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CO2 capture and storage at power stations

Summary

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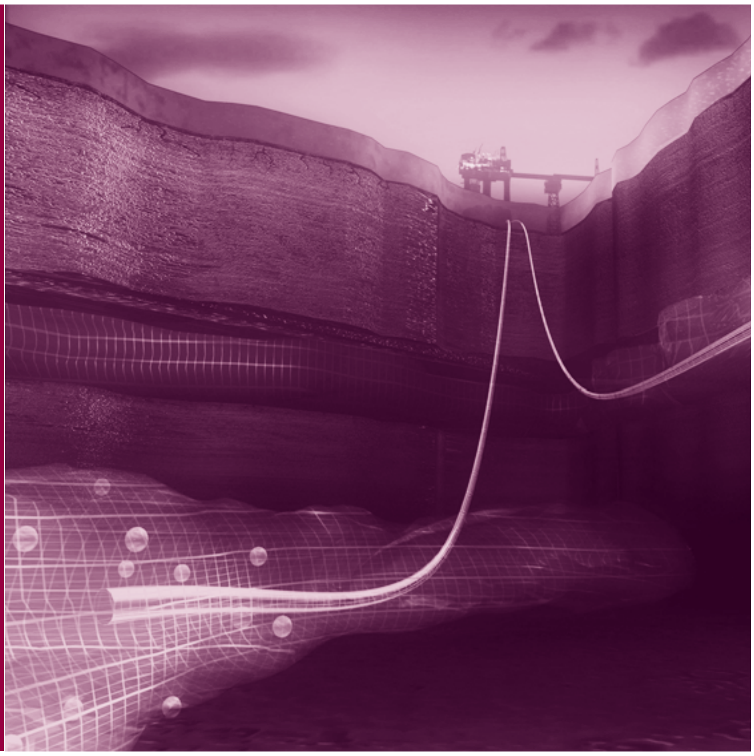

SUMMARY

Carbon dioxide (CO_2) is inevitably produced when fossil fuels are used and is usually released into the atmosphere, where it affects the climate. One option for climate protection is to capture the CO_2 and isolate it permanently from the atmosphere. This is the principle of CO_2 capture and storage (CCS). This procedure is primarily suitable for large, stationary CO_2 sources, e.g. electricity-producing power plants or certain industrial processes (e.g. manufacture of ammonia or cement). CCS is being discussed particularly in the context of coal-fired power plants as these emit the highest amount of CO_2 in relation to electricity production. But CCS could in principle be an option for other fossil fuels, too. With the use of biomass, it is even conceivable that the CO_2 content of the atmosphere might even be actively reduced. Experts expect it to take about 15 to 20 years for CCS technology to reach large-scale maturity.

For an overall evaluation of whether CCS technology is compatible with the principle of sustainable energy supply, the question of reducing greenhouse gases is not the only central topic. On the contrary, other criteria must be considered, in particular the conservation of exhaustible resources, economic efficiency and social factors, e.g. management of long-term risks in terms of intergenerational fairness and social acceptance.

STATUS OF THE TECHNOLOGY: THE NEED FOR RESEARCH

The CCS technology chain consists of three elements: *separation* of CO_2 in as concentrated a form as possible at the power plant, *transport* to a suitable storage site and actual *deposition* below the earth's surface.

Separation of CO_2

There are three options for separating CO_2: (1) It can be filtered out of the flue gases after combustion; (2) the carbon can be removed from the fuel before the actual combustion process; or (3) combustion can be conducted in an oxygen atmosphere so that (practically) the only flue gas produced is CO_2. These three options are termed (1) *post-combustion*, (2) *pre-combustion*, and (3) *oxyfuel*. The feature common to all the above-mentioned processes for separating CO_2 is that they require a considerable expenditure of energy, which reduces the power plant efficiency by up to 15 percentage points and results in an additional requirement of fuel that can reach 40%. Each of these methods has specific advantages and disadvantages. Thus, at present it remains an open question which of them offers the best prospects for the future.

