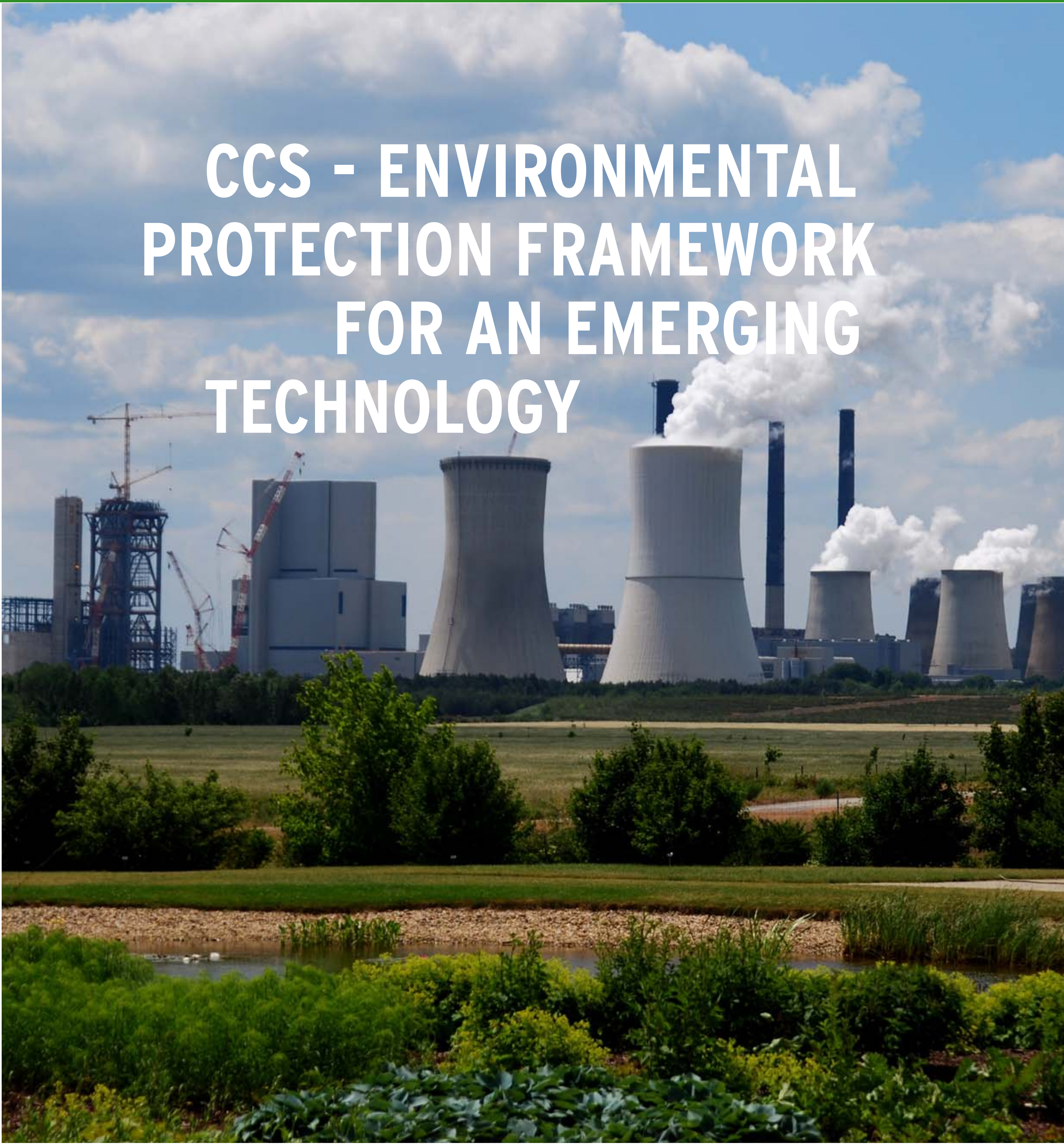
CCS – ENVIRONMENTAL PROTECTION FRAMEWORK FOR AN EMERGING TECHNOLOGY



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Wörlitzer Platz 1
06844 Dessau-Roßlau
E-Mail: pressestelle@uba.de
Internet: www.umweltbundesamt.de

