The idea behind emissions trading:
What is crucial is not **where**, but **the fact that emissions** are reduced. This is done with the aid of **"flexible mechanisms"**.

Emissions trading:
Trade in emission allowances is possible between industrialized countries.

Joint Implementation (JI):
Lower emission thanks to investment by one industrialized country in another are credited entirely to the emissions account of the investing country.

Clean Development Mechanism (CDM):
Lower emissions thanks to investment by an industrialized country in a country without reduction obligations are credited to the emissions account of the investing country.



Europe's emissions-trading system seeks to reduce CO_2 where it costs least

In 1997, the industrialized nations, in the Kyoto Protocol, undertook to lower their GHG emissions by 8 % in the period 2008 – 2012, relative to 1990 levels. Orientation on this subject is provided here by Dr Henning Rentz, head of energy policy at RWE Power.

In the Kyoto Protocol, the European Union gave a pledge to reduce its emissions by 8 % between 2008 and 2012 relative to the 1990 level. To reach this target, the EU member states undertook to achieve national climate-protection targets. Germany has promised to lower emissions of the chief GHGs by 21 % in this period (relative to 1990). One key tool here is trade in emissions. Under the Emissions Trading Directive, which became effective in October 2003, EU member states are obliged to adopt National Allocation Plans (NAPs) to implement the trade in emissions. The German government submitted its NAP to the EU Commission in Brussels on 31 March 2004. Germany's 2007 Allocation Law (ZuG 2007), with which the NAP is translated into national law, was passed by the Bundestag on 28 May 2004.

CO_2 emissions come at a price

The emissions-trading system is set to cut CO_2 emissions where it costs least to do so. Economic sectors and each plant concerned are given concrete reduction targets and allocated emission allowances in that amount free of charge. These allowances are tradeable. If the company achieves its targets by taking low-cost CO_2 reduction measures of its own, it can sell any allowances surplus to requirements on the market. Alternatively, it must buy in more allowances if its own reduction measures would be more expensive. If the company fails to meet its reduction duties, sanctions threaten, amounting to € 40 per tonne in the first trading period – and the underachieved reduction target must still be met after the event in the following year. In Germany, 1,860 plants are affected. These are mostly large firing systems (with more than 20 MW furnace capacity) and selected sectors in energy-intensive industries.

By the end of 2004, nearly all NAPs had been submitted to the European Commission; only Greece's NAP was missing. Most plans were approved by the Commission, including those of Germany and Britain, although stipulations were set for both these countries. While the Commission complained primarily about a lack of arrangements for newcomer plants in the British plan, it stumbled over the option contained in the German NAP of providing for subsequent adjustments to allocations already made (so-called ex-post adjustments) in certain cases.

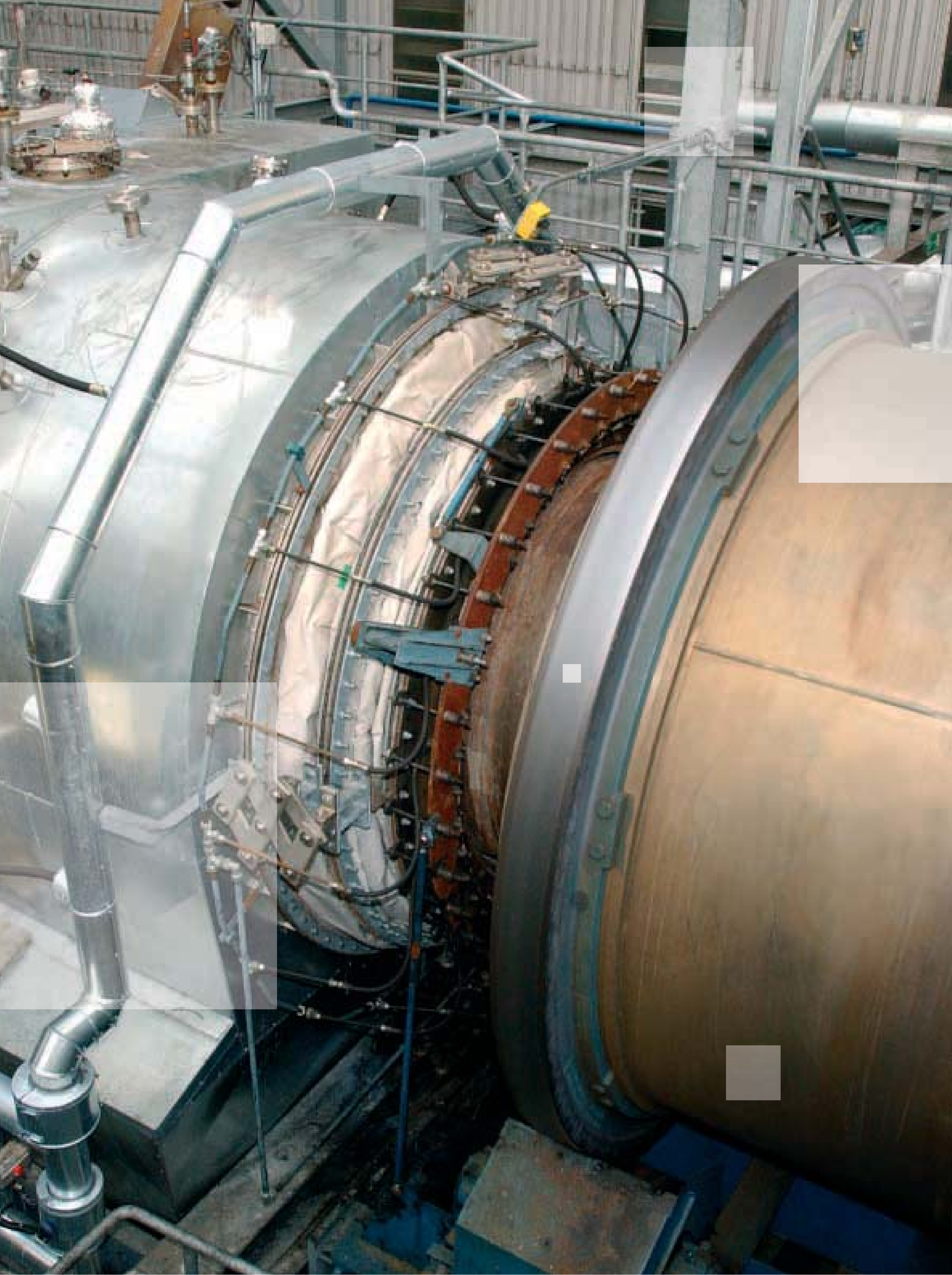
Uneven distribution of the reductions

Criticism must be levelled at the lack of harmonization of the allocation rules and at the uneven distribution of emission reductions in Europe. Only very few countries are keen to lower their emissions compared with the base period (incl Germany and Slovenia). Most other countries will record increases. The resulting distortions to competition can be the intention neither of the German government nor of the EU Commission. For the next commitment periods, heed will have to be paid above all to ensuring that reduction efforts are distributed more evenly in the sectors affected by emissions trading.

Just what specific implications the trade in emissions will have for plant operators, the various sectors and the entire economy cannot be finally assessed as yet. That will depend, inter alia, on the price that emerges for emission allowances, on whether a liquid market evolves and, most of all, on what energy and environmental-policy targets are set for the period after 2012 at German, European and global level.

The author: *Dr Henning Rentz*

RWE Power
Head of energy policy



Power generation in Germany

Electricity sector in a phase of upheaval

The German power sector has been caught up in a continuous process of change since the start of competition reform, which was triggered by the EU internal market directive and the amendment of the Energy Industry Act. The following presentation of the status quo shows how the sector and the market have evolved since liberalization.

Photo pages 22/23

Sparing resources and re-use: in the ConTherm system at the Westfalen power plant at Hamm, special refined waste, like old plastic and sorting and processing residues, are carbonized and decomposed, producing process gas and coke which can then be used to fire the power plant. The ConTherm system enables savings of about 10 % on the fossil energy source, coal. This pyrolysis process also yields iron, stone and glass, which are passed on for further use to the construction and steel industries, among others.

Photo: André Laaks

Dependable and forward-looking concept mandatory

The call for a dependable and forward-looking concept for power generation and supplies is at the centre of the current energy-policy debate in Germany. Besides climate-policy and other underlying conditions set by both the international and the European community of states, national considerations play a significant role, e.g. security of supplies, efficiency and technological leadership.

The most important contribution in covering 2003 power needs came from domestic electricity generation with 597 bn kWh. Of this, 88 % was accounted for by utilities' power plants (incl Deutsche Bahn), and 12 % by industrial power stations and private grid suppliers. Production at the German locations was supplemented by imports which, at 45.8 bn kWh, were equivalent to some 7.5 % of gross power consumption in 2003. Electricity exports amounted to 53.8 bn kWh. In 2003, the structure of gross power generation was as follows:

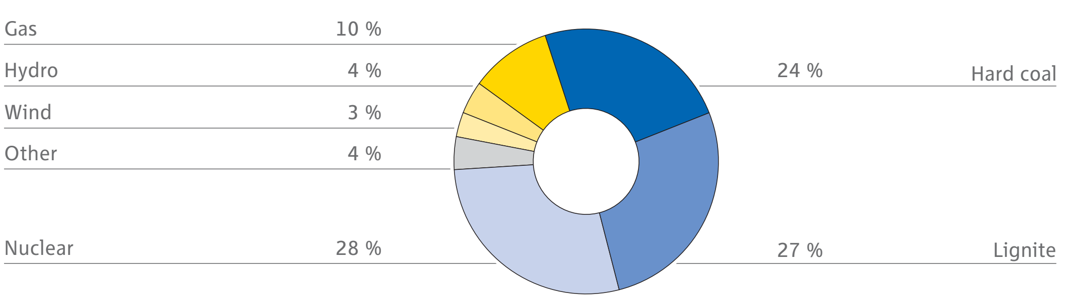
Nuclear energy

Germany currently operates 18 nuclear power stations with a good 21,700 MW gross capacity. These stations, at 165 bn kWh, contributed some 28 % to Germany's gross power generation in 2003.

Lignite

In Germany, lignite-fired power plants with a gross maximum capacity of over 21,000 MW are connected to the grid. Lignite-based power generation of nearly 160 bn kWh was equivalent to 27 % of the country's total production. By investing in power plants, Germany's electricity sector has in recent years created the preconditions for a level of efficiency in the use of lignite that is unrivalled at global level. In Germany's new federal states, for example, nearly 9,000 MW of old plants have been shut down and eight 500-MW units retrofitted. In these systems, efficiency increased by 10 %. Seven new units were built with a total capacity of approx. 5,500 MW. These plants reach efficiencies of more than 40 %. In the Rhineland, modernization of the power plant fleet has already made significant headway, including retrofit measures for existing plants. Also, at the Niederaussem location near Cologne, a 1,000-MW lignite-fired power station with optimized plant engineering (BoA) was built. Upon completion of the trial operations, operating responsibility for this new unit, which boasts efficiency of more than 43 %, passed to RWE Power AG at the start of 2003.

Energy mix in Germany, 2003
Gross power generation: 597 bn kWh



Source: RWE AG

Hard coal

With a share of 24.5 %, hard coal is the third-largest energy source in Germany's power generation. The power plants are supplied with both domestic and foreign products. In Germany's 2003 power generation, 68 bn kWh was accounted for by domestic hard coal and 78 bn kWh by imported steam coal. Most of the imported coal comes from Poland and overseas.

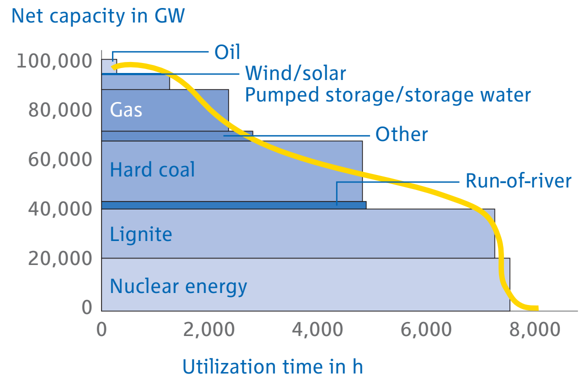
Natural gas

With a 9.6 % share in power generation, gas is a further important pillar in Germany's widely diversified energy mix. This means that some 13 % of German natural gas consumption went into power plants to generate electricity. Natural gas-based power is generated in peak-load condensing power plants, in CHP systems close to customers in municipalities and in industry. The trend toward such plants continued in the year just past. In 2004, 1,080 MW new capacity was connected to the grid to replace older and uneconomical plants.

Renewables

In 2003, renewables had a 7.7 % share, or 45.3 bn kWh, in Germany's power generation. Hydropower accounted for 20.4 bn kWh, wind energy for 18.9 bn kWh, biomass for 3.7 bn kWh, waste for 2.0 bn kWh (power generation from waste is rated as 50 % renewable), and photovoltaics for 0.3 bn kWh.

Average utilization time of German power plants, 2003



Source: VDEW, 2004 electricity figures (net generation and net capacity)

Owing to the dry weather and the hot summer, hydropower stations supplied definitely less electricity in 2003 than in 2002. The highest growth was reported for wind power in 2003. According to data from the Federal Association of Wind Energy, Osnabrück, new wind-energy systems with a total capacity of 2,645 MW were installed in Germany in 2003. The total number of installed wind turbines increased to 15,387 thanks to these additions.

Focus

Power plant mix in electricity generation

Nuclear power stations have the highest average utilization rate of 7,570 annual hours, followed by lignite-fired power plants with 7,300 and run-of-river power stations with 4,900 hours per year. They produce low-cost base-load electricity – the basic requirements that remain virtually constant around the clock.

For the demand peaks that fluctuate during the day there are intermediate- and peak-load power plants. They generate power from hard coal, storage water and natural gas, and work an average of 4,850, 1,200 and 2,400 resp. hours per year.

Depending on the weather, wind farms are also used. In an annual average for 2003, these systems generated electricity for some 1,400 hours.

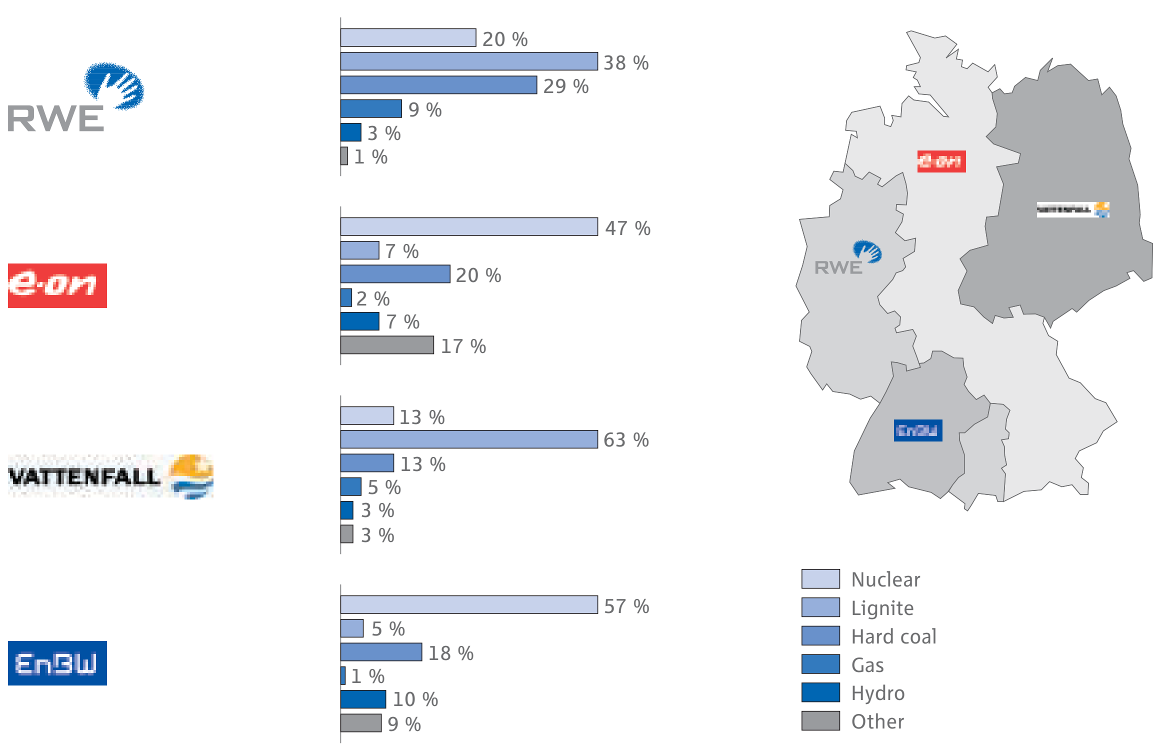
Source: VDEW

Total output rose 22 % from 11,964 MW at year's end 2002 to 14,609 MW at the end of 2003. The amount of wind-based power generation was up from 15.9 bn kWh in 2002 by just under 20 % to 19.0 bn kWh in 2003. Owing to unfavourable wind conditions, however, growth lagged behind capacity developments.

German electricity market in upheaval

The German electricity sector has been in a phase of upheaval since the start of liberalization. Despite consolidation tendencies, the German electricity market, with 1,100 companies, is still the most varied in the EU: among the biggest power suppliers in 2003 were four supra-regional and four regional energy companies, along with two municipal utilities. The highest electricity sales to end consumers on the German market in 2003 were posted by RWE, Essen, with some 103 bn kWh, followed by E.ON, Düsseldorf, with 85 bn kWh and EnBW, Karlsruhe, with 64 bn kWh. Vattenfall Europe, Berlin, sold approx. 32 bn kWh of power. Ranking fifth was the regional group EWE, Oldenburg, with 11 bn kWh. MVV Energie, Mannheim, and GEW RheinEnergie, Cologne, follow, occupying slots 6 and 7 with about 8 bn kWh. N-ERGIE, Nuremberg, Stadtwerke München GmbH and Stadtwerke Hannover, with some 5 bn kWh each of electricity sold, occupied places 9 and 10.

The four biggest power utilities in Germany



Source: RWE Power

Definite rise at wholesale level

The 2003 wholesale electricity prices were up roughly one third on the previous year's level (comparison of annual average spot prices). Although the 2002 quotes for forward deliveries in the following year were higher than the spot prices in 2002, actual spot prices – moving at around € 30/MWh in the base load – were nevertheless one quarter above the forward prices for 2003, which had amounted to between € 24 and 25/MWh in 2002.

The crucial reason for the rise in wholesale prices was the unexpected strong growth in fuel input costs for both gas and hard coal. Another result of the dry summer of 2003 was a fall in the supply of electricity from hydropower as well as cooling-water problems at nuclear power stations and fossil-fired plants. Also, wind conditions were unfavourable. The markets factored in some unexpectedly conspicuous risks as regards power plant availability; this had also become apparent in the annual forwards. Just what impact emissions trading, which started on 1 January 2005, has or will have, cannot be reliably assessed at present.