> The *post-combustion process* as a typical »end-of-pipe« procedure has the advantage of being potentially integrable into existing industrial processes and power plants. However, this advantage of possible retrofitting is offset by relatively high costs and energy losses. CO_2 separation using chemical absorption is currently the only commercially available procedure and is used, for instance, for natural gas processing. To be amenable for use in (large) power plants, it would have to be scaled up by a factor of 20 to 50. Further research and development targets are to increase efficiency, particularly by further developing the solvents used, but also to improve the process integration and optimize its deployment in power plants. One interesting perspective could lie in innovative processes (e.g. membrane processes), since these promise greater efficiency and reduced costs. These are currently still at an early stage of research.
> The *pre-combustion process* in comparison has a lower energy requirement and offers the perspective of producing hydrogen or synthetic fuels from fossil fuels with relatively low CO_2-intensity. The disadvantage here, however, is the great complexity of the plants and their operation. Key components for the pre-combustion process are highly efficient hydrogen turbines. These are currently still at the pilot stage and must be significantly further developed before they can be put into commercial use. Progress in membrane technology could contribute to increasing the efficiency and economy of this process. Beyond the development of individual components, a further significant challenge is to control the process chain in its entire complexity on a real power plant scale and to guarantee a high level of availability for the whole plant.
> The *oxyfuel process* has the advantage that a relatively high concentration of CO_2 is present here, and the flue gas stream to be processed is much smaller than for the other processes. The disadvantage of this process is that the production of pure oxygen is bound up with a high use of energy and considerable costs. Air separation plants for producing oxygen have been in industrial use for some time. The high energy consumption required for liquefying air, however, makes it seem necessary to significantly further develop this process or alternative methods for oxygen production (e.g. membrane technology). As with the other processes for CO_2 separation, integrating the individual steps of the process into an efficiently working overall system is a major task.

Post-combustion, pre-combustion and oxyfuel are processes that can be deployed in the short or medium term for CO_2 separation in power plants. In addition, research is being pursued into other alternative separation procedures, which in the long term promise considerable progress, especially with regard to energy requirements and costs. The feature common to these innovative processes is that they are all currently at the stage of conceptual studies and laboratory tests. Their use is thus only to be expected in 20 to 30 years at the earliest. Promising candidates here include the use of fuel cells, the so-called ZECA process and »chemical looping combustion«.

CO_2 transport

For transport, the CO_2 must be compressed after separation. The energy consumption required for this corresponds to a loss in power plant efficiency by about 2–4 percentage points. For the large amounts produced in power plants (in a coal-fired power plant with electrical power of 1000 MW about 5 million t CO_2/year are produced), the most eligible means of transport are ships and pipelines. Transporting CO_2 in pipelines is in principle no different from transporting oil, gas and liquid hazardous substances, which is being done extensively worldwide. The biggest difference in CO_2 pipelines is that the materials used must be highly corrosion resistant. Transporting CO_2 by ship is currently only used to a very limited extent; the technology is not essentially different from the conventional transport of liquid gas (liquefied petroleum gas, LPG). Transport by ship is above all suitable for great distances (more than 1000 km) and amounts that are not too large.

Despite its important function as a link between capture and storage, CO_2 transport has so far been accorded little attention by research and – if at all – is mainly discussed in terms of cost. Important questions that should be addressed would include the temporal and geographic coordination of setting up a transport infrastructure, national or regional preconditions or barriers for this and questions of the acceptance of transport through densely populated areas.

CO_2 storage

For the long-term geological storage of CO_2, depleted oil and gas fields and so-called saline aquifers are particularly worthy of consideration:

> Oil and gas reservoirs have the advantage that they have been shown to be enduringly impermeable over millions of years. Thanks to the exploration and exploitation of the repositories, the composition of the rocks and the structural layout of the storage and sealing formations are known very precisely. The biggest problem for storage safety is posed by old abandoned drill holes, which in some cases may be present in oil and gas fields in large numbers. Finding and particularly sealing off old drill holes is time consuming and costly. The injec-

tion of CO_2 can if applicable be used for prolonging the extraction of oil or gas from almost depleted fields (so-called enhanced oil/gas recovery, EOR, EGR).

> Saline aquifers are highly porous sedimentary rocks which are saturated with a strong saline solution (brine). The space in their pores can be used for CO_2 intake whereby some of the brine is displaced. To be suitable as a CO_2 storage area, there must be a seal rock above the aquifer which is as CO_2-impermeable as possible. It has to be assured as far as possible that no CO_2 can escape along crevasses, rift zones or similar and the brine can not come into contact with groundwater near the surface.

STORAGE POTENTIAL

CO_2 capture and storage can only provide an appreciable contribution to climate protection if sufficient storage capacity is available to accommodate the separated CO_2. The range of current estimates for the worldwide storage potential is enormous (from 100 to 200 000 billion t CO_2). They are thus far too imprecise to allow any reliable estimate of the possible significance of CCS on global climate protection.