Authors: Ralf Becker, Alexander Boehringer,
Thomas Charisse, Jörg Frauenstein,
Frank Gagelmann, Harald Ginzky,
Hans-Joachim Hummel,
Karsten Karschunke, Kai Lipsius,
Christiane Lohse, Michael Marty,
Klaus Müschen, Lutz Schäfer,
Rainer Sternkopf, Kathrin Werner

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Translation: Michael Gromm

CCS – Environmental protection framework for an emerging technology

Update of the German Federal Environment Agency's position paper on the technical capture and geological storage of CO_2

With this paper, the German Federal Environment Agency (Umweltbundesamt, UBA) updates[1] its position paper of 2006[2] on the technical capture and geological storage[3] of carbon dioxide (CCS: carbon capture and storage).

After a brief description of the development status of the process steps of capture, transport and geological storage of carbon dioxide (CO_2) in Chapter 1, we look into the possible risks for human health and the environment (Chapter 2), which up to now have been little discussed or researched. These risks will largely depend on the integrity of storage sites. On the assumption of functioning capture technology at cost-effective conditions, the capacity of available and secure storage sites will decisively determine the scale of possible greenhouse gas emission reductions through CCS (Chapter 3). In examining storage capacity, it has always to be considered that the geological storage of CO_2 can compete with other uses of underground geological formations, such as geothermics or compressed-air and natural-gas storage (Chapter 4). The Federal Environment Agency takes the view that these factors determine the role that CCS can play as an additional climate protection measure (Chapter 5).

In Chapter 6 we show how CCS, in its application, should be integrated into emissions trading. CO_2 emission reduction should in our view only be acknowledged when it is effectively and demonstrably ensured through permanent storage. Chapter 7 deals with necessary reforms of liability law, which legislators should undertake in order to assign the dangers and risks of CCS to those responsible for them. In Chapter 8, we summarize the fundamental demands on legislators, while Chapter 9 is devoted to issues concerning the source and application of funds for research and development.

[1] The editorial deadline was Oct 5th 2009.

[2] UBA, 2006

[3] The German Federal Government's CCS bill speaks of permanent storage (dauerhafte Speicherung). The word "Speicherung" – i.e. storage – is also commonly used in German publications, although in German mining law it stands for fixed-term, temporary storage. In effect, with CCS a "deposit" or "disposal" is involved, terms that would also be more appropriate. In this paper we nevertheless fall into line with the use of "(permanent) storage" in connection with CCS.

1 What is CCS?

- The objective of CCS technology is the reduction of CO_2 emissions into the atmosphere, which occur, above all, in the combustion of fossil fuels at large point sources.
- The climate-protection effect of CCS requires a functioning process chain comprising capture, transport and permanent storage.
- CCS is not yet available. None of the above three steps is presently sufficiently developed. It is therefore not clear whether CCS could be an option for large-scale CO_2 emission reduction and thus a significant climate protection measure.

Climate-policy background

The control of climate change is one of the key challenges of the 21st century. The Intergovernmental Panel on Climate Change (IPCC) has demanded that the global average temperature should not increase by more than 2 °C compared to the pre-industrial level.[4] Only on the basis of this limitation will the consequences of global climate change – among others, the number of people directly affected by coastal flooding, aridity and extreme weather conditions, flora and fauna threatened with extinction, damage to coral reefs and the risk of damage to infrastructure and agricultural production – be controllable on the basis of current scenarios. This 2° C stabilization target for the earth's temperature initially requires a successful turnaround by 2015 to globally decreasing greenhouse gas emissions. Beyond that, global CO_2 emissions would have to fall by 50 – 85% by 2050, compared to the level of the year 2000[5].