Wholesale prices in Germany, 2003

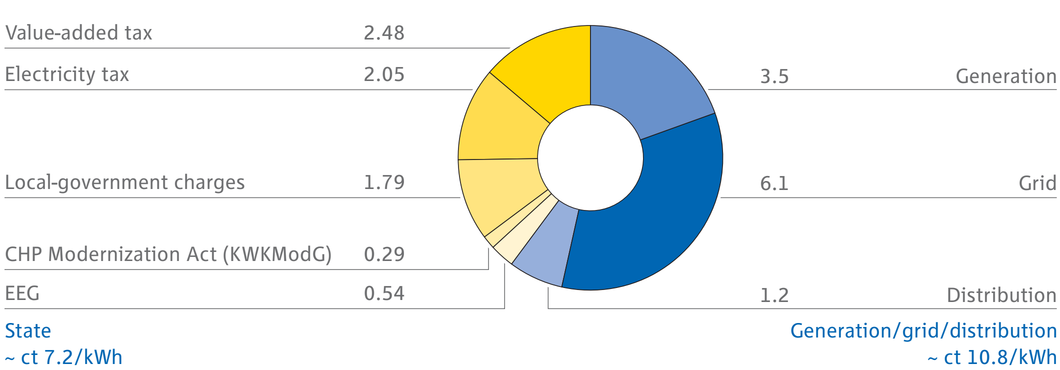
	Annual average	
	2002 €/MWh	**2003** €/MWh
a) Over-the-counter trade*		
Base load	22.51	30.73
Peak load	33.53	47.06
b) Quoted at EEX **		
Base load	22.5	29.48
Peak load	32.43	42.85

* German Power Index (GPI); average of day-ahead quotations
** EEX hourly values, Leipzig power exchange

State levies with considerable impact on prices

Annual mean consumer electricity prices for 2003, compared with the same period in the previous year, rose by an average of 8.5 % across all buyer groups. In a breakdown by sector, the following trend was observed: electricity prices for private households, according to a survey of the Federal Statistical Office, were up 4.5 %. The growth rate for industrial customers (high-voltage purchases under special contracts) was 14.1 %. When comparing these percentages, it must be borne in mind that the prices for the industrial group are less than half as high as the average prices for private households (base effect). Besides market developments, the electricity tax – which went up on 1 January 2003 – as well as the burdens from the Renewable Energy Sources Act (EEG) and from the Combined Heat and Power Generation Act (KWKG), had a massive effect on power prices.

Breakdown of average electricity price for private households of some ct 18.0/kWh



Source: VDEW 19/05/2001 and 05/11/2003
Basis: household of 3 with 3,500 kWh/year

Electricity prices must offer incentives for investing in new plants

On the electricity market, price formation on the basis of average costs is history. The crucial price determinants are supply and demand. What consequences this has is explained by Dr Hans-Wilhelm Schiffer, head of energy management at RWE Power.

Today, as in other markets, it is the variable costs of the marginal seller that are the key parameter in price formation. This being so, it is the level of demand that decides which power plants the market will have recourse to. If demand is especially high, e.g., during prime working times on workdays or on cold winter or hot summer days, then the plants with the higher variable costs, too, must come in. Their capacity can then be dispensed with in times of weak demand, at weekends, say. With prices formed this way, the marginal seller, i.e. the provider who is just able to cover demand, is the price setter.

Soaring fuel costs

Hence, pricing on the basis of marginal costs means that the marginal seller is reimbursed his variable costs, though not his fixed costs. If prices rise, this does not even necessarily mean that the plants that rank before the marginal sellers' in the industrial cost curve, i.e. plants that produce with more favourable variable costs, will earn a profit. In fact, it is quite possible that even rising prices do not ensure full cost coverage for all the power plants deployed. For the operator, there is nevertheless an incentive to use such plants as well wherever this enables him to cover at least some of his fixed costs on the market.

In recent months, fuel prices, as a crucial element in variable costs, have soared. The spot prices of steam coal, for example, doubled on the world markets to an average of USD 90/tonne of coal equivalent (tce) in the second half of 2004 – compared with USD 41/tce in the first half of 2003. The average prices free German border of steam coal, quoted in euros, which are also determined by deliveries with – in places even lower – contractually fixed prices, have likewise spiralled despite the firming of the exchange rate for the euro; for October 2004, they were quoted at € 62/tce, which was nearly 50 % more than in 2003. German hard coal, too, is sold at these prices. The import price of natural gas, too, has increased since October 2004 due to its being tied to the price of oil, which it follows with a time lag. The fuel input in lignite-fired and nuclear power stations is independent of these price swings on the world markets.

Liberalization squeezes income

Plants that are not affected by these price rises can earn extra income. Conversely, any fall in wholesale electricity prices, e.g., as a result of falling fuel prices on international markets, is associated with a fall in income at nuclear- or lignite-based power plants. So, besides the desolate initial situation that marked producer prices immediately after liberalization, these two facets of price formation on free markets must be considered.

The market can, and does, generate prices that do not fully cover costs, as in the power generation field after the 1998 opening of the market, which was characterized by excess capacities. For base-load power, for example, the annual average quoted at wholesale level in 2000 was ct 1.8/kWh. Equally typical are phases in which profits can be posted. The latter situation is absolutely essential, since otherwise no production capacity would be replaced. Capital is scarce and goes where the highest yield may be expected – and not to where losses must be feared.

Where prices do not cover the full costs of new structures (incl capital costs), they will offer no adequate incentives for investors. The result is scarcity, which drives up prices. If, on the other hand, prices do offer incentives for constructing new systems, these will in fact be erected. It is the efficiency of plants in particular that dampens the impact of price fluctuations for primary energy and, hence, electricity prices, and it is precisely these effects that are the hallmark of a functioning market.

The author: *Dr Hans-Wilhelm Schiffer*

RWE Power
Head of energy management

Focus on market developments in the energy sector

Underpinning energy-policy balance via competition and efficiency

Germany's energy sector, specifically power generation, is facing significant macro-economic decisions for which planning certainty is urgently needed. What is at stake is energy-policy equilibrium based on security of supplies, economic efficiency and environmental compatibility. Competition- and efficiency-geared tools are the suitable solutions here.

Perspectives for power generation in Germany – Challenges in the decades to come

Between 2010 and 2020, wide sections of Germany's power plant fleet will have to be replaced. Unlike most other countries in the world, Germany has to date been operating very well equipped power stations. Still, such a high need for replacements means that, on average, at least one in three power plants must be replaced. This is equivalent to investment needs of some € 30 bn.

The German energy sector has created most of the technical prerequisites for tackling the tour de force of a ground-covering power plant renewal. Especially in the case of lignite-based electricity generation, a plant technology has been developed that is second to none in the world.

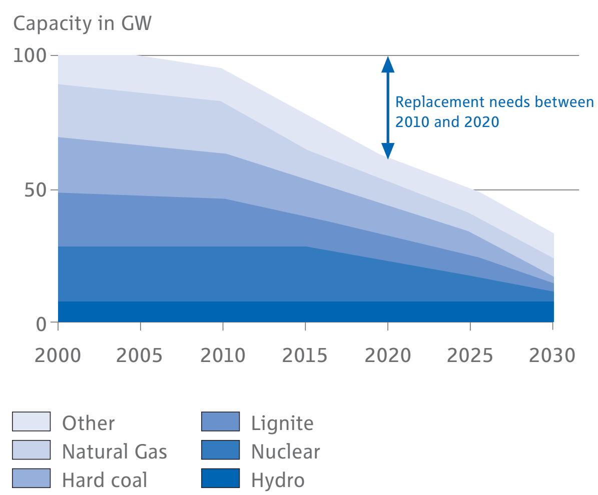
Investment climate must be right

Nevertheless, success in technical developments by itself is not enough. The huge investment amount involved can only be raised if the investment climate is right. The most important precondition for this is a dependable political framework that does not invalidate tomorrow's investment the very next day. After all, this investment will only pay off after very many years.

Politicians are called upon to create long-term and stable underlying conditions and issue political guidelines for the entire energy sector as a basis for the upcoming investment in replacements. The German energy sector is a branch of industry willing to do its bit and to collaborate constructively in a balanced overall concept. To secure its power generation, Germany as an industrial location will go on needing a broad-based energy and technology mix.

There must be room for all fossil, but also renewable, energy sources. The energy sector stands by its agreement with the German government on the further use of existing nuclear power plants. As regards the requirements that will have to be met in future for the prevention of climate change, however, it is necessary to leave open an option to use nuclear energy for the next generations. It must be left to them to decide whether they wish to include nuclear energy in securing a sustainable power supply.

German power plant fleet: Investment running into billions needed
Age-related fall in power plant capacities



Premise: unitary decommissioning after 40 years. If the basis is the residual term for the nuclear power stations pursuant to the phase-out resolution, there will be greater needs for replacement in 2020.
Source: VGB PowerTech

High dependence on imports

Another feature of Germany's energy supplies is a high dependence on imports. In 2003, nearly 75 % of the country's energy requirements had to be covered by imports.

The import rate for oil is especially high. It is the most important energy source for supplies, with an import share of 97 %. In the case of gas, Germany has to cover almost 80 % of its demand with imports. As regards hard coal, too, imports now exceed domestic output. In line with political agreements, the contributions made by domestic hard coal and nuclear energy will fall in future. The result: the import rate will continue to grow.

Oil and gas deposits often in crisis hotspots

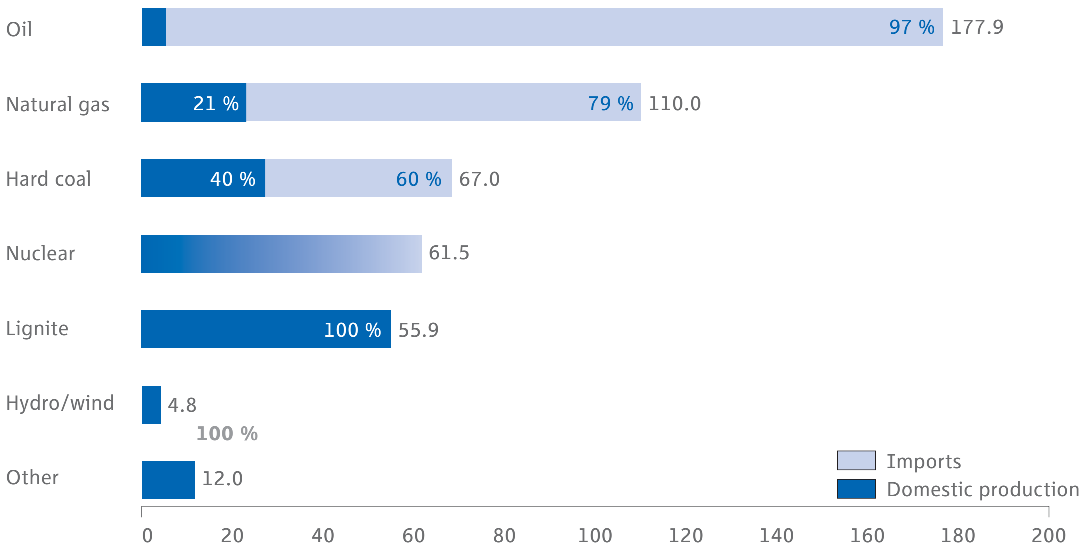
Our chief fuel supplier is the Russian Federation. From Russia we obtain crude oil, natural gas and hard coal. The next-important suppliers are Norway, The Netherlands and the UK. Germany buys gas from The Netherlands, and both crude oil and natural gas from Norway and Britain. Among oil suppliers the list then includes Libya, Kazakhstan, Syria, Saudi Arabia, Algeria and Nigeria in the next slots. The main countries of origin for hard coal to supply the German market in 2003 were Poland, South Africa, Colombia and Australia. Germany imports lignite to a very limited extent. Statistically speaking, nuclear energy is an imported energy since the raw material, natural uranium, is not extracted inside the country. As regards security of supplies, however, nuclear energy may be accorded the same significance as domestic energy sources.

More than two thirds of the world's oil and gas reserves are accounted for by the so-called strategic ellipse, i.e. the earth's acute and latent trouble-spots. So the best way to counter the associated uncertainties is by having a broad energy mix in place that keeps all energy options open, ruling out no generation technology and, in particular, taking adequate account of competitive domestic energies.

Lignite most important domestic energy source

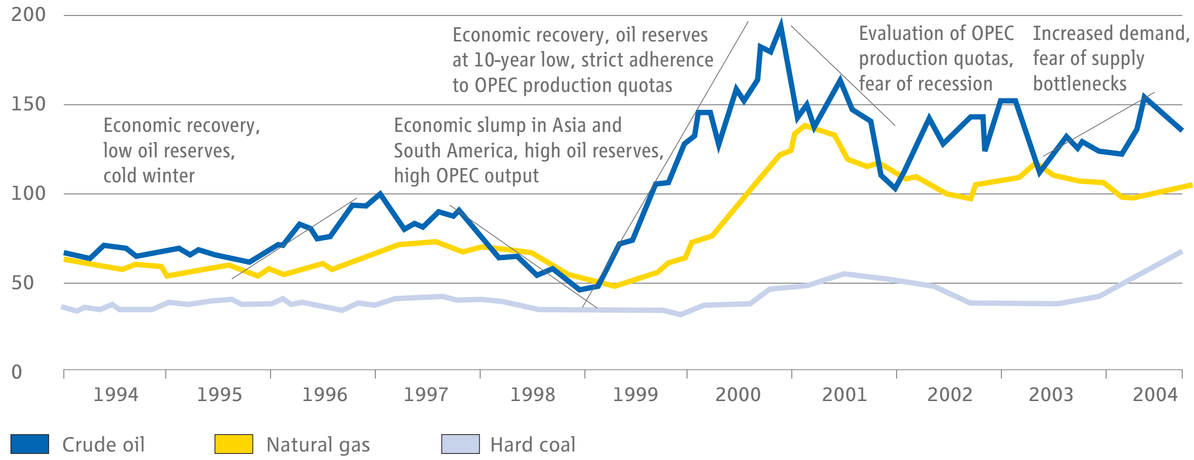
Deposits of any magnitude in Germany are largely confined to hard coal and lignite. In this respect, lignite mined in opencast operations – as a measure of quantities extracted and of calorific value – is the most important energy source. What is more, lignite is the only domestic and competitive energy source available in sufficient quantities that gets along

Germany's dependence on energy imports in 2003
in mill. tce



Source: Arbeitsgemeinschaft Energiebilanzen 01/2004
(Percentages calculated as shares of domestic production in the primary energy consumption concerned)

Price fluctuations as risk factor in the energy sector
Import prices, free German border, in €/tce



Source: RWE Power

Strong price fluctuations for oil and gas; fluctuation bandwidth for hard coal prices much lower; lignite not subject to price fluctuations

without any subsidies. This being so, the underlying political conditions must be shaped in such a way that lignite can be used without discrimination in those areas where the best possible use options exist. For lignite, this means power generation in the base load.

Making efficiency as climate-friendly as possible

In the coming years, the fossil energy sources of coal, oil and gas will remain indispensable – even if utmost efforts are made to increase the share of renewables. A broad-based and balanced mixture of energy sources is the best economic and ecological policy for making Germany a future-proof industrial location.

The key criterion is to make deployment as climate-friendly as possible by ensuring high efficiency. From a security of supplies standpoint as well, economic domestic energy sources – above all subsidy-free lignite – must be given adequate use options in Germany.

Reliance on a widely diversified energy supply allows power consumption to be optimized, also from an environmental and climate-protection angle. A broad and balanced energy mix established by the market creates the best possible equilibrium between the energy-policy goals of security of supplies, economic efficiency and environmental protection. It guarantees the necessary flexibility in energy supplies and optimizes the entire system by having a sound combination of energy sources. This being so, energy mix is the key element in a future energy policy to back the industrial location.

Climate policy: Germany has paid its dues up front

Germany has undertaken to achieve a 21 % cut in the emissions of its chief greenhouse gases (GHGs) by 2008/2012 relative to 1990, so that it has already made considerable concessions in climate policy. Other countries, by contrast, are still quite hesitant in implementing their climate-protection commitments. A staggering 75 % of the EU's emission-reducing obligations has been shouldered by Germany. By 2003 already, some 90 % of the targets had been achieved. Besides an expansion of renewable energies and a restructuring of the eastern German economy, this achievement was largely due to growing efficiency in industry and the energy sector.

Other countries, too, must do their bit

Further progress will require effective international coordination as well as more account taken of cost effectiveness of climate-policy measures. Climate-protection policy must not lead to an excessive erosion of resources that might put the brakes on Germany's economic development. The precondition for national climate-protection goals is that other countries, too, do their adequate bit. Cost effectiveness must be the decisive criterion in selecting climate-policy measures.

NAP, EEG and EnWG re-set the scene for Germany's energy sector

NAP, EEG and EnWG: three abbreviations that kept policy-makers and energy sector on their toes last year. What the National Allocation Plan (NAP), Germany's Renewable Energy Sources Act (EEG) and the Energy Industry Act (EnWG) contain is shown in the following brief overview.

Buzzwords "trade in emissions"/"National Allocation Plan": the set of regulations for implementing the EU Directive dated 13 October 2003 has entered into force. This is true both of Germany's Greenhouse Gas Emissions Trading Law (TEHG; 14 July 2004), the 2007 Allocation Law (ZuG; 31 August 2004), the 2007 Allocation Ordinance (ZuV; 1 September 2004) and of the 2007 Emissions Trade Cost Regulation (EHKostV; 1 September 2004). In November 2004, companies received their notifications on the emission allowances to which they are entitled between 2005 and 2007 from a new specialist unit set up in Germany's Federal Environmental Agency (UBA) as an enforcement and supervisory authority, viz. the German Emission Allowances Trading Office (DEHSt). Other central tasks of the DEHSt include the posting of allowances and the registration of any transactions (German emissions trade register). Accounts, both for plant operators and for professional traders, interested private individuals or associations, were opened in late autumn.

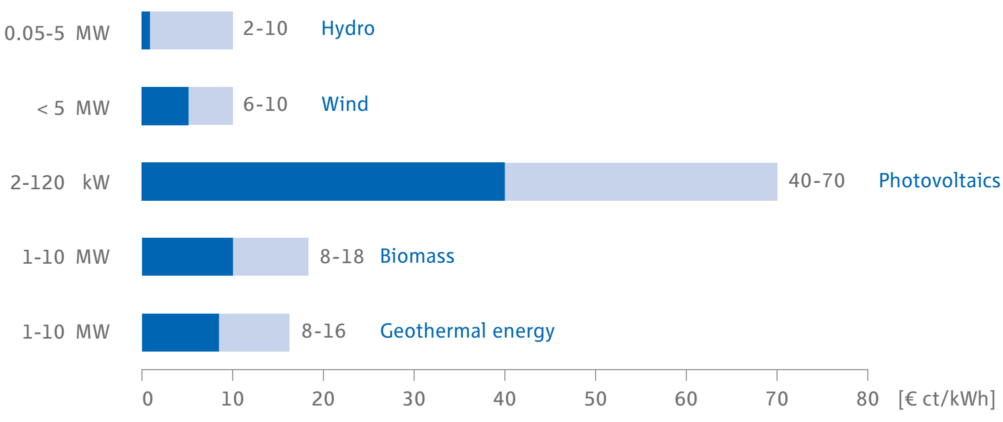
Preparations for the second trading phase 2008-2012 are already under way. The NAP 2008/12 (NAP II) must be submitted to the European Commission by the end of June 2006. A new allocation law and a new allocation ordinance are required. In this connection, Germany's environment minister has asked all operators affected to document and identify the problems encountered in preparing for the first trading phase. It must be assumed that changes will be needed.

Requirements to be met by NAP II

The future regulations in NAP II and ZuG II are to be simple and transparent as possible. The CO_2 emission budget for the energy sector and industry must not fall below 495 mill. t/year in the second trading phase. If economic developments are favourable, the emission budgets may have to be adapted.

Any future regulations must continue to allow investment in new power plants. In general, a simplified system should be advocated here.

Cost price of electricity for renewable energies in Germany



Source: Arbeitsgemeinschaft Energiebilanzen 01/2004
(Percentages calculated as shares of domestic production in the primary energy consumption concerned)

New EEG to prevent excessive subsidies

The chief element in the promotion of renewables is the Renewable Energy Sources Act (EEG). The EEG, in its amended version dated 1 August 2004, follows on from the old regulations, but differentiates more strongly and increases the total level of fees. For wind farms, a minimum-income criterion was introduced. Among the new features we also find "evidence of provenance", a "double-marketing ban" and a "transparency rule" that obliges system operators to publish detailed information on the energy amounts to be offset and any fee payments made.