In *Germany*, several natural gas fields are reaching the end of their production phase and would thus become available in principle in the next few years for storing CO_2. The overall storage capacity in aquifers and depleted natural gas repositories together amounts to about 40 to 130 times the annual CO_2 emissions from German power plants (approximately 350 million t/year).

The question whether this potential can be economically tapped for CO_2 storage and indeed be used is dependent on a number of geological details, economic, legal, and political conditions and social acceptance. In addition, geological formations which are suitable for CCS are also interesting for alternative forms of use (e.g. geothermal energy, seasonal natural gas storage). It is thus to be expected that the usable capacity for CCS in practical terms is considerably smaller than the theoretical potential.

RISKS, ENVIRONMENTAL EFFECTS

The possibility exists all along the CCS processing chain that CO_2 will escape – with adverse effects both for the local environment and for the climate. Generally, the risk of technical plants (e.g. separation equipment, compressors, pipelines) is judged to be low or manageable with the usual technical means and controls. The discussion of risk thus concentrates on the geological reservoirs.

Still a matter of controversy is the minimum time that the CO_2 must remain underground for CCS to be able to make a positive contribution to reducing greenhouse gases in the atmosphere. The times discussed usually range from 1000 to 10,000 years.

The most important processes which could compromise the safety and permanence of CO_2 storage according to the state of knowledge today are:

> geochemical processes, particularly the dissolution of carbonate rocks through the acidic CO_2-water mixture;
> pressure-induced processes, e.g. the expansion of existing small fissures in the seal rock through the overpressure of CO_2 injection;
> leakage through existing drill holes, relevant particularly in oil or natural gas repositories;
> leakage via undiscovered migration paths in the seal rock (crevasses etc.);
> lateral expansion of the formation water, which is displaced by the injected CO_2.

General statements on the safety of particular storage types are only useful to a limited extent and do not suffice by any means for a decision to be made as to a concrete location on injecting CO_2. For this, each potential reservoir must be examined individually with regard to its specific features. To estimate risk profiles of geological reservoirs, it is urgently necessary for further studies and field experiments to be conducted.

The long-term security of geological CO_2 repositories is not only a question of geological features. It is rather the case that appropriate regulation and continuous monitoring are necessary to guarantee a sufficient degree of knowledge so that storage risks can be minimised.

COSTS, COMPETITIVENESS

The costs of CO_2 separation and storage are made up of the costs for the individual process steps (separation, transport, and storage) together. In addition, the degree of loss in power plant efficiency and the ensuing higher consumption of primary energy sources must also be taken into account.

The dominant cost factor lies in the expenditure for CO_2 separation. Compared with a power plant of the same type but without CO_2 separation, the additional costs are estimated at between 26 Euro/t and 37 Euro/t (in relation to the amount of CO_2 avoided). For coal-fired power plants this means almost doubling the cost of electricity generation, and for natural gas combination power plants it means an increase of 50%. On the basis of the cost analyses available so far, no clear preference can be inferred for a particular technique (e.g. oxyfuel versus pre-combustion). The costs of preventing CO_2 by means of CCS in coal-fired power plants – assuming introduction onto the market in around 2020 – amount approximately to between 35 and just under 50 Euro/t CO_2, while for natural gas power plants they are significantly higher.

CCS technology will only be deployed on the electricity market if it is competitive with other manufacturing options. The prerequisite for this is that production of climate-friendly electricity is rewarded. In other words, the price for CO_2 emissions, such as is determined on the European market for CO_2 emission certificates (EU allowances, EUA), must be set at least so high that CCS power plants can compete with fossil fuel power plants without CO_2 separation. In the light of the above-mentioned CO_2 separation costs, this would mean a price of about 30 to 40 Euro/EUA.

A comparison of the prime costs of electricity in CCS power plants with other low-CO_2 and especially regenerative production methods shows that, in the year 2020, most of the regenerative technologies that have been examined could have reached a cost level similar to that calculated for CCS power plants (in range of 0.05 to 0.07 Euro/kWh). Although the prognostic power of such long-term projections should not be overinterpreted, it seems incontestable that CCS will not have the field to itself, but will have to compete with other technologies for low-CO_2 electricity generation.