[4] IPCC, 2007

[5] IPCC, 2007

In order to reach these targets, industrialized countries – as the present main emitters of greenhouse gases – will have to shoulder greater burdens than the developing countries. Industrialized countries will have to achieve emission reductions of 80-95%, compared to 1990 levels, by 2050[6]. Germany must accordingly reduce its greenhouse gas emissions from around 1.2 billion tonnes of CO_2 equivalent in the year 1990 to about 0.06 - 0.24 billion tonnes CO_2 eq. by 2050. By 2008, Germany had already reduced its greenhouse gas emissions, compared to 1990, by 23% to approximately 0.96 billion tonnes CO_2 eq., and has set itself an interim reduction target of at least 40% by 2020 in the case of global and comprehensive agreement for the period after 2012.

The main source of CO_2 emissions is energy conversion, which up to now, both in Germany and globally, has been dominated by the combustion of fossil fuels. There is no doubt that successful climate policy is only possible with a substantial reduction of these greenhouse gas emissions.

Priority should therefore be given to the development of the energy system (energy conversion and use; cf. Chapter 5) that satisfies sustainability criteria[7] and avoids CO_2 emissions before they arise. The possible contribution of CCS should be discussed with this in mind.

Principle of CCS technology

The objective of CCS technology is the reduction of CO_2 emissions into the atmosphere from the combustion of fossil fuels. In plants with CCS technology, CO_2 still arises in the combustion of fossil fuels (due to increased specific energy consumption, in fact up to 40% more[8]); CCS is intended, however, to permanently keep 65 - 80% of the CO_2 out of the atmosphere and thus prevent its adverse effect on the climate[9]. Whether CCS can fulfil this promise has not yet been clarified and is currently the subject of numerous research and pilot projects.

CO_2 must be captured at the place of occurrence (mostly a power plant), transported to the storage site and securely and permanently stored in suitable, deep underground geological formations. Only the effective interaction of all process steps will enable a contribution on the part of CCS towards the reduction of CO_2 emissions.

CCS technology has not yet been fully developed. There is worldwide no example of the large-scale application of the overall process from capture in the power plant to storage, or experience with the capture of the complete CO_2 flue-gas stream at a power plant.

Development status of the process step "CO_2 capture"

Previous experience with CO_2 capture relates to other forms of process engineering, such as the separation of CO_2 from extracted natural gas, or to small-scale pilot projects, such as in Schwarze Pumpe in the federal State of Brandenburg, in which much smaller quantities of CO_2 arise than in large-scale operations.[10] Estimates of the capital expenditure, energy and expendable materials required by this technology, estimates of achievable efficiency, capture rate and purity of the CO_2 flue-gas stream, as well as statements on the reliability of the technology and its effect on the operational availability of the power plant and thus power supply security, are all fraught with great uncertainty[11]. There is still a considerable need for research and development. Commercial availability is therefore not to be expected before the year 2020.[12]

Development status of the process step "transport"

The transportation of the CO_2 gas stream is technically unproblematic, with high demands placed on the purity of CO_2 in order to avoid corrosion. With pipelines and tankers this is nowadays common practice. Transportation involves, however, great costs and high consumption of resources, and CO_2 storage should therefore ideally take place close to the power plant where it is captured. It is the large quantities that present major challenges for transportation and storage for fully-fledged CCS application.

Should CCS, for example, contribute 10% to the required worldwide reduction of CO_2 emissions (this would be around 1.5 billion tonnes annually and corresponds to about one-third of the CO_2 production of fossil-based power plants), this would amount – compressed to storage pressure – to a CO_2 volume of around 3 million cubic

6 IPCC, 2007
7 Enquete-Kommission, 1998
8 IPCC, 2005
9 WI et al., 2007

10 Vattenfall, 2008
11 MIT, 2007
12 McKinsey, 2008

metres. By contrast, worldwide annual production of crude oil amounts to around 5 billion cubic metres. The required new transport system for CO_2 would thus have to cope with quantities of a similar size.[13].

Development status of the process step "geological storage"

The leakage-free geological storage of CO_2 on a permanent basis – that is, over very long periods of time – is a new technology. As yet, no detailed knowledge exists regarding large-scale feasibility and actual effects, or monitoring and inspection. For this reason, a precautionary approach is advisable.