The fee prescribed by statute exceeds the market value of the supplied power by multiples. Especially high are the subsidies for solar power which are up to 62.4 cents per kilowatt hour. The degressively staggered fees are as much as ct 8.7/kWh for wind power (on-shore), up to ct 17.6/kWh for biomass, up to ct 9.67/kWh for hydropower, and up to ct 15/kWh for geothermal energy.

It is estimated that some 37 bn kWh was promoted pursuant to the EEG in 2004 (source: VDEW). In the calendar year just past, consumers had to bear a burden of approx. € 2.2 bn for promotion under the provisions of the EEG. Since the 2000 EEG came into force, spending by consumers has soared as a result: in the first year, customers subsidized green power with a "mere" € 0.9 bn.

Besides the EEG, incl the biomass regulation, the German government uses further instruments to promote renewable energies. Specifically, these include state investment grants. The government's measures are supplemented by promotion programmes mounted by the German states and the energy utilities.

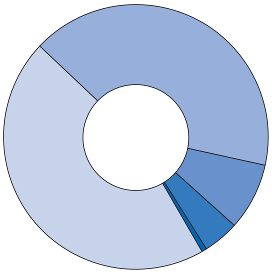
Energy Industry Act passed

On 28 July 2004, the German cabinet approved the government draft bill to amend the new Energy Industry Act (EnWG). The EnWG offers a framework for the statutory instruments to be expected, which will deal with further details (e.g., system access).

The most important change compared with the legal situation pertaining hitherto is that in future the 1,700 or so operators of power and gas grids in Germany, too, will be subject to state supervision. This is to be performed by the former regulator for telecommunications and postal services (Reg TP) under the new name "Federal Regulatory Office for Electricity, Gas, Telecommunications and Postal Services". Further details will not be available until the draft bill has gone through the legislative procedure, which is expected for 2005.

Power generation from renewable energies in Germany, 2003

45.3 bn kWh = 7.6 % of gross domestic power consumption*



20.4 bn kWh**	hydro
18.9 bn kWh	wind
3.7 bn kWh	biomass
2.0 bn kWh	waste
0.3 bn kWh	photovoltaics

* estimate
** excl pumped storage without natural inflow
Source: VDEW

Innovations to prevent climate change
in fossil-fired power plant technology

Responding to the challenges of growing energy consumption

Growing energy consumption, a serious rise in greenhouse gases – how can industry respond to this challenge? What is needed are innovations to prevent climate change in the area of fossil-fired power plant technology. Important developments in this sector are presented, scrutinized and assessed in what follows. Well-known authors from industry, politics and science convey a broad spectrum of opinions and prospects. Also, RWE Power explains its strategy as well as its research and development commitment for innovative fossil power plant technologies.

Photo pages 36/37
In the conveyor belts that transport coal and overburden in the opencast mines, energy savings of up to 6 % can be obtained by optimizing the chemical composition of the rubber in the belts and the disks for return idlers, this according to the results of laboratory and bench tests. Using a specially developed in-house technology, a conveyor belt in the Garzweiler opencast mine is being checked as to whether and for how long this works in practice. The photo shows the head of the test department of the Opencast Mine Engineering Centre, Dr Bruno van den Heuvel, with a thermography camera monitoring temperature and heat profiles.

Photo: Klaus Görgen

In electricity generation, RWE Power prioritizes the route of efficiency increases

Power plant technology on the basis of fossil energy sources offers considerable potentials for sustainable climate protection in a global setting, thanks to the high technical standards already achieved and the foreseeable development horizons. Highly efficient clean coal and natural-gas technologies are being prioritized today, as Dr Johannes Lambertz, Executive Vice President of RWE Power, explains.

Efficient coal- and gas-fired power plants are indispensable for energy supplies. In the foreseeable future, renewable energies will not be available for this purpose in sufficient quantities. If nuclear energy is phased out, coal and gas will have to provide even more capacity. So fossil-fired power plants will do their crucial bit in perceptibly lowering global CO_2 emissions, thanks to a steady increase in efficiencies. Each increase in efficiency also helps spare resources, which is in line with the sustainability principle. This being so, the continuous further development of steam power plants to yield even more efficient technologies for low-CO_2 power stations is an effective way of ensuring economic efficiency, security of supplies and environmental compatibility.

Extra outlays required enormous

The vision of a zero-CO_2 fossil-fired power plant holds out a promise of further reduction potentials. Unlike an increase in efficiency in power plant technology, which is a primary measure, CO_2 capture and storage in zero-CO_2 fossil-fired power stations are secondary measures. The additional outlays required to capture and store CO_2 are enormous in the light of today's knowledge. Compared with the most efficient technology available today,

- the specific capital costs of a power plant are up by about a factor of two;
- power generation costs rise between 80 and 150 %;
- resource consumption, due to the loss of efficiency, grows by up to one third.

Besides economic efficiency, public acceptance, too, will play a large part. This concerns both the much higher consumption of resources needed to produce energy, and the long-term storage of CO_2 in aquifers and depleted oil or gas deposits.

Zero-CO_2 power plant no royal route

This being so, the route toward a zero-CO_2 fossil-fired power plant is no royal route. Until the zero-CO_2 power plant technology can be deployed on a widespread commercial scale, extensive parallel developments in power plant and storage technology must take place along with the requisite long-term studies. These will be concluded in 2020 at the earliest.

RWE Power is primarily backing the route of increasing efficiency in electricity generation and, hence, low-CO_2 power plants. Power plant renewals and an active role played in developing even more efficient technologies are an expression of this commitment. In parallel, we are working on turning the vision of a zero-CO_2 fossil-fired power plant into reality.

The development of new power plant technologies that can be deployed on a commercial scale requires high outlays. In view of tight markets, adequate promotion of research is indispensable. Free from ideology, it should include all options and, hence, take specific account of developments in efficiency increases in view of the high potential they offer for sustainable prevention of climate change.

The author: *Dr Johannes Lambertz*
RWE Power
Executive Vice President
Fossil-fired power plants portfolio

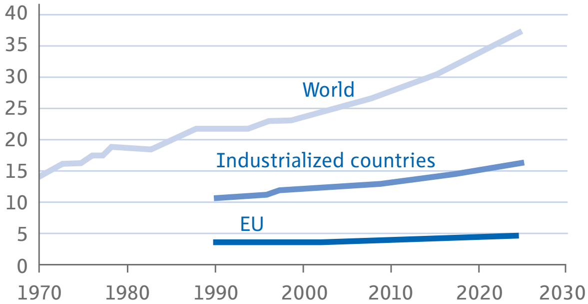
Strategy of three innovation horizons offers the best options for lowering CO_2

The prevention of climate change finds itself in a field of tension marked by strong growth of worldwide energy consumption and the associated increase in CO_2 emissions. Thus, the World Energy Outlook 2004 published on 26 October 2004 by the International Energy Agency (IEA) shows that global energy consumption will rise by just under 60 % from 14.8 bn tce in 2002 to 23.6 bn tce in 2030. Accordingly, worldwide annual CO_2 emissions will increase from the present 24 bn t. to 38 bn t. In the same period, global power generation will double from 16.1 to 31.7 trillion kWh. The average annual growth rates for primary energy consumption will be 1.7 % and, for power consumption and generation, 2.5 %.

Fossil energies will continue to dominate the supply side. Their share will even increase slightly, viz. from 80 % in 2002 to 82 % in the year 2030. Absolute fossil energy quantities will grow by 63 %, so that CO_2 emissions cannot fail to rise, quite contrary to the goals of preventing climate change. In the face of this dilemma, innovations in modern power generation technologies on the basis of fossil energy sources – the pillar of worldwide energy supplies – are the crucial key to efficient prevention of climate change.

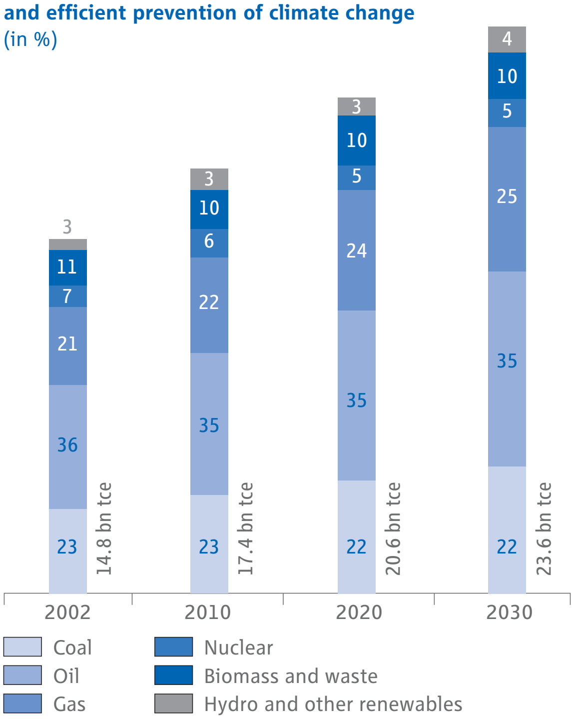
The fact that innovation in power plant construction is also key for climate protection is shown by the examples of ultra-modern power plant technology on the basis of the fuels lignite, hard coal and natural gas. Compared with average global efficiencies of around 30 % in fossil-fired power plants, modern fossil-fuel stations today already reach values between 43 and 58 %. Since CO_2 emissions are conversely proportional to efficiencies, the emission of this greenhouse gas can already be significantly reduced using existing state-of-the-art power plants.

Worldwide CO_2 emissions, in bn t
Field of tension: prevention of climate change



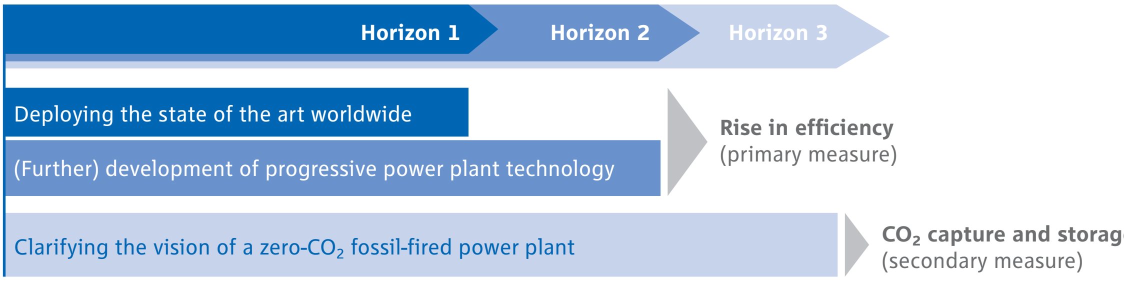
International Energy Outlook 2004
Source: Energy Information Agency (Washington)

The challenges of strongly rising energy requirements and efficient prevention of climate change
(in %)



World energy consumption until 2030 by energy source reference scenario
Source: IEA (Paris), World Energy Outlook 2004

Strategy for CO_2 reduction in electricity generation



A systematic and innovation-powered strategy for CO_2 reduction in the use of fossil energy sources ought to encompass three horizons, these to be pursued in parallel.

- **Horizont 1** involves the worldwide deployment of state-of-the-art technology in replacing old power plants or in the construction of the additional power plants required. The successive renewal of the world's coal-fired power plant fleet can lead to a CO_2 reduction of nearly 2 bn t/a. This drop of over 30 % is equivalent to the entire CO_2 emissions of Europe's road traffic. A big help along this route could come from cutting red tape in the rules for the flexible instruments JI and CDM in the Kyoto Protocol.

- In parallel, **Horizon 2** concerns the further development of the very latest in power plant technologies. The crucial levers here are the increase in the parameters of power plant processes and the introduction of pre-drying in lignite-fired power plants. The development of such technologies is a task above all for industrialized countries. The two horizons aim at reducing CO_2 levels by increasing efficiency. This primary measure combines the sparing use of resources and preventive climate protection. This being so, the efficiency-increasing road has no alternative. In the past 50 years or so, for example, it has been possible to cut specific CO_2 emissions per kilowatt hour by 30 %. In about 2030, further technological developments will have made an additional 20 % possible.

- Virtually zero-CO_2 electricity generation on the basis of fossil fuels that cannot be obtained by increases in efficiency alone may possibly be realized using the secondary measure of CO_2 capture and storage. To this end, the point of **Horizon 3**, likewise being pursued in parallel, is to clarify the vision of the zero-CO_2 fossil-fired power plant. The main incentive here lies in paving the way for practically climate-neutral power generation using the energy source coal, which certainly has the most extensive reserves worldwide and is of the greatest importance for world electricity generation. The technologies required for this purpose largely build on existing developments. In the case of CO_2 capture and storage, however, we are dealing with a further secondary measure in the electricity generation process, linked with a significant increase in energy and resource consumption. This gives rise to considerable additional expense. The first step must be to examine this route from a technological, economic, ecological and geological angle. CO_2 storage that is safe in the long run and enjoys adequate public acceptance will be essential for this line of technology.

Focus on all technological options

The strategy of three innovation horizons for reducing CO_2 levels in power generation worldwide does not require any decisions in principle to be taken today on the best technology for the future. In view of the challenges facing the world energy supply, what matters is that we address all technological options – with appropriate weighting, of course. The increase in efficiency can be obtained at once and worldwide using existing technology; in parallel, even more efficient power plant technology can be developed. That is why efforts on behalf of increases in efficiency have top priority today.

The following sections introduce, scrutinize and classify innovations for climate protection in the area of fossil energy sources. The overview of power plant technology is supplemented by special contributions on CO_2 capture and storage techniques. These are accompanied by examples of technological developments already launched. Information on national and European promotion policy and the various development programmes involved in power plant technology is provided by staff from the Federal Economics Ministry and the EU Commission. The IEA Greenhouse Gas Programme is introduced. Its main remit is to observe, assess and pass on the relevant technical developments. This subject is rounded off with an evaluation and classification of the innovation routes discussed.

Climate protection places greater demands on power plant technologies

In the next few decades, the energy sector will note an enormous demand worldwide for the replacement of old, and the construction of additional new power plants. Here, the fossil energies coal and gas will also go on being the dominant energy sources. The challenges of climate protection are placing growing demands on the environmental compatibility of all power plant technologies. Ways to achieve low-CO_2 power generation are outlined in this report.

Emissions trading steps up pressure to modernize power plants

Until now, power plant design has largely been based on given stationary operating points with a focus on a technical and economic optimum. This line of development has led to a state of the art with efficiencies of over 43 % for lignite-based power plants and over 45 % for hard coal-fired power stations. Such efficiencies are in line with steam temperatures of 600 to 620 °C and pressures of 300 bar made possible by the steel types available today. Prof Dr Günter Scheffknecht (Stuttgart University) and Dr Georg-Nikolaus Stamatelopoulos (Alstom Power Boiler GmbH) describe three horizons.

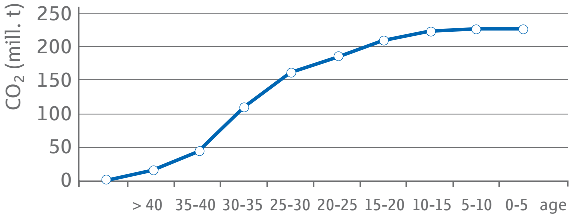
Horizon 1: The liberalization and deregulation of the electricity market are intensifying competition and leading to greater efforts to optimize power plant deployment and cut operating costs. With smaller units in particular being shut down, growing demands are being placed on the remaining power plants and on new plants as regards their load-following properties. In addition, the prevailing policy of promoting renewable energy sources is steadily increasing their share in the interlinked German and European energy system. They have a low rate of plant utilization, are difficult to forecast in deployment planning and give rise to greater requirements in the way of balancing energy and reserve capacity. On the basis of the EU resolution – in a preparatory pilot phase starting in January 2005 and as binding control mechanism starting in January 2008 – to introduce a trading system for CO_2 emissions, the technologies for reducing, and concepts for avoiding, CO_2 are now gaining in importance. Coal-fired power plants, in view of the fuel employed, have higher specific CO_2 emissions. In the short and medium term, reductions here will depend entirely on improved efficiency or on a change of fuel. Three trends can be noted:

- Optimization of the use of existing power plants by increasing their availability, flexibility and reliability. The high availability values in today's power plants are to be maintained even if coals outside the original design bandwidth are combusted. Besides the introduction of intelligent boiler cleaning systems, RWE and Alstom are cooperating on new, cleaning-friendly heating-surface concepts.

- Replacement of old power plants by new plants designed for flexible deployment with daily start-up and shutdown. Besides the specifications for primary reserve capacity to support the system frequency, such plants are expected to have an adequate hot-start capacity as far as the number of starts or their duration are concerned, as well as sufficiently fast load-change behaviour. In this respect, it is advisable to limit the design steam conditions to approx. 560 to 570 °C. This gives the operator a plant, which can – if necessary – be started up and closed down on a daily basis and can safely reach load-response rates of some 4 %/min. The gain in flexibility comes at the cost of an efficiency loss of approx. 1 % point.

- Replacement of old power plants with new plants designed to achieve maximum efficiencies or steam parameters mainly for base-load operations. A simple comparison shows that replacing old with modern coal-fired power plants boasting an efficiency of 43 % can generate a saving of 3 mill. t CO_2/a with a capacity of 1,000 MW. Given today's age and efficiency distribution in the European power plant fleet, this would be equivalent to a saving potential of some 225 mill. t CO_2/a, which amounts to 92 % of the Kyoto target for the EU.

CO_2 reduction by raising efficiency in EU



Source: ALSTOM

Accumulated savings in CO_2 for the various age groups of existing plants, assuming that they are successively replaced by new ultra-modern coal-fired plants.

Technical progress most meaningful in medium term

In conventional pulverized coal-fired power plants, a further rise in efficiency is possible mainly by increasing the steam parameters, viz. pressure and temperature. In the case of lignite-fired power plants, pre-drying of the raw lignite is an additional option.

Horizon 2: Besides the increase in steam parameters, efficiencies in the past were obtained mainly by improving internal turbine efficiencies and optimizing the cold end or the entire water/steam cycle, by multiple reheat, and by reducing auxiliary power requirements. These potentials have been largely exhausted by now. In future, increasing the steam parameters will play a decisive role.

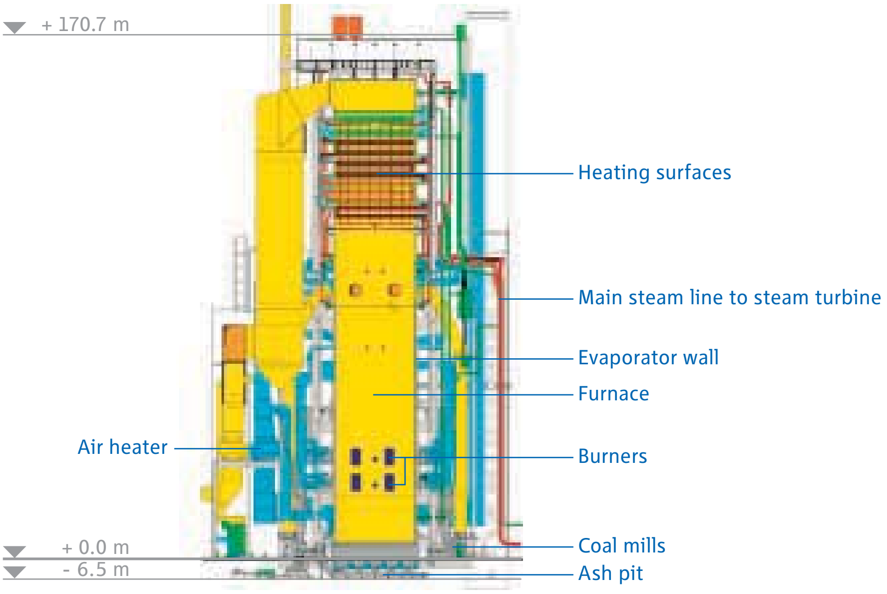
In Germany, the last ten years have chiefly seen the construction of lignite-fired power plants. In 2002, for example, the eighth supercritical lignite-fired power plant unit in Germany since 1990 went on stream: this was unit K at the Niederaussem power plant belonging to RWE Power with steam outlet temperatures of 580 °C at the high-pressure section and 600 °C at the reheater and with an efficiency of over 43 %. The design of the unit is based on the BoA concept: lignite-fired power station with optimized plant engineering. The twin-unit plant in planning at the Neurath location is a witness to the systematic further pursuit of this line of development. A further increase in steam temperature to over 600 °C improves circuit efficiency. Also, performance is raised by a further 10 %.