INTEGRATION INTO THE ENERGY SYSTEM

In Germany, the age structure of the power plants means that in the next two to three decades there will be considerable need for renewal. The contribution that can be made by CCS technology to reducing CO_2 against this background depends strongly on the answers to the following questions:

> When will CCS really be available?
> Is it feasible to retrofit existing power plants with CCS technology?

> Is it an acceptable idea to prepare this retrofitting in new power plants that are being built (i.e., make them »capture ready«)?

Since effective climate protection can only be addressed globally, CCS should also be evaluated from an international perspective.

Timeframe for availability

In various papers on research strategy and so-called roadmaps, one topic is the projected time in which CCS technology could be available. A common feature of most of these publications is that 2020 is quoted as the target year for commercial availability on a power plant scale. Among experts, this is regarded as very ambitious. One reason for this brief time period could be the recognition that the contribution that CCS can make to CO_2 reduction becomes increasingly smaller, the longer it takes to make the technology fully available. If one takes a look at the currently initiated projects or planned pilot and demonstration projects, it only seems possible to keep to the stated time frame if the economic and political conditions are favourable.

Potential retrofitting/»capture ready«

In principle, existing power plants could be retrofitted with CO_2 separation plants. Post-combustion with following flue gas cleaning causes the least technical effort and means the smallest amount of intervention in the power plant process itself. The question of whether power plants really will be retrofitted depends not only on the technological feasibility, but crucially on the economic viability. Retrofitting power plants is costly and as a rule more expensive that integrating CO_2 separation into a new plant. It is to be assumed that retrofitting would only be conducted on a larger scale if the economic incentives for CO_2 separation are high enough or if, for example, an obligation to upgrade were introduced.

The idea of preparing new power plants today in such a way that they can be retrofitted later with CO_2 separation plants in a technically uncomplicated and cost-effective way as soon as the technology and corresponding CO_2 repositories are available looks at first sight to be plausible and attractive. This »capture-ready« concept is currently the subject of much discussion among experts, especially since the EU Commission introduced the suggestion into the debate of only approving those fossil fuel-fired power plants in the future that are capture ready. However, the options for installing capture-ready components in power plants to be built today are extremely limited.

From today's perspective, only those measures would be economically acceptable which cause only little costs, e.g. reserving the building site for the CO_2 separation plant and keeping a simple access open to components which would probably have to be upgraded or replaced in the course of retrofitting. Another factor worth considering is paying careful attention to the choice of location for power plants so that they are found close to a potential repository or to an existing infrastructure for CO_2 transport.

For a robust estimate of whether the capture-ready concept is acceptable, there is still a considerable need for technical-economic analyses. In addition, criteria must be developed which, for example, permit approval authorities to judge the capture readiness of power plants.

International/global perspectives

CCS technology could be particularly attractive for countries which have so far been sceptical about climate protection measures (e.g. USA) and/or want to continue to use their domestic primary energy basis of fossil fuels (especially coal; e.g. China, India).

In China alone, between 1995 and 2002 about 100 000 MW of fossil fuel power plant capacity (primarily coal-fired power plants) were built. For the period 2002 to 2010 it is forecast that a further 170 000 MW will be added to this. If this trend were allowed to progress unchecked, the success of international climate protection efforts would be called completely into question.

In order for the deployment of CCS technology to become an attractive option in these and other emerging nations, it would have to first be successfully further developed and proven. The most suitable candidates for this are industrial countries with their technical know-how and financial possibilities. In the face of the dynamics of power plant expansion, however, CCS would have to be introduced as quickly as possible, since otherwise the window of opportunity would close again and might remain closed for many decades.

PUBLIC PERCEPTION AND ACCEPTANCE

Public perception can have considerable and unexpected effects on planned technological and infrastructure projects. Disputes – especially with regard to atomic energy and genetic engineering – are a clear illustration of this. Technologies like CCS whose long-term risks to our security, health and the environment are hard to assess are particularly prone to triggering public unrest and possibly resistance.

Ensuring a high degree of public acceptance should thus be a high-priority target from the very beginning. One important prerequisite for acceptance is the creation of transparency by providing comprehensive information both about the targets of CCS in general as well as about concrete intentions and projects. As the past has shown, however, measures relying purely on information and advertising are by no means sufficient to create acceptance. To avoid crises of acceptance and trust, an open-ended process of dialogue should be initiated between industry, interest groups, science and the public at an early stage.