In the CCS process, geological storage presents the most uncertainties and potential adverse effects on the environment. There are worldwide few reference examples. Besides a number of small pilot storage sites – such as in Ketzin[14] in the federal State of Brandenburg – there are presently four major storage projects, which each inject a maximum of about 1 million tonnes of CO_2 per year in subterranean formations for the purpose of geological storage. These projects are located in Norway (Sleipner and Snoevit), Algeria (In-Salah) and Canada (Weyburn)[15]. On the basis of the exemplary calculation in the above section on transport involving 1.5 billion tonnes of CO_2 annually, 1,500 storage projects of this size would be required. Other projects – above all, in the USA – that use CO_2 injection for the purpose of enhanced oil recovery cannot serve as a reference from the point of view of storage, since no monitoring of CO_2 containment takes place.

Monitoring and post-storage maintenance

As yet, no appropriate monitoring methods exist for the comprehensive monitoring of stored CO_2. Initial research is being carried out, for example, in Ketzin[16] Mere surveillance from the earth's surface – for example, with seismic methods – is insufficient. There is a lack of technical knowhow concerning monitoring at great depths with the required accuracy. Long-term forecasts on the basis of measurements are therefore a necessary addition to such measurements. Monitoring of leakage and quantitative measurement of CO_2 leakage has primarily to be carried out at storage depth at the storage site. Besides CO_2, leakage of natural gas and formation water, which are present in storage sites and are displaced by the injected CO_2 stream, has to be monitored. From this, important pointers emerge regarding potential leakage paths and the localization of possible storage-site vulnerabilities. Furthermore, indirect effects of storage have to be investigated, such as an increase in pressure on surrounding (subterranean) space.

Finally, as provided for in the Federal Government's bill on the regulation of capture, transport and permanent storage of carbon dioxide,[17] storage site operators have to lay down post-storage measures and technical contingency plans at the time of commencing operations, in order that they and the authorities can react appropriately in the case of leakage or accidents. It is still unclear, whether post-storage remediation measures will be available in the case of leakage, and if so, which measures.

2 Possible risks of CCS technology for human health and the environment

- Storage integrity and additional adverse environmental effects from capture, transport and storage are important factors concerning the environmental performance of CCS technology.
- Effective monitoring of qualitative and quantitative demands on storage integrity is a prerequisite for the acceptability of environmental effects.
- CCS will significantly increase CO_2 emissions per produced unit of energy through energy expenditure on capture, transport and storage.

In assessing a new technology – as here with CCS technology – relevant effect categories[18] for the protection of human health and the environment have to be examined, as developed and updated by the Federal Environment Agency for assessment in environmental performance evaluations.

Human exposure

Carbon dioxide (CO_2) is not classified as toxic (according to CLP Regulation EC 1272/2008). It is

13 IEA, 2008 and internal calculations

14 GFZ, 2008

15 BMWi et al., 2007

16 GFZ, 2008

17 Bundesregierung, 2009; Parliaments approval was not achieved during the 16th legislative period. A new bill from the federal government could deviate from the text considered here.

18 UBA, 1999: Bewertung in Ökobilanzen. Texte 92/99

colourless and odourless, non-flammable and in low concentration a constant gaseous component of ambient air. CO_2 has a higher density than air, however, and can therefore collect in low-lying areas or basement rooms, where it can displace oxygen. Possible consequences are high CO_2 concentrations, which in the case of prolonged human exposure can cause breathlessness and, in extreme cases, asphyxia. Risks for human health are therefore only possible in the case of substantial leakage as a result of accidents during transportation and storage.

With proper handling of CO_2 during capture, transport and storage,[19] release in concentrations that pose a risk to human health is not to be expected.

Effects on the environment

Adverse effects on the environment may be a result of storage-site leakage. Leakage increases concentrations of CO_2 in subsurface air, and can therefore inhibit the breathing of plant roots and result in their dying off. Released CO_2 not only reduces the pH value of ground-, capillary and seepage water, it can also trigger geochemical processes and reactions (for instance, acidification, the release of calcium from limestone and the mobilization of heavy metals). The consequences are toxic effects on soil organisms and plants, the occurrence of which is to be expected primarily at a local level and on a small scale. Contamination and admixture of other substances in the injected CO_2 stream may also cause adverse effects on the environment. The precise significance of such effects cannot presently be assessed.