The trend can be seen in other countries as well with the first supercritical plant at the Florina location (Greece) and the Patnów plant (Poland) with steam data of 266 bar/544 °C/568 °C.

The new challenge – the 700 °C power plant

The next possible step in the medium term is the realization of steam parameters in the range of 375 bar/ 700 °C/720 °C with an efficiency of over 50 %.The advantage of this line of development is that the overall process remains the same and can benefit from long years of operational experience with plants of this type. Progress is concentrating on developing and testing new materials for a the few critical power plant elements.

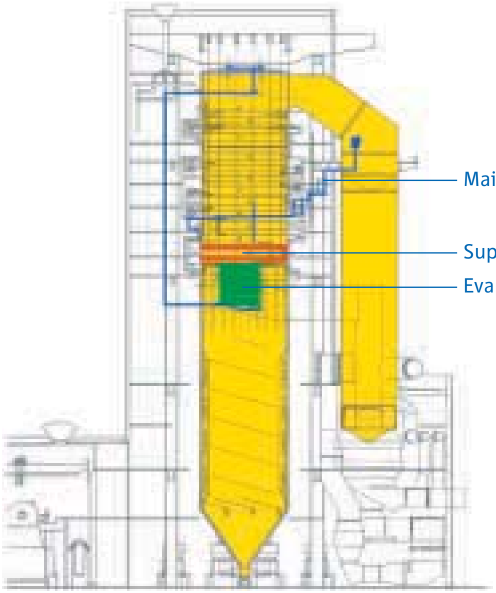
Schematic diagram of a BoA power plant in the 1,000-MW class



Source: ALSTOM (2)

BoA power plant in the 1,000-MW class: Better utilization of waste gas heat, an increase in steam conditions and process optimization, along with 10-stage condensate heating, modern steam turbine, improved cold end and lower auxiliary power requirements, all go to increase efficiency by 9.7 % points relative to existing 600-MW units.

Component testing plant COMTES 700



A milestone in the development of 700 °C technology is the trialling of critical power plant components for this temperature bracket at the Scholven F plant belonging to E.ON Kraftwerke. The project, known under the acronym COMTES 700, is financed by a consortium consisting of the nine European energy suppliers RWE, E.ON, EnWB, Vattenfall, EDF, Electrabel, Elsam, Energi E2 and PPC, by the European Commission within the scope of the Research Fund for Coal and Steel (RFCS) and by the manufacturers involved, viz. Alstom Power Boiler, Babcock-Hitachi Europe, Burmeister & Wain Energy and Siemens. In this project, heating surface sections, thick-walled components, piping and fittings are being tested at an existing hard coal-fired 750-MW power plant in the course of power plant operations at 700 °C for a period of over three years. At such high temperatures, the use of nickel-based materials is necessary. Their manufacture on a commercial scale is proving to be a particularly sophisticated task. In addition, operational experience will be gained on expansion, steam oxidation and flue gas corrosion behaviour for the critical power plant components.

Compared with the average for coal-fired power plants installed in the EU, 700 °C technology will yield a 30 % reduction in CO_2 emissions and, in this way, limit the specific CO_2 emissions to some 650 g/kWh in the case of hard coal.

Pre-drying as attractive efficiency potential

Especially in the case of lignite-fired power plants, the pre-drying of raw lignite makes it possible to increase efficiency by approx. 4 % points: Drying the raw lignite with low-pressure steam in a fluidized bed provides the necessary drying energy at a low-exergy level without directly using the fuel heat for this. At the same time, the energy of the released vapours is used internally in the process. For this, RWE has systematically further developed its own fluidized-bed drying technology (WTA) in the course of the last 10 years. The commercial-scale operability of coarse-grain drying was already successfully proved, from 1993 on, at the WTA demonstration plant in Frechen with a throughput of 50 t/h raw lignite. The breakthrough came in 2002 with the operation of WTA fine-grain drying, likewise in Frechen, with a throughput of 30 t/h. In fine-grain drying, the raw lignite is finely ground to a grain size of 2 mm prior to being input in the fluidized-bed drier. The fine-grain drying technology lowers the volume of the drier, reduces the specific capacity of the vent stack scrubber fan, and, in this way, meets the original target of increasing plant efficiency with constant electricity-production costs.

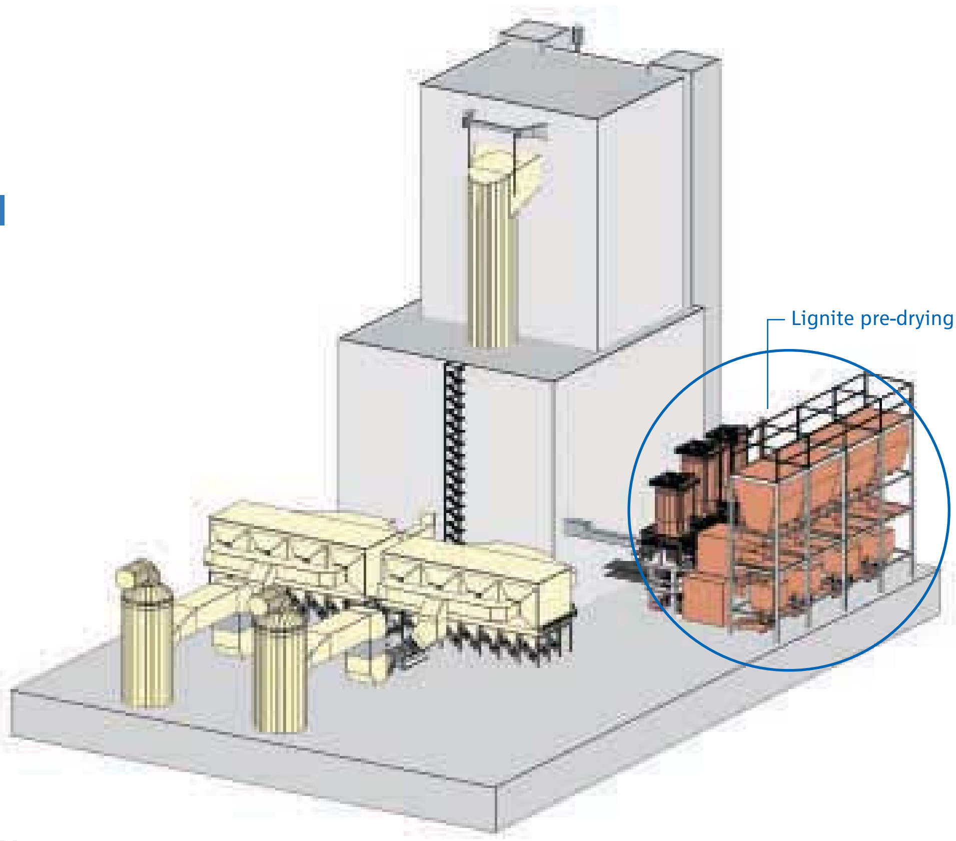
In 2004, RWE Power launched a WTA prototype plant project at the BoA unit in the Niederaussem power plant. The project comprises the planning and construction of a prototype plant for the pre-commercial 1:1 testing of fine-grain WTA technology as well as the co-combustion of dried lignite in the BoA unit.

Further developments continue the trends of recent years

Within the scope of an EU-promoted sub-project, ALSTOM, along with other partners, is assisting in the planning and operations in particular. Also, the company, as part of a study for RWE Power, has investigated the design of a steam generator fired with dried lignite (BoA-Plus concept). While the burner system is very similar to hard coal firing, it is the lignite and ash properties as regards propensity to slag and NO_x emissions that are crucial for the combustion chamber design.

The further development of progressive power plant technology is systematically continuing the trends of the last 50 years. Stepping up efficiencies helps save resources, reduce all pollutant emissions and meet the targets for the reduction in CO_2 emissions. The goal is to compensate the extra investment costs for efficient plants by having higher efficiency rates and lower fuel consumption, so that electricity production costs can be kept constant. Compared with other CO_2 capture or avoidance technologies, therefore, the result is the lowest level of CO_2 avoidance costs. This makes further development of the progressive power plant technology the most effective and economically meaningful option for lowering CO_2 emissions in the short and medium term.

BoA-Plus with lignite pre-drying (schematic diagram)



Source: RWE Power

Capture and storage still too expensive at present

The option of a further reduction in CO_2 emissions going beyond the increase in efficiency may possibly be developed and opened up on a commercial scale by technologies for capturing and storing CO_2.

Horizon 3: In recent years, growing efforts have gone into examining such technologies for use in power plants. Separation processes already employed in refineries are a possible technological road leading to CO_2 capture in conventional power plants.

In parallel, combustion is being developed at laboratory level using pure oxygen either produced in an air separation unit or taken from a gas mixture using suitable membrane technology. In this process – also known as Oxyfuel – the flue gas following condensation of the steam share consists almost entirely of CO_2. Maintenance of the temperature in the combustion chamber of the steam generator is by flue gas re-circulation. In fluidized-bed systems, the temperature can be regulated in part by suitable ash re-circulation. At present, this technology is being examined in detail on a laboratory scale in Germany as well.

Significant rise in electricity production costs

In addition, there is the option of converting solid fuels into a synthesis gas by gasification and freeing this of CO_2 prior to combustion. The integrated gasification combined-cycle power plant (IGCC) permits a thermodynamically very advantageous form of this variant. This technology, too, is currently to the fore in investigations in Germany and worldwide.

What is important is that these developments are accompanied by clarification of stable long-term CO_2 storage. The concepts provide for the CO_2 to be stored in liquid form in former oil or gas deposits or in deep layers carrying salt water (saline aquifers). Quite apart from the fact that CO_2 capture and storage have not yet been sufficiently investigated and the problems involved not yet finally solved, CO_2 capture and avoidance technologies are not economically defensible yet under the present underlying conditions. With the most favourable assumptions, electricity production costs will rise by some 70 % relative to today's levels owing to CO_2 capture, transport and storage, while efficiency will worsen and the range of resources significantly decline.

In numerous R&D projects, operators, manufacturers and universities have joined forces to turn CO_2 capture and avoidance technologies and, hence, the visions of a zero-CO_2 power plant, into a realistic long-term option for the period after 2020.

Upshot

Employing the modern coal-fired power plant technology available today can help achieve considerable reductions in CO_2. Hence, there is no reasonable alternative to this route as far as effective climate protection is concerned. Whether and to what extent further-going capture and storage of CO_2 will be available after 2020 will depend crucially on the feasibility of safe storage and on public acceptance.

The author: Dr Georg-Nikolaus Stamatelopoulos

ALSTOM Power Boiler GmbH
Head of calculations and development

The author: Prof Dr Günter Scheffknecht

Director of the Institute for Process Technology and Boiler Engineering at Stuttgart University

Capture and storage: options for handling carbon dioxide

What is the state of play in developments for CO_2 capture and storage? What technologies are feasible at all for CO_2 separation? What options exist for storing carbon dioxide? Answers to these questions and specific project examples that are attracting the efforts of researchers at universities and in companies are discussed in this chapter.

Three technological routes open up possibilities for CO_2 capture in fossil-fired power plants

Using efficiency-enhancing measures, CO_2 emissions associated with the output of present-day fossil-fired power plants in Germany can be reduced by some 30 %. Any CO_2 reduction going beyond this calls for processes that are able to capture as much of the CO_2 produced from the power plant process as possible. Here, three optional technologies can be identified which are now being developed and evaluated worldwide. This subject has been addressed by Prof Dr-Ing Alfons Kather (technical university TU Hamburg-Harburg) and Dr Ludolf Plass (Lurgi AG).

Depending on the specific location of the CO_2 capture in the material-conversion chain, three separating strategies in principle can be distinguished:

1. Flue-gas decarbonization: CO_2 separation from flue gas following combustion with air.

2. CO_2 concentration in flue gas following combustion with oxygen.

3. Fuel-gas decarbonization: CO_2 capture from fuel gas prior to combustion.

The capture process concerned is closely linked with the underlying power plant type. Whereas measures in line with the first of the above capture strategies – CO_2 scrubbing from the flue gas – can be installed downstream of practically any fossil-fired power plant type, the other separation processes require substantial intervention in the actual power plant process, or even a completely new power plant concept.

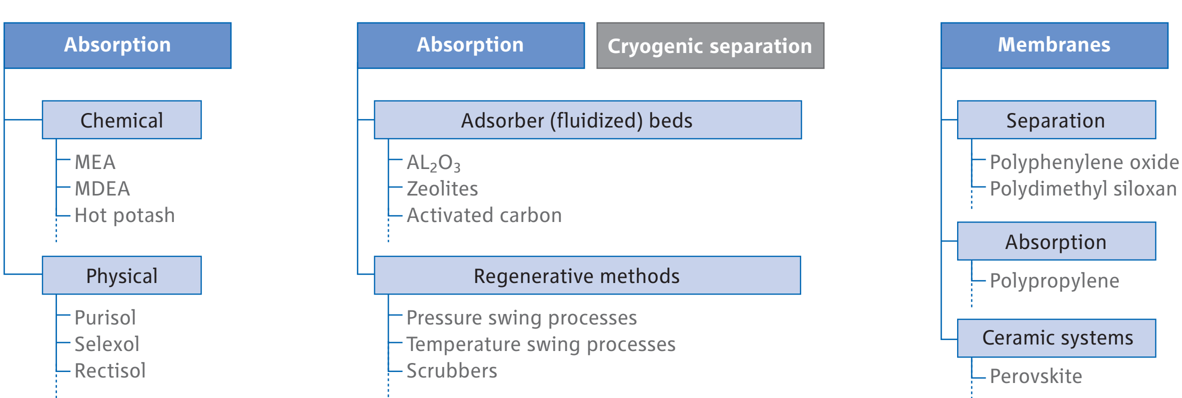
The absorption technologies for CO_2 capture in particular, i.e. scrubbing processes, are familiar in principle and have been extensively tested in the chemical industry. A commercial-scale installed example for Rectisol scrubbing can be found in fuel synthesis, as realized by Sasol in South Africa, for instance.

Extra requirements in the way of fuel, higher investment

All the same, the availability and efficiency of these processes must be demonstrated under power plant conditions in pilot plants as well. Commercial-scale use in power plants is possible in the medium term. Depending on capture process and power plant type, the present state of knowledge indicates a considerable loss of efficiency here (6 – 15 % points). For the same rated capacity, this calls for extra fuel requirements of 10 – 35 % and considerable additional investment (30 – 150 %).

The most important technological routes being pursued at present are shown on the following pages.

Chief technologies for CO_2 separation



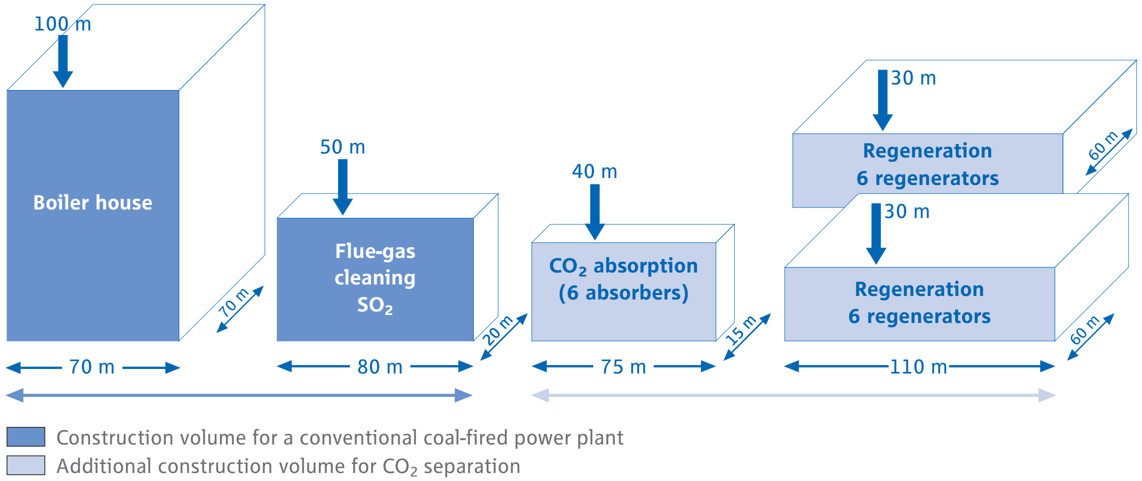
Conventional coal-fired steam power plant with CO_2 separation: In the conventional steam power process, the separation of CO_2 from the atmospheric flue gases can be implemented using a solution of monoethanolamine (MEA), water and, possibly, other auxiliary substances, e.g. to avoid corrosion. Heat from the low-pressure steam is used to regenerate the MEA solution. As a result, the total efficiency of the steam power plant unit falls by approx. 10 – 15 % points. Such high losses of efficiency are a consequence of the low CO_2 concentration in the atmospheric flue gases, which calls for the use of a scrubbing liquid with a chemical effect and high regeneration steam requirements.

CASTOR examining separation with scrubbing liquid

In addition to the existing volume of construction for the boiler house and for flue-gas cleaning in conventional plants, there is almost as much again for the absorption plant and the regeneration. In principle, this technology offers the possibility of retrofitting existing power plants. At the Esbjerg coal-fired power plant in Denmark, the CASTOR European research project is currently engaged in representative investigations of the separation of CO_2 (1 – 2 t/h) from the flue gas flow with the aid of various scrubbing liquids.

Summing up, it can be said that, in CO_2 separation from conventional flue gases downstream of conventional coal-fired power plants, the present state of our knowledge shows that conditions are least favourable owing to the higher investment costs, a very serious reduction in efficiency and, hence, extra expense for fuels.

High additional construction volume in the case of a conventional power plant with CO_2 scrubbing



Simplified diagram showing the structural dimensions of a plant for a 660-MW hard coal unit with downstream CO_2 scrubbing

Coal-fired steam power plant with oxygen combustion and CO_2 capture (Oxyfuel process): Conditions are more favourable for the so-called Oxyfuel process, which is why this process is also being further pursued as a focus within the scope of the German research programme COORETEC (see p. 65). First mention was made of the coal-fired Oxyfuel power plant process with CO_2 separation in connection with the provision of CO_2 for the Enhanced Oil Recovery process (EOR) in the early 1980s. Nonetheless, no pilot plants have been built so far for this process.

The process is based on the classic coal steam power plant, with the combustion of the coal taking place in the steam generator not with air, but in an atmosphere of oxygen, provided by an air separation unit, and recirculated flue gas. The main components of the flue gas are CO_2 and water, so that the CO_2 can be favourably separated and liquefied in energetic terms by condensing the water. Scrubbing with regeneration is not required here. A further advantage of the Oxyfuel technology is the possibility of dispensing with costly waste gas scrubbing systems like DENOX and flue gas desulphurization (FGD). This eliminates some of the additional investment costs.

Striking innovations

The process is basically divided into the main components air separation unit (ASU), steam power plant, flue gas condensation, waste water treatment and flue gas liquefaction. The flow of oxygen obtained in the ASU is mixed with recirculated flue gas in order to keep the combustion temperature and, hence, the thermal impact on the heat transfer surfaces within a technically controllable range. To this end, in the case of pulverized coal furnaces, some two thirds of the flue gas quantity must be recirculated downstream of the steam generator.