LEGAL ISSUES

For the testing, introduction and distribution of CCS technology, a suitable regulatory framework must be created which should aim towards three targets at the same time: first, establish the conditions for the *admissibility* of the various components of CCS technology (separation, transport, storage), second provide *incentives* for investing in CCS technology, and third, guarantee that CCS does not fail due to a lack of *acceptance* and especially due to the locations of storage facilities.

Under current law, there is neither a procedure for *exploring locations* for repositories nor for the *storage* of CO_2. Creating an adequate regulatory framework means a double challenge. If one assumes on the one hand that the rapid introduction of CCS on an industrial scale is in the public interest in terms of climate protection, then it is necessary in the short term to authorise initial CCS projects in order to gain experience with the technology. This experience is necessary both for the further development of the technology as well as for political and legal guidance. In Germany there are several companies which already have concrete plans with this aim, some of which are at an advanced stage. The planned projects are, however, inadmissible if current law is not adapted in the short term.

On the other hand, a regulatory concept should preferably take all the relevant factors into account: selective use of the limited number of storage facilities available, consideration of competing claims for use, questions of liability, creating transparency, challenges in regional planning, integration into the climate protection regime, etc. Although a regulatory concept of this kind would greatly contribute to promoting acceptance and avoiding conflict, this would require sufficient time for its elaboration, discussion, decision-making, and realisation.

NEED FOR ACTION

On the basis of the current state of our knowledge and assuming there is public interest in the deployment of CCS technology to promote climate protection, TAB assesses that the following factors should be given priority.

Broaden the knowledge base: close critical gaps in our knowledge

The current status of our knowledge is by far too insufficient to permit any robust assessment of the technical and economic feasibility of CCS or any evaluation of the contribution that CCS can provide for achieving the targets of climate protection. In order to be able to do this, numerous critical gaps in our knowledge must be closed.

With regard to research and development in the field of CO_2 separation and the technologies for CO_2 conditioning and transport, the onus is on industry as the primary actor (power plant and equipment construction, utilities, chemical industry). The main task for state actors in this context would be to maintain or create a reliable environment so that companies could fully develop the socially desired research initiatives. The fields of action that offer the most promising candidates for justifying public funding of research would be for highly innovative procedures with great potential for public benefit, whether ecological and economically, and for cross-cutting fields (e.g. materials research).

The greatest deficit in our knowledge and the greatest need for research is currently in the area of geological CO_2 storage. In this field, there is also a special need for state action. Questions which would represent particularly good choices for publicly funded research projects would include the interaction of injected CO_2 with rock formations and the determination of storage capacity and investigations into the suitability of geological formations for the long-term storage of CO_2. There is an urgent need for research in the field of possible competitors with alternative uses (natural gas storage, geothermal energy). This also includes the question of how to resolve any usage conflicts if necessary (e.g. priority rules).

An urgent recommendation is that accompanying research in the social and environmental sciences be integrated in pilot projects at an early stage to ensure that technological development can be geared to the criteria of sustainable development and that knowledge about the economic, ecological and social effects of CCS that will be needed for later decisions will be available. This includes the analysis of potentials, risks, and costs, considerations of life cycle assessment and questions of integrating CCS in the energy system.

Triggering a public debate

To prevent a lack of acceptance from becoming an obstacle to further development and to the use of CCS technology, a national strategy of communication, information, and participation should be designed and implemented early. This process should be structured so as to leave the outcome open and should sound out whether and how one could reach the broadest social consensus possible. This is a demanding task which should be initiated before the first concrete location decisions are to be made. A first possible step in organising this process of communication, namely the establishment of a national »CCS forum«, is put forward for discussion, which could bring together all the relevant positions of stakeholders in Germany.

Creation of a regulatory framework

There are several companies in Germany that are already planning concrete CCS projects, some of which are at an advanced stage. Without any short-term adaptation of the current law, these planned projects are, however, inadmissible. Thus there is urgent need for action here.

A two-step procedure would be ideal: In the course of an interim solution which should be realised short term, the legal preconditions should be created so that projects which are mainly concerned with the research and testing of CO_2 storage can be promptly initiated. The central element in a short-term regulatory framework would be the creation of an admissible event in mining law.

At the same time, a comprehensive regulatory framework should be developed and if possible coordinated at the EU level and internationally which accommodates all aspects of CCS technology. This could supersede the interim regulation as soon as CCS is available for large-scale technical deployment.

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