The steam generator itself as well as the water/steam cycle resemble those of conventional modern steam power plants, but also have significant differences. The need to cool off the flue gas to the ambient temperature and condense out the water contained, with the air heater being dispensed with, leads to a change in the supply of heat on the flue gas side, which mainly entails an increase in the supply of low-temperature heat. Incorporating this into the process affects the extent of the regenerative heating of the feed water and requires additional flue gas-heated heat exchangers in the steam generator, which may have a great impact on investment costs.

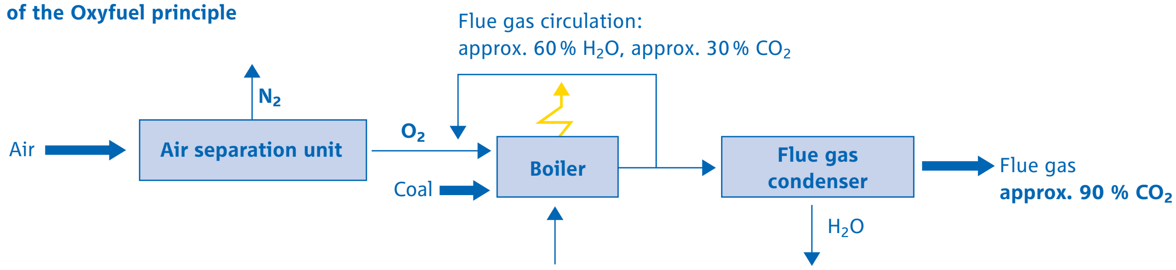
8 % points loss of efficiency

The flue gas is cooled off to dew-point temperature in the flue gas condenser and, in this way, freed from a large part of the water load. The residual water is removed from the flue gas by molecular sieves. The concentration of CO_2 in the now-dry flue gas is some 90 %.

The rest consists mainly of superfluous oxygen as well as argon and small quantities of nitrogen as well as sulphur and nitrogen oxides. While some of the pollutants dissolve in the condensed-out water and in the liquid CO_2, it is necessary to separate oxygen and argon during the liquefaction of CO_2 at about 20 bar and at -45 °C. At a transport pressure of some 100 bar, the CO_2 obtained in this way remains fluid even at ambient temperatures.

In a study undertaken by TU Hamburg-Harburg, the Oxyfuel principle was applied to a modern hard coal-fired power plant. The results indicate that, relative to the basic process, there is an 8 % point loss of efficiency.

Block diagram of the Oxyfuel principle



IGCC process with CO_2 capture: In the combined-cycle power plant with integrated gasification (IGCC), understoichiometric partial oxidation of coal with oxygen yields a fuel gas instead of flue gas, the main components being carbon monoxide, hydrogen and carbon dioxide. The fuel gas is scrubbed and conducted to the combustion chamber of a gas turbine. The downstream combined-cycle system is comparable with a natural gas-fired CCGT process. So far, five demonstration plants with capacities between 100 and 300 MW have been commissioned worldwide with different gasification processes for the fuel hard coal. In view of the substantial gain in efficiency, thinking in Germany during the early 1990s was also directed toward building a large-scale combined-cycle power plant with integrated coal gasification, but any such plans were later discontinued specifically because of the high initial investment required, the complex plant technology and availability risks and because of the successful increase in the efficiency of conventional power plant units.

Adjustments to gas turbine and burner

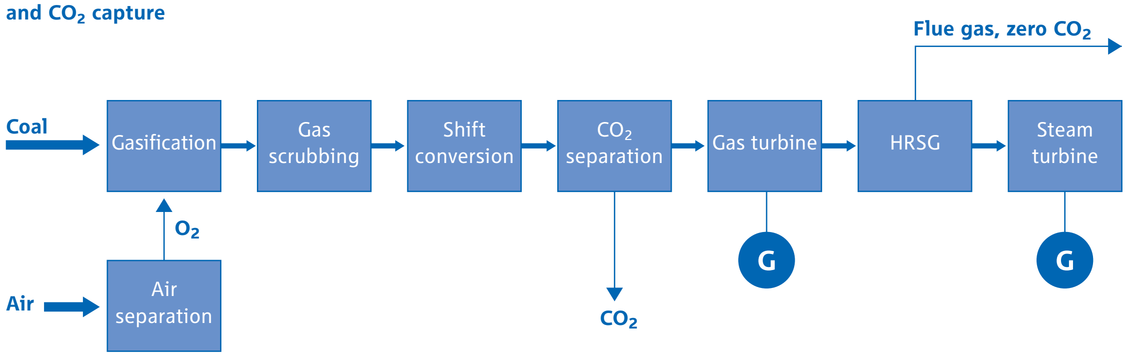
When viewed from the angle of additional integrated CO_2 capture, however, the IGCC process again looks like a very promising proposition, since favourable CO_2 separation can be obtained here upstream of the combustion. The gasification of the coal with oxygen is followed by the conversion (shift) of the CO in the synthesis gas into hydrogen and CO_2. A first gas scrubbing unit removes undesirable gas components (H_2S, COS, HCN, NH_3).

The CO_2 is separated in a second scrubbing unit. The process control of the fuel gas preparation is practically identical with one of the processes already implemented in many cases for producing ammonia from coal. Following the CO_2 separation, the fuel gas has a relatively high H_2 content. The adaptation of the gas turbine and, in particular, the burners to this change in the gas composition is one focus of further developments leading to a zero-CO_2 IGCC power plant.

COORIVA to identify weak points

The overall efficiency of the circuit, viz. 42 to 46 %, is 6 to 10 % points lower than in the case of a comparable modern IGCC without CO_2 capture. Hence, the high development level of combined-cycle power plant technology as well as the relatively moderate impact of CO_2 separation on costs and efficiency make IGCC technology an attractive solution for zero-CO_2 power generation. Key development tasks have already been tackled or are being prepared. The focus of the European research project ENCAP, now up and running since early 2004, is not only on the drawing up of optimized configurations for hard coal and lignite as well as natural gas, but also and in particular, on the development of gas turbine burners for fuel gases high in hydrogen. The COORIVA scheme applied for at the Federal Ministry of Economics and Labour (BMWA) within the scope of COORETEC will, above all, identify the still-existing underlying weak points in the IGCC processes and, in particular, develop tenable concepts on availability and costs.

Coal-fired IGCC with CO conversion and CO_2 capture



Upshot

For the future option of separating CO_2 from fossil-fired power plants, three basic technology routes are feasible:

1. Conventional steam power plant process with CO_2 capture from the flue gas
2. Steam power plant process with oxygen combustion and flue gas recirculation (Oxyfuel process)
3. Integrated gasification combined-cycle power plant with CO_2 capture from the fuel gas.

Relative to the processes without CO_2 capture, all routes are generally associated with considerable extra expense and additional energy consumption. In detail, however, differences do lead to a differentiated appraisal.

1. Although CO_2 capture from the flue gas by means of amine scrubbing is already practiced in some special cases, it requires comprehensive testing especially for coal-specific flue gases. This route involves the highest additional costs and the greatest losses of efficiency.
2. In the Oxyfuel process, the effects of CO_2 capture are more moderate than in the case of amine scrubbing, so that this process looks much more attractive. On the other hand, its key steps still have to be examined and the whole scheme developed to commercial maturity.
3. The most promising route, as things look today, is the integrated gasification combined-cycle power plant with CO_2 capture. This achieves the highest efficiencies with comparatively low cost increases. Development tasks concentrate on the gas turbine, which must be designed for the combustion of a fuel gas high in H_2 (see p. 62).

Efforts are now being redoubled to develop processes with CO_2 capture in numerous national and international projects. The important point is that the indispensable proof of CO_2 long-term storage keeps pace with these developments.

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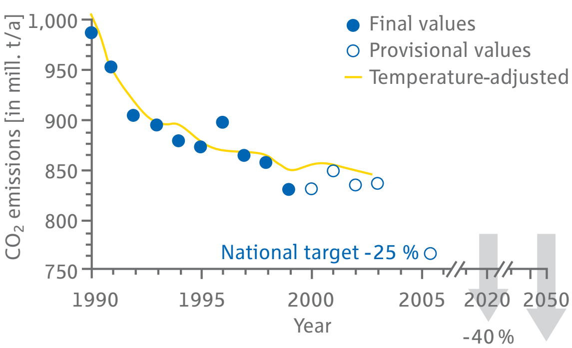
Options for underground storage already being trialled in practice

Zero-CO_2 electricity generation can only be justified if long-term storage of the separated CO_2 is assured and if release into the atmosphere can be safely ruled out. Peter Gerling from Germany's Federal Institute for Geosciences and Natural Resources (BGR) turns his attention on the next few pages to options for CO_2 storage.

Within the scope of the Kyoto Protocol, Germany undertook to achieve a 21 % reduction in its climate-affecting gas emissions by 2008/12 relative to 1990 levels. In view of a reduction already obtained of over 18 %, this target has already been virtually achieved.

CO_2 emissions and reduction targets in Germany



Source: BGR (5)

Further developments in power plant technology with the goal of increasing efficiency will, in addition, tap CO_2 reduction potentials for electricity generation. As regards further CO_2 reductions for fossil-fired power plants, the vision has emerged of a zero-CO_2 or, at least, of a low-CO_2 power plant.

Bridge technology for achieving climate targets

The concept provides for the capture of CO_2 from the combustion gases of large local sources and subsequent storage in geological structures. This route could be a bridge technology for achieving future climate goals. Such a view is held, for example, by the German Advisory Council on Global Change (WBGU) in its report "Towards sustainable energy systems" and the German Council for Sustainable Development in "The perspectives for coal in a sustainable energy industry".

Initial practical experience is already being obtained with underground storage of CO_2 in the Norwegian North Sea, where the CO_2 from the Sleipner gas field is being injected, following its capture from the extracted natural gas, directly back into an aquifer located at a depth of some 1,000 m. A second project is under way in Weyburn, Canada, where CO_2, after transportation by pipeline from a location some 300 km distant in the USA, is fed into an oil field. This process significantly increases the oil output. The CO_2 extracted again with the additional oil is captured and re-employed.

Geotechnical feasibility of storage in Germany

Is underground storage of CO_2 possible in Germany as well? Viewed from a geotechnical angle, the answer is a definite yes. For over 30 years now, natural gas has been stored in Germany in caverns, aquifers and former oil or gas fields. All the same, there are significant differences between this and CO_2 capture:

- Natural gas consists of gaseous hydrocarbons – methane in the main. These gases behave differently underground than CO_2.
- Natural gas – more precisely: the working gas in storage – is generally renewed at least once a year, i.e. the sojourn time of the gas underground is limited in time.
- The legal framework for subterranean storage of natural gas is unambiguously regulated by Germany's Federal Mining Act, by DIN and other provisions. No such arrangements exist at present for CO_2.

The following remarks deal with the specifics of CO_2 and also contain an estimate of various storage potentials in Germany.

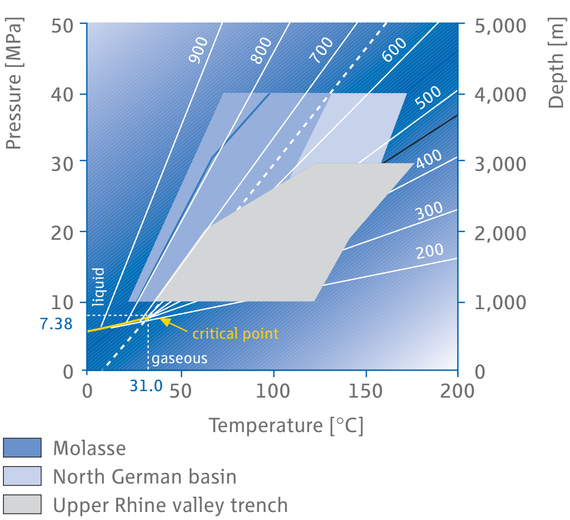
In the storage of CO_2 underground, one important variable is knowledge of its phase behaviour – in principle, carbon dioxide can occur in a solid, liquid or gaseous state. This crucially determines the storage quantity per reservoir volume.

Underground, CO_2 can only assume a liquid or gaseous state – the phase transition, dependent on pressure and temperature, is shown in the figure below. At a pressure of 7.38 MPa and a temperature of 31 °C, the critical point of carbon dioxide is reached – it is near the usual pressure and temperature gradients in hydrostatic conditions. Above this point, carbon dioxide is in a supercritical state – it is no longer possible to distinguish between gaseous and liquid states. In the supercritical area, pressure and temperature in the deposit directly decide the density of the carbon dioxide.

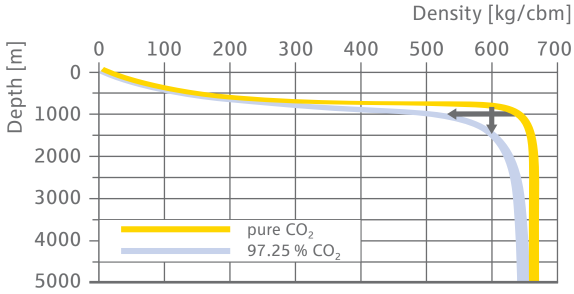
CO_2 storage capacity is dependent on depth

Under hydrostatic conditions, the pressure underground rises by 10 MPa per 1,000 m depth. The relevant depth and temperature conditions in the three major German sedimentary basins with CO_2 storage potential – north German basin, upper Rhine valley trench, Alpine foothill basin – are shown below. Although this representation only gives a rough idea, it does make it clear that the upper Rhine valley trench, in view of its higher temperature gradient, offers the most unfavourable conditions for CO_2 storage – also, this region is an earthquake-endangered zone.

Phase diagram and characteristics of German sedimentary basins



Density/depth profile of pure and contaminated CO_2



On the basis of hydrostatic conditions (10 MPa/km) and a geothermic gradient of 30 °C/km, the changes in the density of CO_2 with increasing depth can be shown by way of example in the diagram above. Under these conditions, CO_2 at depths of less than some 600 m is gaseous and has only a low density. Until the critical point is reached at a depth of some 700 to 800 m, marginal changes of pressure and temperature cause substantial variations in CO_2 density. Below some 1,000 m, CO_2 is susceptible to only slight compression – it is a supercritical fluid whose density changes only slightly with increasing depth.

Special requirements of the Oxyfuel process

The above remarks only apply to pure carbon dioxide gas. If, for example, the combustion gas to be stored derives from an "Oxyfuel process", contamination with argon and oxygen is conceivable. In the case of total contamination of 2.75 % with these two gases, the density of the gas mix would be significantly reduced compared with pure CO_2. Accordingly, in a 1,000-m-deep reservoir, only 500 kg instead of 650 kg could be stored per cubic metre of pore volume. In order to nonetheless obtain a storage density of 600 kg/cbm, the reservoir would have to be installed at a depth of 1,500 m instead of some 900 m.

If the pore space is to be filled effectively, i.e. with high mass, depths of 800 to 1,000 m must be reached.

The Federal Republic of Germany, with a total of some 850 mill. t/a is the EU's biggest CO_2 emitter. Its fossil-fired power plants, refineries, integrated iron mills and steel mills, cement works and parts of the chemical industry account for some 350 mill. t/a of the total.

For economic reasons, it is meaningful to capture the CO_2 primarily at source and to store it in appropriately voluminous "sinks". Owing to the already described underlying physicochemical conditions, the search for forstorage options can be confined to areas with adequately widespread and thick sediment packages – viz. the north German basin, the upper Rhine valley trench and the Alpine foothill basin. What matters here is not just the search for storage options; it is equally important to take account of the existence, distribution and long-term stability of overburden layers.

Federal institute examining storage options

In the course of a research project (GESTCO) partially funded by the EU, the Federal Institute for Geosciences and Natural Resources (BGR) has evaluated for Germany oil and natural gas fields, deep-lying aquifers, coal seams located below the mining limit, as well as salt and coal mines, to check their suitability as CO_2 storage options. Assessment criteria were: storage capacity, permeability of reservoir rock, the existence, retention capacity and integrity of overburden layers, knowledge of present pore content, any conflicts of use as well as the possibility of using CO_2 storage for the simultaneous production of hydrocarbons.

Depleted natural gas fields as interesting locations

Depleted or nearly depleted gas fields are certainly interesting locations for CO_2 storage. The first and most important argument in their favour is that they have already retained their tightness throughout geological time – meaning millions of years.

Most natural gas fields in northern Germany were filled some 80 to 90 million years ago with their present content and have been storing it ever since. Also, the operators of these deposits know from extraction history how the reservoir has been emptied over time. Knowledge of extraction behaviour is already being utilized in their subsequent use for natural gas storage – annual deposit and withdrawal – and could in future also be of great value in any subsequent use for CO_2 storage. In the drilling sites, the wells and their linkage to the pipeline network, an infrastructure already exists, some of which could be used – possibly following adaptation – for the new use.

In addition, one further aspect can be fielded in favour specifically of the economic efficiency of this subsequent use of natural gas fields. In the conventional production of natural gas, some 75 to 80 % of a deposit are exploited. If it were possible to increase the output rate by timely commencement of the injection of CO_2 into a virtually depleted gas field, this could absorb part of the costs of CO_2 storage. What would emerge would be a de facto win-win situation.

Thin section – mottled sandstone
Pore volume is possible storage space

Below the required minimum depth of 800 – 1,000 m, aquifers filled with highly saline water are widespread in the sedimentary basins in many geological formations. The figure shows as example the section of a sandstone sediment that can feed CO_2 in the pore volume.

Project CO2SINK gaining practical experience

In view of the quality of the pore content and the great depth, these rock packages can be ruled out for future provision of drinking water. The potential storage volume of CO_2 is put at some 10 times higher relative to the natural gas fields. There are constraints, however. Detailed information on the lateral distribution, thickness, porosity and permeability of the storage rocks are based on comparatively few wells. The nature of the rock can change within short distances, and not enough is normally known about the geometry of the structural traps and their overflow points. The viscosity difference between CO_2 and the formation water, as well as the heterogeneity of the shapes of the storage space can lead to preferred flow paths, for the injected CO_2. These bifurcations, while reduc-ing storage capacity, also promote the solubility of the CO_2 in the formation water. Pinpointed reservoir management – by using several injection wells, for example – can optimize the spread of the CO_2 in the storage space (flooding efficiency).

Practical experience in this field is to be gained in the research project CO2SINK coordinated by GFZ Potsdam. At the Ketzin location – situated not far from Berlin – CO_2 is to be introduced into an aquifer in reed sandstone below a discontinued gas storage facility. The work programme focuses specifically on observing CO_2 diffusion in the aquifer using geophysical and geochemical methods, the matching of results from numerical modelling and the development of strategies for risk assessment. The scheme is to be accompanied by a comprehensive public relations effort.

The theoretical storage capacity of German natural gas fields and aquifers – the option with what is definitely the largest storage volume – could suffice for some 65 to 85 years to store the above annual CO_2 output of 350 mill. t/a. The remaining storage options are of secondary importance and not entirely suitable. In view of the limited domestic capacities, the options for storage abroad, too, would have to be taken into consideration.

Options assessed by BGR for suitability as CO_2 storage facilities in the Federal Republic and their estimated storage capacities

Option	Storage volume [bn t CO_2]
Natural gas fields	2.56
Aquifers	20±8
Coal seams	0.37 to 1.67
Oil fields	0.11
Salt mines	0.04
Coal mines	0.78

Field trial with coal seams in Poland

The technical basis for the coal seam option is an adsorption of CO_2 by coal that is proved and preferred relative to methane. By applying this concept to the natural surroundings, an attempt is made to bind CO_2 to coal and, at the same time, to release the energy source methane. It is with this in mind that a field trial in Poland (ROCOPOL) is currently investigating the quantities with which this phenomenon is to be reproduced under natural conditions. In view of the very low permeabilities of coal, however, it must be doubted whether this process can be economically implemented in Germany.

North Sea out of the question for storage

Finally, a remark on options that are often discussed but not relevant: Germany's North Sea area cannot be considered, in view of the competing uses (Wattenmeer - mudflats - national park, FFH areas, navigation routes, wind farms, etc.) for CO_2 storage. Reasons can also be fielded against storage in the ocean: apart from the transport distances involved between Germany and the deep Atlantic, there is also, and in particular, the possible uncontrollable impact on ocean flora and fauna that speak against this option in principle. What is more, the legal consequences of uncontrolled CO_2 transportation into the sovereign territory of other countries would have to be taken into account. Precipitation of the carbon dioxide in the form of magnesite – directly at the power plant – is no solution on account of the limited availability of the required raw material magnesium silicate in Central Europe.

Legal clarity is the basis for entrepreneurial planning certainty – and, in line with this motto, there are some basic legal issues to be cleared up.

Until now, no CO_2 storage facilities have existed in Germany, which explains why the likely legal treatment of such storage is still an open question. Underground storage of natural gas is subject to Germany's Federal Mining Law (BBergG), it being assumed here that the gas will be withdrawn again. If CO_2 storage is equated with "dumping", then heed would have to be paid to the Product Recycling and Waste Management Act (Krw/AbfG). This explicitly does not refer to "gaseous materials not stored in containers". Also, storage in aquifers is subject to the Water Resources Act (WHG) or the corresponding state water laws. Deep waters rich in salt may mean, on the one hand, brine deposits subject to mining law or, on the other, groundwater subject to the Water Resources Act, which does not classify groundwater by depth or properties. Accordingly, the discharge of material into groundwater is not allowed if this causes deleterious changes to its properties. The dissolution of CO_2 in the formation water and subsequent reactions with the wall rock cannot fail to cause deleterious changes in its properties – in the pH value, for example. Going beyond these questions of approvals for storage, the fundamental problem of the long-term responsibility for a geological structure underground filled with CO_2 must be clarified.

Transparent communications for implementation important

Besides economic considerations, public acceptance is a further important factor in implementation by potential operators. When it comes to implementing a new technology with complex consequences, an environmentally aware society must be expected to respond with scepticism, possibly by rejecting it. A negative public opinion might lead to the failure of a storage project even with a positive assessment of CO_2 storage by state, industry and research. Since public opinion is affected in particular by the nature of media reporting, it is up to all those concerned to make timely, open and proactive efforts. Taking underground natural gas storage as an example, though, it can be shown that people are, at bottom, prepared to share risks incurred by their own conduct.

Upshot

Viewed from a geological angle, storage of CO_2 in Germany is meaningful and possible in principle both in natural gas fields and in deep aquifers – all other options seem to promise less success.

Since CO_2 reduction goals go beyond the Kyoto Protocol, the years to come will have to clarify outstanding technical details – in addition to the legal issues mentioned. Many technical issues, like the development of adequate inexpensive monitoring instruments or the stability of wells and well cement can be solved within the scope of various international research activities. The questions to be clarified at national level, by contrast, are all those that deal with the suitability of specific storage locations. In this respect, one valuable basis could be the drawing up of a nation-wide storage register.

Despite all these questions, it must not be forgotten that underground CO_2 storage can and should bear only part of the reduction in emissions. Otherwise, national storage potentials would be exhausted in a relatively short time. The prime consideration must continue to be CO_2 avoidance. In particular, reductions in CO_2 obtained by improving efficiencies must underpin the sustainability of the way we handle energy resources.

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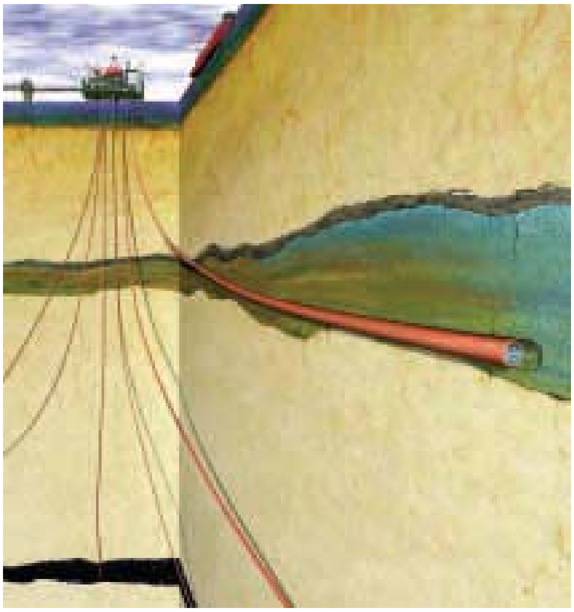
Pioneering Sleipner project points to ways for safe CO_2 capture and storage from natural gas

Statoil is a Norwegian oil and gas company with its main production in the North Sea but is also expanding internationally. How the company views the global climate problem and contributes to lowering the emission of greenhouse gases (GHGs) is described by Gelein M. de Koeijer, in charge of research in CO_2 capture, transportation and storage at Statoil.

For Statoil, the issue is not whether the world faces a climate problem or how severe it may be, but how harmful emissions can best be overcome. The Kyoto Protocol is therefore accepted as a good basis for a rational global policy. Statoil also cooperates widely with other companies and authorities.

Natural gas production and CO_2 recirculation in the Sleipner project



Source: Statoil (2)

Natural gas with CO_2 (lower dark formation) flows up to the Sleipner platform, where CO_2 is captured and re-injected into the Utsira aquifer (middle) for safe long-term storage

The company, together with partners, primarily reduces its CO_2 emissions by capture and storage of CO_2 from natural gas at three plants:

1. the Sleipner platform in the North Sea;
2. In-Salah in the Algerian desert;
3. the Snøhvit liquefied natural gas (LNG) plant in northern Norway (planned).

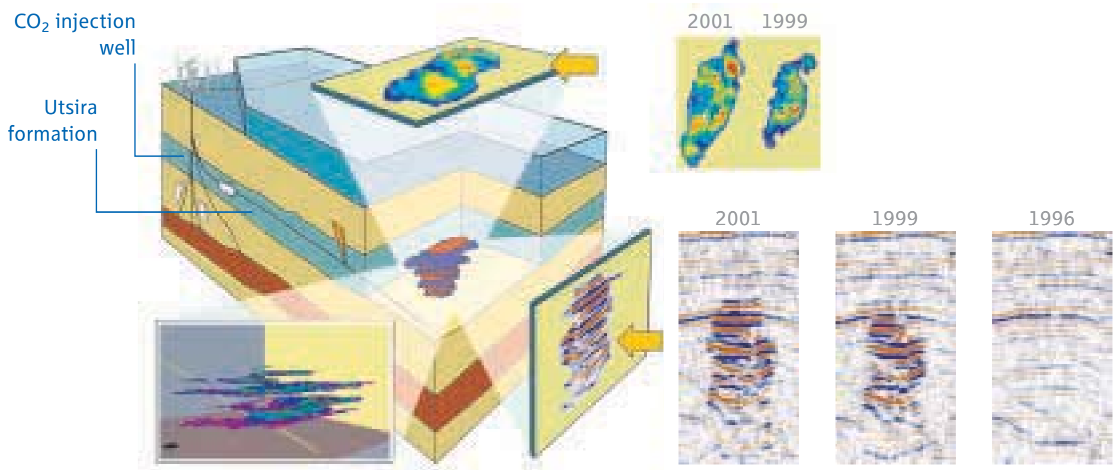
CO_2 capture and storage can, in the medium or long term, drastically reduce CO_2 emissions. Moreover, this new technology can be a bridge to the long-term vision of an electricity and hydrogen society with high energy efficiency and increased use of renewable energy sources.

The Sleipner platform in the North Sea

During development of the Sleipner West field in 1990, it was realized that the 4 to 9.5 % CO_2 content in the natural gas would have to be reduced to less than 2.5 % if it were to be fed directly into gas pipelines for sale in Europe. A team of technical experts came up with the unprecedented idea of capturing the CO_2 offshore and injecting it into a saline aquifer beneath the Sleipner installations. An aquifer is a sand layer the pores of which are filled with saline water, well suited for long-term CO_2 storage. In this way, the Sleipner plant would minimize CO_2 emissions – the prime motive – while avoiding environmental taxes of around US$ 40/t CO_2.

Despite its pioneering character, this became the partners' approved solution. Since start-up in 1996, up to 1 mill. t of CO_2 a year has been injected into the Utsira aquifer. In its environmental efforts, the Sleipner plant notched up two world firsts – large-scale offshore carbon dioxide capture and injection into a saline aquifer 1,000 m below the seabed.

Results of seismic monitoring of CO_2 storage in the Sleipner field



CO_2 injection well:
metrological evidence of the spread of CO_2 underground

All research so far shows: Sleipner is safe

In order to learn as much as possible from this pioneering operation, a cooperative research project was started to examine the behaviour of the CO_2. It was called the Saline Aquifer CO_2 Storage Project (SACS, 1998 – 2003). The partners involved were several European research institutes and the partners of the Sleipner plant. The project was partly funded by the European Union. The main results came from regular seismic monitoring of the underground CO_2.

The time-lapse seismic sections prepared between 1999 and 2001 show that the injected CO_2 is in place and that the volume has increased substantially – a fact which is further corroborated by the corresponding seismic amplitude maps.

Simulations suggest that the carbon dioxide "plume" may reach its ultimate size after a few hundred years, thereafter shrinking and finally disappearing within a few thousand years. Seismic monitoring has revealed no carbon dioxide leakage in the overburden. Until now, all research has indicated that CO_2 storage at Sleipner is safe.

The partly EU-funded research project CO2STORE is continuing the work of SACS. Among other things, an optimized approach for better determination of the carbon dioxide density and mass distribution is being considered. Moreover, a start has been made with the ultimate objective of combining chemical and flow-oriented modelling approaches, the goal being to make reliable long-term forecasts about CO_2 storage behaviour.

Follow-up projects

In the summer of 2004, CO_2 injection started at In-Salah, a natural gas field in the middle of the Algerian desert. This is a joint operation between BP, Sonatrach and Statoil. Some 1.2 mill. t of CO_2 will be stored per year in the same geological formation as the natural gas, but at a safe distance.

Statoil and its partners are planning the second-largest offshore CO_2 storage project at Snøhvit with start-up in 2006. The Snøhvit LNG project is the first oil and gas development in the environmentally sensitive Barents Sea, the first LNG gas-field development in Europe, and the first LNG production site where the captured CO_2 will be stored. Furthermore, it is the first Norwegian offshore development with no surface installations. With all of the production equipment residing at water depths of 250 to 345 m, none will interfere with fishing activities. Operations will be remotely controlled from land. The natural gas contains 5 – 8 % CO_2 and is captured by amine absorption. After capture, the CO_2 is compressed and transported in a dedicated pipeline back to the gas field. Around 0.7 mill. t of CO_2 per year will be injected into an aquifer below the gas reservoir at a depth of 2,600 m.

Involvement also in projects in the power area

The CO_2 emissions from electricity production are much greater than those from natural gas production. However, capture is much more expensive. Past and present research is bringing the possibility of cost-effective carbon dioxide capture and storage from power plants ever closer. Statoil has been and is involved in several co-operative R&D projects. The CO_2 capture project (CCP) has recently been finalized and has indicated a number of opportunities for improvement. Currently, Statoil is a partner in several other projects that are partly funded by the EU.

ENCAP aims to develop long-term technology for CO_2 capture. CASTOR will build an amine absorption pilot plant at an Elsam-operated coal-fired power plant in Denmark, developing a technology to be available in the shorter term. Moreover, four feasibility studies on CO_2 storage will be carried out at different locations in Europe. In the CO2SINK project, monitoring and verification of CO_2 storage will be further developed at a storage pilot in eastern Germany. These projects are large cooperative projects with up to 30 partners. RWE is a valuable partner in several of these.

Info

Further information:
www.statoil.com
www.co2store.org
www.co2captureproject.org

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Statoil ASA
Research into CO_2 capture, transportation and storage

IGCC technology: moderate impact on costs and efficiency thanks to favourable conditions for capture

Today's open-cycle and combined-cycle gas turbine plants are mainly operated with natural gas and, to a lesser, extent, with light fuel oil. It is for these high-value fuels that open-cycle and combined-cycle technologies have been developed and trialled on an industrial scale. Today, such units are commercially available as base-load power plant type with net efficiencies of over 58 %. In the past two decades, the combustion of low calorific synthesis gases, too, has been developed and trialled in gas turbines. For electricity generation from coal or refinery residues, therefore, this opens up high efficiency potentials of combined-cycle technology. Details are presented by Dr Nicolas Vortmeyer from Siemens Power Generation.

The technology known today as integrated gasification combined-cycle (IGCC) uses gasification with oxygen under pressure to produce a synthesis gas that is cleaned in a further process stage and fed to the gas turbine as fuel. IGCC plants on a coal basis are currently in commercial operation as demonstration plants in Europe and the US. Using the latest gas turbine technology, efficiencies of up to 50 % can be reached.

For a zero-CO_2 electricity generation, the IGCC technology, in particular, because of high CO_2 concentrations in pressurized fuel gas, offers favourable conditions for capture. The implications for investment costs and efficiency can be kept at a relatively moderate level, therefore. This potential offers an incentive for necessary development work.

Composition of conditioned fuel gases for gas turbines

Application	Natural gas	Synthesis gas	ZEIGCC (H_2-rich gas)
Gas composition	% vol.	% vol.	% vol.
H_2	0.0	12.3	41.5
CO	–	24.8	0.3
CO_2	2.0	0.8	0.1
N_2	0.9	42.0	43.7
CH_4	89	–	3.6
H_2O	–	19.1	10
Calorific value	46.5 MJ/kg	4.3 MJ/kg	8.2 MJ/kg

Source: Siemens Power Generation (4)

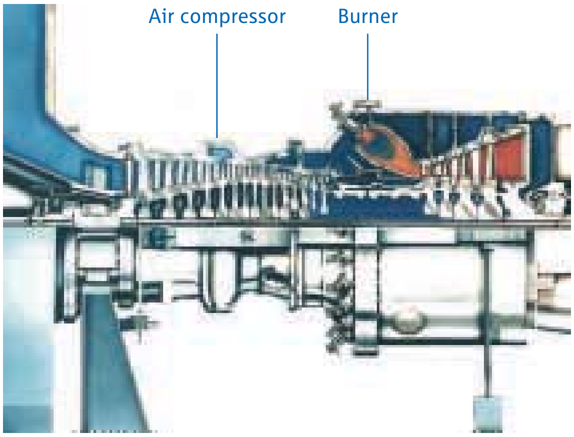
Fuel properties	CH_4	H_2	CO
Calorific value (mass-related) [MJ/kg]	50.3	119.9	10.1
Calorific value (volume-related) [MJ/cbm]	33.9	10.2	12.6
Flame velocity (in air) [cm/s]	43	350	20
Stoichiometric combustion temperature	2,227	2,370	2,374
Standard density [kg/cbm]	0.72	0.09	1.25
Heat capacity [kJ/kg]	2.18	14.24	1.05
Ignition limits [vol. %]	5 – 15	4 – 75	12.5 – 74

In the transition to zero-CO_2 IGCC technology (ZEIGCC), a fuel very rich in hydrogen reaches the gas turbine. In the combustion of these gases rich in hydrogen, use can be made of the experience gained with synthesis gases (Table, left).

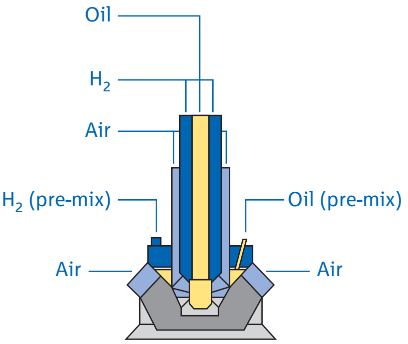
However, the hydrogen shares, again much higher, in the fuel gas of the ZEIGCC relative to synthesis gases call for structural changes in the burner. The crucial factor here is basically the different fuel properties of natural gas, hydrogen and synthesis gas and the resulting criteria for burner development. The above Table presents an overview of the key fuel components and their most important properties.

As in the case of synthesis gases, the first parameter for the combustion of hydrogen is the much higher volumetric flow of the fuel, compared with natural gas owing to the lower volumetric calorific value. To limit the resulting high gas discharge velocity and burner pressure loss, adjustments to the burner nozzles are necessary.

V94.3A Gas turbine



Development focus: H_2 burner with combustion chamber



In addition, the very high reactivity and laminar flame velocity of hydrogen is a further crucial criterion for the combustion. To avoid the resulting risk of flashbacks and early ignitions, special structural changes are necessary in the burner to ensure combustion that is both stable and low in NO_x. Of special importance for this is, above all, the setting of a homogeneous fuel-air mix and the avoidance of backflow areas inside the burner.

Support from manufacturer, operator and EU

The start of this development work on the combustion of hydrogen-rich gases as part of the ENCAP project in early 2004 was an important step in the direction of zero-CO_2 IGCC technology. Besides the gas turbine suppliers Siemens and RWE Power, other European manufacturers and operators are engaged in this project, which is supported by the EU with funds from the 6th Framework Project for Research.

The terms of reference cover both the development of a hydrogen burner for progressive gas turbines and the plant design for lignite, hard coal and natural gas with a CO_2 capture focus. The concepts in each case proceed from a partially integrated air separation unit and a Siemens V94.3A gas turbine (figure above). To meet the requirements of a ZEIGCC, adjustments are necessary in this machine for the burner/combustion chamber system, the upstream fuel system and an air withdrawal from the gas turbine. Additional investigations of the hot-gas conducting parts in hydrogen combustion are planned.

The framework conditions required for a burner design, such as fuel gas composition and temperature, are determined within the scope of the thermodynamic calculations as part of the drawing up of the ZEIGCC concept and made available in the course of the project. Burner development is a step-by-step process on the basis of the tried-and-tested Siemens hybrid burner design (diagram above).

In a first step, the operating limits of this standard burner are obtained under machine-typical framework conditions in the combustion of a H_2/N_2 mix. In a second step, taking account of the results and the framework conditions from the overall plant study, a hydrogen burner suitable for low-NO_x combustion is designed, produced and tested for use in a progressive V94.3A gas turbine.

High gas-turbine inlet temperature indispensable

The ENCAP project, therefore, takes a first major step toward a low-NO_x combustion of gases rich in hydrogen. High gas-turbine inlet temperatures are an indispensable precondition for use of the highly efficient IGCC technology in zero-CO_2 electricity production.

The author: *Dr Nicolas Vortmeyer*
Siemens Power Generation
PG CT
Chief Technology Officer

Research and development underpin significant export share on world market

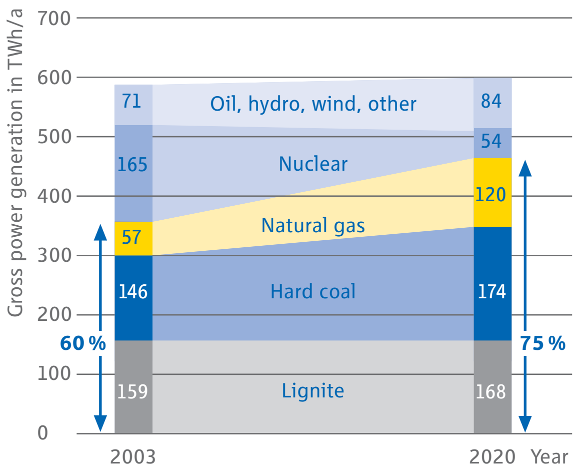
Research and development involving modern power plant technologies have a long tradition in Germany, and this has led, not least, to the highest efficiency rates worldwide in the existing power plant fleet. They ensure for German industry a significant export share on the world market. On this basis, at the initiative of the Federal Ministry of Economics and Labour (BMWA), the new R&D concept COORETEC has been drawn up in the past two years in a joint effort with industry and science.

COORETEC: technological innovations to create highly efficient and zero-emission power plants by 2020

The COORETEC research and development concept with a time horizon until 2020 shows the development of necessary technologies for highly efficient, virtually flue gas-free and economic coal- and gas-fired power plants. For the first time worldwide, this has enabled a realistic and detailed road map to be produced for power plant developments. Details of this concept are discussed by Dr Thomas Rüggeberg, responsible in the BMWA for research and development in power plants on a coal and gas basis.

The energy sources coal and gas today account for a share of 60 % in annual electricity production of 590 TWh in Germany. Nuclear energy covers 28 % of the power supply. The German government's object is to increase the share of renewables from today's 8 % to 20 % with a simultaneous exist from nuclear energy. As a consequence, the share of coal and gas will have to rise to some 75 % by the year 2020.

Energy mix in Germany



Source: PROGNOS/EWI

100 experts worked on the concept

In view of the remaining importance of fossil-fired power plants for a secure power supply, and of the potential for further technological improvements for economic efficiency and climate protection, let alone international developments in CO_2 capture and storage, the Federal Economics Ministry in early 2002 initiated the drawing up of a national concept for future research in the area of coal- and gas-fired power plants. Within 12 months, a circle of some 100 experts from industry and institutes presented a COORETEC concept showing how technological innovations in the area of power plant technology can help achieve the goal of very highly efficient and zero-emission fossil-fired power plants by the year 2020.

The concept can be broken down into two complementary basic lines of strategy:

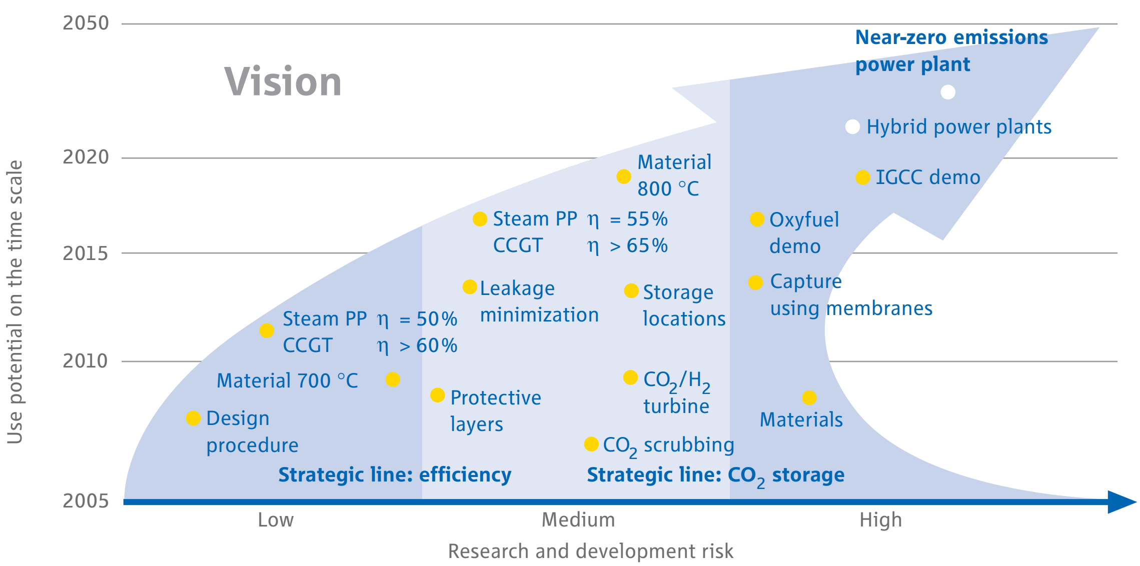
- **Line 1: energy efficiency**
  The process of power generation is to be further improved with the goal of using coal and gas as efficiently as possible and, at the same time, reducing emissions as far as possible.

- **Line 2: CO_2 capture and storage**
  The CO_2 inevitably produced in power generation must – wherever economically and ecologically defensible – be captured and safely stored.

By 2020, the efficiencies of conventional power plant concepts can be increased by up to 20 % relative to the state of the art. In a steam power plant, some 50 % and, in a combined-cycle gas turbine plant, some 65 % of the energy stored in the energy sources can be converted into electricity (today 43 – 47 or 58 %). To achieve this target, it is necessary to increase the process parameters pressure and temperature and to reduce energy losses along the entire conversion chain.

In the same period, some 40,000 MW power plant capacity will have to be renewed in Germany. The efficiency-strategy line of the concept can help save some 20 % of the CO_2 emissions in power generation. This will suffice to give a neutral CO_2 shape to the replacement of nuclear energy by fossil-fired power plants.

The COORETEC road map



Source: BMWA

Further CO_2 reductions can be obtained thereafter by capture and storage in accordance with strategic line 2.

The goal of COORETEC is to cut the costs for capture and storage of CO_2 to below € 30/t. Ignoring nuclear energy, this would make coal and gas, as things look today, the most economical form by far of a zero-CO_2 and secure energy supply.

Beacon projects started in 2004

Within the scope of the COORETEC initiative, important "beacon projects" were developed or commenced in 2004.

A first beacon project OXYCOAL was launched in the second half of 2004. This concerns the development of technologies for a new power plant concept that is suitable for capturing at low cost the CO_2 produced in the combustion of coal. The basic idea is to combust coal in an oxygen atmosphere. The waste gas produced consists basically of steam and CO_2 that is easy to capture. One challenge in this concept consists in the development of membranes for obtaining oxygen to be used instead of the usual, but cost- and energy-intensive air separation by liquefaction.

For comprehensive investigations on the IGCC power plant with CO_2 capture, the application for funds of a project initiative has been submitted under the short name COORIVA. A further project applied for with the brief name ADECOS examines the Oxyfuel process with conventional air separation.

Behaviour of CO_2 in deep salt water layers

The CO2SINK project likewise funded by the EU in Ketzin near Potsdam was launched in April 2004 under the lead management of the geo-research center Geoforschungszentrum Potsdam. The remit of this project is to clarify the behaviour of CO_2 in deep salt water layers in a former natural gas intermediate store. In the run-up already, the project is attracting considerable international attention, since the investigation results to be obtained here may be of central importance in Europe and worldwide for CO_2 storage in zero-emission power plants.

RWE Power has been involved from the very beginning in the COORETEC initiative and is playing a part in all projects named.

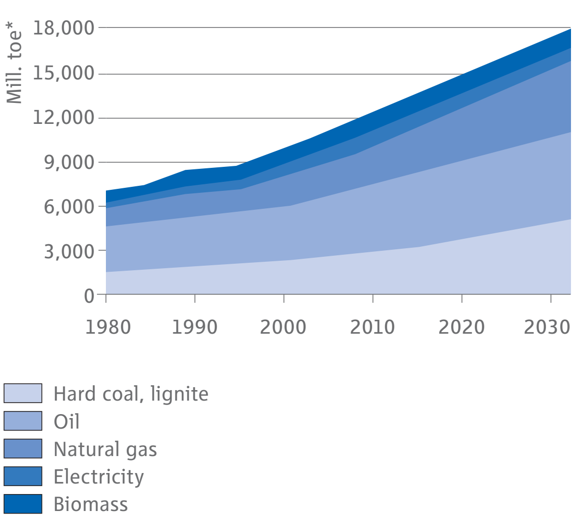
The author: *Dr Thomas Rüggeberg*
Federal Ministry of Economics and Labour
Energy research: new energy conversion techniques

Quick-start projects to boost Europe's economy support EU research strategy

In the transition toward a more sustainable energy sector based on renewable energy sources, fossil fuels are likely to remain the primary source of global energy supply for several decades. This is a challenge, also for the EU, as Pablo Fernández Ruiz, working for the European Commission as director with a focus on energy, explains.

All the current energy-supply scenarios indicate that dependence on fossil fuels is here to stay, at the very least, up to the period 2020 – 2030, even when the effect of current policies is taken into account. However, related CO_2 emissions are a major problem as they contribute to global climate change. The challenge for European economies relying on fossil energy is to be able to use fossil fuels while eliminating CO_2 and at the same time, maintaining Europe's industrial competitiveness in global markets.

Scenarios and forecasts – world fuel shares up to 2030



*1 tonne of oil equivalent (toe) = 1,428 tce = 41.8 GJ

Source: European Commission: World Energy Technology Outlook to 2030, Brussels 2003

The dependence on fossil fuels over the coming decades can be reconciled with the fulfilment of the Kyoto obligations by way of CO_2 capture and storage. This will require the availability of competitive technologies and the necessary public acceptance of their use.

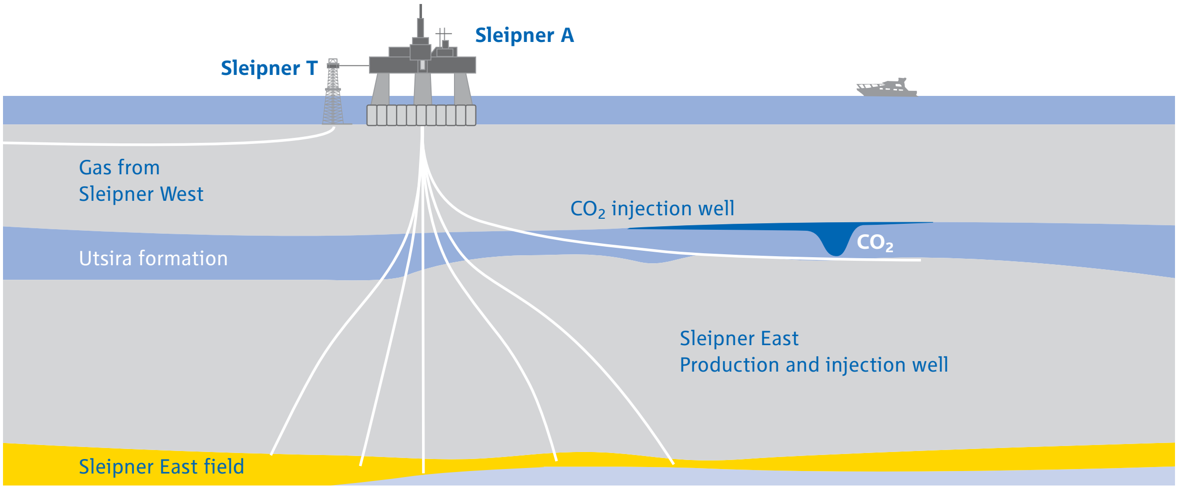
Significance of technologies set to grow

The beneficial effects of the use of capture and storage technologies will be even more significant for any post-Kyoto agreement, together with renewables, energy efficiency and demand management. The possibility exists for a zero-CO_2 system based on fossil fuels if hydrogen is the fuel ultimately used for energy production. In a transition to a renewables-based energy system, hydrogen from fossil fuels could be produced, including carbon capture, in large facilities together with electricity and other products. Hydrogen would then be used in all transport applications which currently use liquid fuels.

Research and development objectives

There are significant costs involved in CO_2 capture and storage, with capture representing 70 – 80 % of total costs. Therefore, the primary RTD objective for the EU is to slash the cost of capture from € 50 – 60 to € 20 – 30 per tonne of CO_2 captured. Methods include pre-combustion capture, post-combustion capture and Oxyfuel combustion.

Sleipner: Large-scale experiment for underground CO_2 storage



Source: Europäische Kommission

On the storage side, there is a strong need to assess both the reliability and long-term stability of geological CO_2 storage and to build public confidence. CO_2 storage options of interest to the EU include geologically based storage in aquifers, depleted oil and gas reservoirs (with a possibility of enhanced oil recovery) and deep unmined coal beds (that offer the benefit of enhanced coal-bed methane recovery).

R&D strategy of the EU

Under its FP5 framework programme, the EU has contributed some € 16 mill. to support nine projects, worth over € 30 mill. of total investment. This included two projects on CO_2 capture, six projects covering CO_2 storage and storage monitoring, and one Thematic Network. This also includes the monitoring of CO_2 injection in the Sleipner field.

The first FP6 call was published in December 2002, with a budget of € 198 mill. for medium- to long-term energy research. The proposed EU support for CO_2 projects amounts to € 37 mill. and total costs are around € 65 mill. Four research projects have been signed recently, looking at pre-combustion capture (ENCAP), post-combustion capture (CASTOR), geological storage in on-land aquifers (CO2SINK) and lignite gasification with simultaneous carbon capture (ISCC). In addition, a network of excellence, grouping 13 research centres, has been launched dealing with geological storage (CO2GEONET). The second large call for FP6 had a deadline in December 2004 and called for projects addressing the following topics in particular:

- CO_2 capture and hydrogen production from gaseous fuels;
- the monitoring and verification of geological CO_2 storage;
- preparing for large-scale H_2 production from decarbonized fossil fuels, incl geological CO_2 storage;
- advanced separation techniques;
- mapping geological CO_2 storage potential matching sources and sinks;
- European coordination and network activities in CO_2 capture and storage.

At EU level, within the European initiative for growth, a number of "quick-start" projects have been launched to stimulate the European economy, one of which is HYPOGEN, a full-size demonstration plant for the production of hydrogen from fossil fuels with CO_2 capture and storage.

International activities

The EU, via the EC, has Science and Technology Cooperation Agreements with many countries such as Argentina, Australia, Brazil, Canada, China, India, Russia, South Africa and the US. The EC has also signed a memorandum of understanding with the US Department of Energy (DoE) and is a member of the Carbon Sequestration Leadership Forum (CSLF), which was initiated by the US and now has about 15 member countries, and offers a framework for international cooperation in research and development for the separation, capture and storage of carbon dioxide.

The EC is active in the International Energy Agency (IEA) of the OECD. It participates in the Committee of Energy Research and Technology (CERT) and in the Working Party on Fossil Fuels (WPFF), with a particular role in the Zero-Emission Technologies Strategy (ZETS). It also sponsors the IEA Greenhouse Gas "Implementing Agreement".

Upshot

The European Union's research priorities include the support of sustainable energy supplies, with energy as a key aspect, while ensuring EU industrial competitiveness. The future fuel mix is expected to be diverse, thereby ensuring security of supply, and fossil fuels will be part of that mix provided that acceptable techniques can be established, with emphasis on carbon management. Accordingly, when considering a post-Kyoto scenario, the development of CO_2 capture and storage systems associated with fossil-fuel power plants is a key priority within the RTD framework programmes of the EU.

Info

Further information on the European Union is available on http://europa.eu.int.

The author: *Pablo Fernández Ruiz*

European Commission
Directorate-General for Research
Director RTD, Energy

IEA R&D programme: information source for reductions in greenhouse gases

The IEA greenhouse gas R&D programme (IEA GHG) is an objective source of information on technologies for achieving reductions in greenhouse gas emissions. IEA GHG was set up as an international collaborative activity in 1991 and will run in various programme phases until 2009. The programme is introduced here by IEA project director Paul Freund.

The object of the IEA programme is to evaluate investigations into the mitigation of GHG emissions from power generation and other major sources and to disseminate the state of knowledge in this area. The principal technology which IEA GHG has worked on since 1991 is the capture, transmission and storage of CO_2 from fossil-fuel combustion. IEA GHG is recognized as the world's leading authority on this technology. The IEA provides objective information for the policy-making, industrial, technical, scientific and economic communities, on the contribution these processes can make to mitigating climate change.

Programme bundles advances and developments

IEA GHG carries out technical and economic evaluations, estimating costs on a transparent, consistent and comparative basis. It identifies gaps and duplications globally and maintains awareness of progress and developments. IEA GHG also fosters international communities of experts, to access the available expertise and to facilitate international cooperation on research, development and demonstration projects. From evaluations of technologies, IEA GHG identifies opportunities as well as key gaps in knowledge and promotes work to fill them, in particular, practical research, development or demonstration.

IEA GHG aims to increase knowledge about mitigation technologies but does not undertake advocacy or policy-making. It produces a series of reports for members and other series for a more general audience, publishes a bi-monthly newsletter "Greenhouse Issues", maintains websites on mitigation options, and organizes expert workshops and international conferences.

Countries, EU Commission and industry lend support

Membership of the Programme is open to most countries, whether or not they are members of the International Energy Agency (IEA). In addition, a number of major and multi-national companies are industrial sponsors of the Programme. In all, 16 countries, the European Commission and 10 industrial sponsors now support the Programme. Industry is also actively involved through the national memberships. Each member country and company has representatives on the Executive Committee, which decides on the work to be done; this is carried out by the Project Team based in Cheltenham, UK, which makes use of expert contractors from around the world.

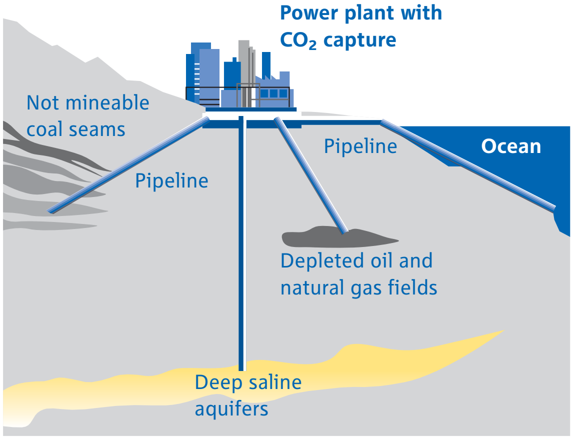
Assessing technology options

Much of IEA GHG's work concerns methods for reducing emissions of the main anthropogenic greenhouse gas CO_2, from its principal source, power generation. Measures appropriate for other sources of CO_2, such as industry and transport, and other GHGs, such as methane and nitrous oxide, are also being addressed.

Technology evaluations cover many different methods of capture, transmission by pipeline and ship, storage in geological formations and by other means. All fossil fuels are considered. IEA GHG investigates ways of reducing the cost, as well as establishing the capacity and environmental performance of CO_2 storage and identifying and assessing new ideas for energy systems with minimal CO_2 emissions. Other aspects examined include legal and regulatory frameworks for CO_2 capture and storage.

Other work by IEA GHG is aimed at putting into context the potential role that fossil fuels could play in the mitigation of climate change with other ways of achieving reductions in greenhouse gas emissions, such as wind power, solar energy and biofuels.

Options for CO_2 storage



Source: IEA

Research networks improve cooperation

In order to improve the various technologies, IEA GHG facilitates practical research and development, both at pilot scale and as demonstration projects of capture and storage of CO_2. IEA GHG's first major achievement in this field was the development, with Statoil, of the monitoring programme for the Sleipner injection. Since then, other major projects have welcomed IEA GHG involvement, such as the Weyburn monitoring project in Canada.

Several international research networks have been formed to improve cooperation. Currently, these networks include CO_2 capture testing, biofixation of CO_2, zero-CO_2 gases, and risk assessment of CO_2 storage. Further networks are in preparation.

Customized information

A variety of publications is produced for different audiences. Members receive very detailed reports on each technical study, typically 12 every year. In addition, several other reports on workshops and technical reviews are published for members. A series of summary reports provides assessments of the state of knowledge about particular technologies. The newsletter "Greenhouse Issues" is published every two months.

As a rule, each issue covers a wide range of topics from around the world. The newsletter is one of the main vehicles used for advertising and distributing announcements about the Programme's publications and conferences, as well as for publicizing related events.

IEA GHG organizes the international conference series on Greenhouse Gas Control Technologies (GHGT); these conferences take place every two years.

Several members of the project team and several members of the Executive Committee are authors of the Intergovernmental Panel on Climate Change's special report on CO_2 capture and storage, due for publication in 2005.

RWE supports the work of the IEA GHG programme as member and sponsor.

Info

Further information:
www.ieagreen.org.uk.
www.co2captureandstorage.info

The author: *Paul Freund*
IEA Greenhouse Gas R&D Programme
Project director, Cheltenham, UK

Innovations to prevent climate change in the context of market developments

"Innovations to prevent climate change in fossil-fired power plant technology" have been described in detail in the previous contributions. The reports and remarks – also in view of developments on the electricity market in the EU or in Germany – must be fitted into the overall context.

Clean coal concept to underpin the economical and ecological long-term use of coal

EURACOAL, the umbrella organization of the European coal industry, advocates retaining a wide field of applications for coal and extending its contribution to the energy supply. Along with the operators of coal-fired power plants, it is pursuing a clean coal concept for CO_2 reduction in power generation with a breakdown into stages and substantive steps. Hence, clean coal is part of a long-term strategy for underpinning the economical and ecological use of coal. Dr Dietrich Böcker who was EURACOAL president until 31 January 2005 and is now working as energy consultant describes the concept.

In a first step, the clean coal concept is set to help apply state-of-the-art technology Europe-wide for the environmentally and climatologically sound combustion of lignite and hard coal. This refers to reductions in dust, NO_x and CO_2 emissions, as it does to the achievement of ambitious power plant efficiencies. In addition, the concept describes pragmatic future developments on the basis of continuous rises in efficiency in the power plant process. The feasible CO_2 reduction potential worldwide from gains in efficiency in coal-fired power plants will suffice to obtain many of the CO_2 savings now agreed internationally or considered to be necessary.

Minimizing economic and ecological risks

The special feature of the clean coal concept is that these potentials can be exhausted without jeopardizing the secure and economic supply of electricity. In its visionary option of a low-CO_2 power plant, clean coal is looking far into the future. In the light of today's knowledge, the realization of the concept for capture and storage is not barred by any insuperable technical obstacles, but does involve considerable economic and ecological risks. To minimize these is an important task for the future, and one to which industry and politics must devote their joint efforts.

EURACOAL advocates a facts-driven examination of these options for CO_2 capture and storage within the scope of the 7th EU Research Programme. At the same time, the association is calling for efforts on behalf of rises in efficiency to be given priority support in this framework programme as the underlying goal of overall developments in power plant technology.

Technology questions clarified by feasibility studies

A concrete timetable and schedule of measures should be drawn up for the development of capture and storage techniques. From the point of view of the coal industry, it should be possible, using feasibility and pilot studies, to clarify by the start of the next decade what technologies are best suited and offer the greatest economic opportunities. In the decade that follows, the statutory bases and framework conditions must be prepared. Initial plants, including the requisite assured CO_2 storage, could be commissioned by 2020, provided that it has been clarified by then whether incisive additional measures are indispensable for reducing CO_2 output.

Coal an essential energy source

EURACOAL is convinced that the primary energy source coal has a crucial role to play in economic, environmentally friendly and safe energy supplies for Europe. New and efficient technologies in the power plant area and the potentials for further improvements in energy efficiency offer good preconditions for ensuring that coal can prevail under its own steam in an open European market.

The author: *Dr Dietrich Böcker*

President of EURACOAL
Umbrella organization of the European coal industry (until 31 January 2005)
Energy consultant

Innovative, fossil fuel-fired power plant technologies offering maximum CO_2 reduction potential worldwide

This article is a first quantitative evaluation of the coal technologies being discussed. The need for clarification on the subject of CO_2 capture, transportation and storage is outlined. The hierarchy of the resulting evaluation of coal technologies is reflected in the subsequently described development strategy and the R&D commitment of RWE Power, discussed here by Dr Johannes Ewers, head of new power plant technologies.

1. Options for CO_2 reduction in a comparison:
Employing the classic criteria of efficiency, investment costs and electricity production costs, we obtain ratios for the chief power plant processes discussed, taking lignite as an example.

CO_2 reduction and efficiency increases

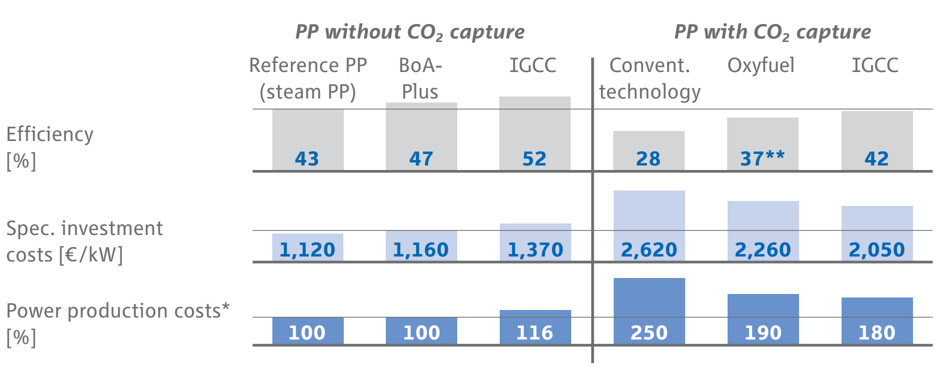
The lignite-fired power plant with pre-drying (BoA-Plus), subject to the same electricity production costs, achieves 4 % point higher efficiency than today's BoA technology (lignite-fired power station with optimized plant engineering) in the Niederaussem reference power plant. A further option for a rise in the efficiency of the steam power plant is the so-called 700 °C power plant with a further efficiency potential of 4 % points. The integrated gasification combined-cycle (IGCC) plant without CO_2 capture is economically inferior to the steam power plant in spite of its 9 % points efficiency edge. What is needed is a fall in investment costs and greater availability than has been obtained so far in some demonstration plants operated around the world. This being so, IGCC technology is not competitive today relative to steam power plants.

With CO_2 capture, efficiency falls

Among the power plant processes with CO_2 capture, the conventional power plant with downstream CO_2 scrubbing in the atmospheric flue gas has a drastic loss of efficiency. This is primarily due to the high energy requirements. Owing to the scrubbing, the net electricity generated falls, while investment outlays rise, so that specific investment costs are some 130 % and electricity production costs 150 % higher than in the case of the reference power plant. This process, when viewed from the angle of sparing resources, is unattractive, as are the costs. In the Oxyfuel process, combustion is with a mix of oxygen and recirculated CO_2. The flue gas, consisting mainly of CO_2 and steam, is cooled after cleaning, so that, following condensation of the steam share, the CO_2 is obtained without an additional scrubbing stage. This process, which has existed until now mainly on paper, promises much lower losses of output; all the same, rising investment costs are expected here, too. Specific investment will roughly double, and electricity production costs will be some 90 % higher than in the case of the reference power plant.

Using the IGCC process with CO_2 capture, the efficiency levels of today's modern power plants could be virtually held, even if, compared with IGCC without CO_2 capture, a perceptible efficiency disadvantage of 10 % points is to be noted.

Power plant (PP) processes compared (1): efficiency and costs, taking the example of lignite



* incl CO_2 compression, liquefaction, 300 km transportation and storage
** incl pre-drying, i.e. efficiency advantages relative to raw-coal combustion considered

CO_2 capture is relatively inexpensive here. Since the IGCC process is generally more expensive compared with the conventional power plant, the specific investment costs and the power generation costs are each about 80 % higher than those of the conventional steam power plant. Of all processes with CO_2 capture, the costing for the IGCC has the soundest basis, because this process is close to being fully evolved both technically and operationally. Altogether, the IGCC process has the greatest potential among the processes with CO_2 capture.

Coal has greatest CO_2 reduction potential

From a climate-protection point of view, CO_2 avoidance costs are a measure of efficient CO_2 mitigation. They are calculated from the difference between the full costs of power generation and the reference power plant as regards the difference in CO_2 output. The BoA-Plus power plant would already be competitive today. This being so, RWE Power has initiated the approval planning process to build a prototype drying plant at the BoA unit in Niederaussem. Among the coal processes with CO_2 capture, the IGCC and Oxyfuel processes have the advantage.

In the case of the natural gas-fired CCGT plant, avoidance costs are high because, in this case, the CO_2 reduction potential is relatively low. By comparison with renewable resources, the coal processes prove to be the most efficient lever of CO_2 reduction in cost terms. At the same time, coal offers the greatest use potential for the power supply and permits the greatest CO_2 reduction by far.

Utilizing this potential is not merely a question of technical development, but presumes in principle

1. that the resulting drastic rise in the costs of electricity, the basic substance for any competitive economy in a situation of worldwide competition will be feasible at all and
2. that CO_2 storage will not only be technically feasible, but also find socio-ecological acceptance.

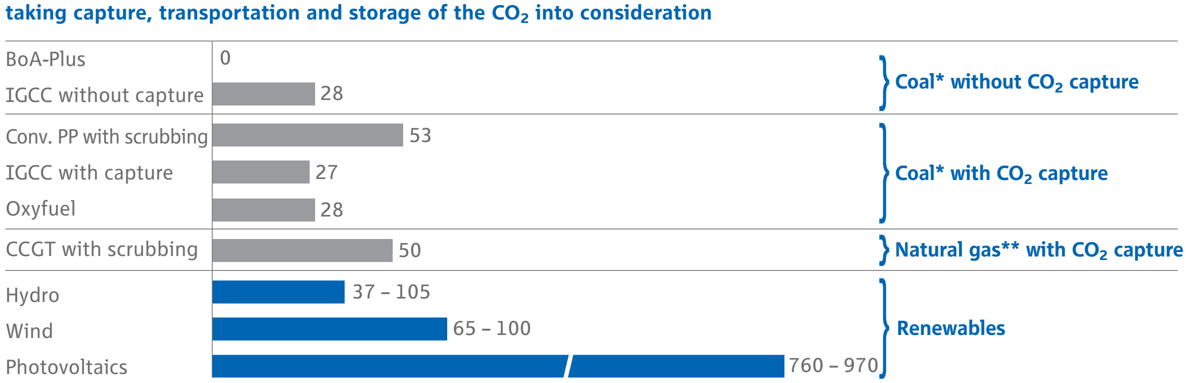
These two questions cannot be viewed in national and European terms alone, but must be regarded and decided in a worldwide context.

Clarification of CO_2 storage a basic condition

Clarification of the storage question must be pursued in parallel with developments in power plant technology. In particular, in view of the testing of long-term effects, roughly the same time horizon of approx. 2020 is assumed for development up to commercial implementation as for development of zero-CO_2 power plant technology. Of the rough storage potential derived theoretically for Germany of 22 – 30 bn t, the largest portion by far is in the aquifers. Here we also find the greatest need for clarification with regard to the effects of CO_2 injection and long-term storage.

Since storage capacity will be limited – the theoretical potential could extend to 65 or 85 years – the zero-CO_2 power plant technology can, at all events, only be an option for a certain period, providing an opportunity for gaining time to develop new technologies as pillars of power generation. The need for clarification in the storage question goes beyond technico-ecological considerations (see Focus, p. 76). Clarification of all issues is a basic precondition for acceptance of the entire technology route. Eventually, we will be left with this all-important, but not yet calculable question of public acceptance. Thoroughness, care and frankness in technological developments are the decisive up-front efforts that have to be made.

Power plant (PP) processes compared (2): CO_2 avoidance costs relative to reference PP [€/t CO_2] taking capture, transportation and storage of the CO_2 into consideration



* taking lignite as example
** result of CCP project, Norway

2. Commitment of RWE Power on behalf of clean coal technologies: the use and development of clean coal technologies is one focus of concrete power plant renewals and of the entire research and development activities at RWE Power.

Rises in efficiency have precedence

Priority in climate protection at RWE Power goes to increases in the efficiency of CO_2 reduction and the saving of resources. Accordingly, within the scope of current power plant renewals – in Horizon 1 of the developments in power plant technology described earlier – the very latest in state-of-the-art in engineering is deployed. A case in point is the BoA power plant, the most modern lignite-fired power plant worldwide. The second and third units of this innovative technology are being planned at present.

In parallel, RWE Power is pressing ahead with the further development of innovative power plant technology. R&D activities and projects have a stress on the medium term (Horizon 2) and long term (Horizon 3). Horizon 2 centres on two major projects. In both cases, the object is to move even more efficient coal-fired power plant technology to the implementation stage. This applies to RWE's own development of highly efficient lignite drying, the combination of which with BoA technology is leading to the so-called BoA-Plus power plant. With a budget of € 40 mill., efforts at a prototype plant for drying at the Niederaussem BoA unit are pushing this technology to commercial maturity. Alongside this development, RWE Power is playing a leading role in the further development of steam power plant technology to produce the so-called 700 °C power plant. This involves extensive cooperation with European partners in the projects shown in the box and has a total budget of € 17 mill.

Focus

Need for clarification in CO_2 storage

- Technical, economic and ecological feasibility
  - Drawing up of register of possible storage facilities
  - Storage tests with comprehensive monitoring (CO2SINK project)
  - Implications for subterranean hydrosphere
- Legal clarification
  - Legal treatment of storage (dumping, interim storage)
  - Legal framework for access rights to potential storage facilities
- Public acceptance
  - CO_2 storage presumes wide public acceptance
  - The feasibility of CO_2 storage in a densely populated area still has to be classified as uncertain

From vision to viable technology

In the long-term Horizon 3 being pursued in parallel, RWE is seeking to develop a feasible and accepted technology ready for implementation from the vision of a zero-CO_2 fossil-fired power plant. The development programme drawn up for this purpose incorporates all three focuses of this new technology:

- power plant technology options
- transportation and storage of CO_2
- environmental and acceptance questions

In view of the breadth of the topic, its processing depth and the outlays of time, labour and money involved, core themes are tackled within the scope of national and European cooperative projects along with partners from manufacturing industry, power generators and universities/institutes. The ENCAP, CASTOR projects for power plant technology and CO2SINK for CO_2 storage are being pursued in the 6th EU framework programme. The COORIVA, ADECOS and OXYCOAL projects are national projects on power plant technology within the scope of the COORETEC concept of the BMWA. CO2TRAP and COSMOS are Federal Research Ministry (BMBF) programmes for CO_2 storage. The total budget borne by the partners for these projects is € 66 mill.

The programme of the zero-CO_2 power plant at RWE Power is aimed first of all at determining the power plant technology that is best suited for this route and also has the best chances economically and ecologically. Here, RWE Power is implementing its extensive experience in gasification and combined-cycle plant technology. The next step is to trial the plant technology on a pilot and demonstration scale. Alongside the development of power plant technology, a further focus is on the CO_2 storage issues mentioned. Likewise in parallel is the clarification of basic issues of approval law and other regulations as well as the underlying conditions for the technology. The time horizon for commercial use of the zero-CO_2 fossil-fired power plant, including an assured long-term storage of CO_2 is in the range of 2020.

Use and development of clean coal technologies at RWE Power – a project overview
(EU and D refer to European and German support projects)

Horizon 1 **Horizon 2** **Horizon 3**

Project power plant renewal
- Use of ultra-modern technology, e.g., BoA 1, BoA 2/3

Project lignite pre-drying/BoA-Plus
- WTA prototype at BoA 1 in Niederaussem (EU support: € 2 mill.)

Budget € 40 mill.

Project 700°C power plant, material developments
- Component test plant COMTES700 – EU
- Materials test at Esbjerg power plant – EU
- Materials test at Weisweiler power plant – D
- Materials test Komet 650 – D

Budget* € 17 mill.

Efficiency increase
(primary measure)

Project zero-CO_2 fossil-fired power plant
- ENCAP – EU (IGCC, Oxyfuel membranes)
- COORIVA – D (IGCC)
- ADECOS – D (Oxyfuel)
- OXYCOAL AC– D (Oxyfuel with high-temperature membrane)
- CASTOR – EU (CO_2 scrubbing, CO_2 storage)
- CO2SINK – EU (CO_2 storage)
- CO2TRAP, COSMOS – D (CO_2 storage)

Budget* € 66 mill.

CO_2 capture and storage
(secondary measure)

* total budget of cooperative projects

Upshot

Today's and future innovations in modern power plant technology on the basis of fossil fuels offer a considerable potential for preventive climate protection by way of CO_2 reductions that can be deployed worldwide. The corresponding developments in power plant technology must be promoted on all horizons indicated. RWE Power has aligned its activities accordingly.

Clear precedence goes to an increase in efficiency. This brings about not only CO_2 reductions, but also a sparing of resources. The instruments of power plant technology are already available today. Their further development opens up further potentials. Hence, increases in efficiency should be promoted within a suitable framework in both European and national research-support programmes.

CO_2 capture and storage require extensive developments and underpinning measures in power plant and storage technology before they can be employed on a wide basis. To this end, RWE Power has drawn up a comprehensive development programme. The core issues in this new technology route are being investigated in depth in cooperation with European partners. Acceptance of the significant increase in the consumption of resources and the long-term storage of CO_2 are among the crucial themes that must be clarified prior to wide use of this technology.

The author: *Dr Johannes Ewers*

RWE Power
Head of new power plant technologies

RWE Power: Production company for continental Europe

Group division RWE Power, Essen/Cologne[1)]

Continental European power generation and extraction of the energy resources lignite, oil and natural gas

- Total sales € 8.6 bn
- Employees[2)] some 18,000

- Power production 200.1 TWh
- Capacity 34.1 GW

RWE Dea, Hamburg[3)]

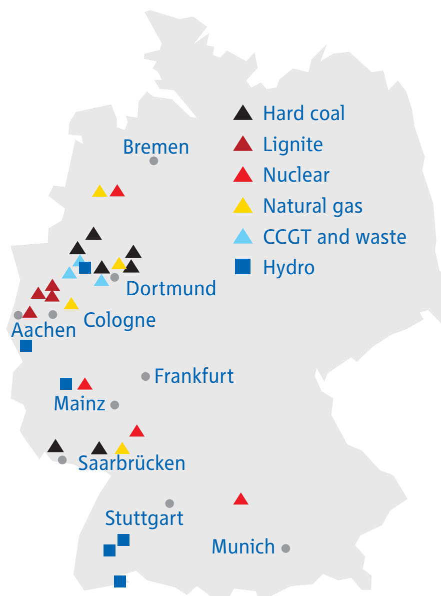
Upstream natural gas and oil

Other major participations

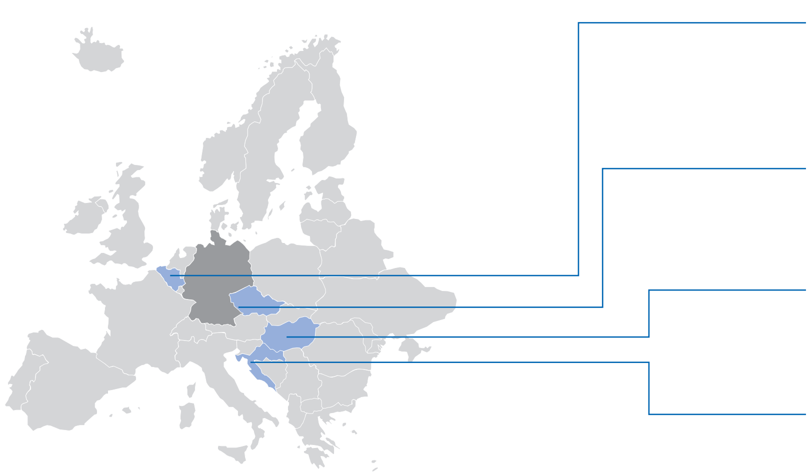
Harpen[3)] (renewables)
Mátra (lignite-based power generation/Hungary)

1) Ratios based on 2004 fiscal year
2) Cut-off date: 31 December 2004
3) Shares held by RWE AG; companies managed by RWE Power

RWE Power locations in Germany



Power plant participations of RWE Power in Europe
Fossil-fired power plants



Masthead

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