Injection of the CO_2 stream may lead to changes in groundwater chemistry, and can also have an adverse effect on groundwater. As a result of CO_2 injection, subterranean pressure regimes change, whereby formation water is displaced from the storage site and can have an adverse effect on aquifers above the storage site. With the storage of CO_2 in saline aquifers, large quantities of salty groundwater are displaced that can permeate into aquifers containing fresh water. In unfavourable circumstances, salty groundwater can reach the earth's surface and result in salinization of soils and surface waters. Such contamination is unacceptable on the grounds of environmental protection, and has to be prevented in accordance with EU and German water legislation.

In the marine environment, the injection of CO_2 leads to a reduction in pH value and, as a result, to adverse ecological effects.[20] Corals, for instance, can no longer, or only inadequately form a calcareous skeleton. In accordance with international agreements on the protection of the marine environment, the injection of CO_2 into the ocean water column or onto the sea floor is prohibited.[21] Unavoidable leakage during the proper operation of a sub-seabed CO_2 storage site should not have an adverse effect if it increased the natural CO_2 stream only marginally (< 10%). For the continental shelf this corresponds to a maximum tolerable leakage of 10 tonnes of CO_2 per square kilometre and year[22].

The more CO_2 is injected into subterranean geological formations on the grounds of climate protection the more the potential risks of adverse environmental effects increase. Our state of knowledge is far removed from that required to confront one environmental effect with another.

Effects on the climate

The greenhouse effect is an additional effect category for the assessment of CCS technology, in so far as the technology is particularly intended to mitigate climate change. The criterion for whether CCS technology has an influence on the greenhouse effect – that is, is of benefit to the climate – is the permanent impermeability of the storage site.

Even small rates of leakage could cast doubt on the benefit for climate protection. It is essential that leakage is understood to be the migration of the stored fluid from a geological formation through the cap rock, and that release into the atmosphere is not a prerequisite.[23] In assessing

19 Our statement is based on the assumption that the capture of CO_2 in more or less pure form takes place, and that no relevant admixture or other harmful gases occur. In accordance with international regulations (London Protocol/OSPAR Agreement), there is an obligation to minimize contamination. To ensure the largely pure form of the CO_2 stream, corresponding demands on capture have to be standardized in the law governing industrial plants.

20 WBGU (2006)

21 UBA (publisher) 2008

22 UBA (publisher 2008

23 The Federal Environment Agency regards the assumption of leakage in the case of migration from a geological storage site formation as necessary on precautionary grounds, since in this case there is the risk of adverse effects on the environment and of direct release into the atmosphere. The Specific Guidelines of the London Protocol on disposal of CO_2 streams into sub-seabed geological formations also define leakage as migration from a geological formation (cf. No. 6.7, London Protocol, 2007).

the effect of CCS as a mitigation measure, it has to be borne in mind that activities within the CCS process chain (cf. Chapter 1) significantly increase CO_2 emissions. Were only the same quantity of CO_2 to be contained in the storage reservoir as that additionally produced by CCS technology, CCS would then have no climatic benefit. The stored CO_2 must therefore remain in the storage site for a long period of time. In terms of figures, with a maximum allowable annual leakage rate of 0.01%, after 1000 years 90.5% of the initially stored CO_2 would still be contained in the storage site.[24]. Were leakage not to exceed this rate, the benefit to the climate would be ensured.

Use of nature

The criterion of "use of nature" is important to the extent that the availability of suitable storage sites for captured CO_2 is finite. Moreover, the issue of competing use can arise with regard to another sustainable energy resource, namely geothermics, or the storage of compressed air and natural gas (cf. Chapter 4). The construction of a pipeline network for the transport of CO_2 would also require substantial use of nature.

Consumption of resources

Finally, "consumption of scarce resources" has to be regarded as a relevant effect category for the assessment of CCS technology. The application of CCS technology increases the consumption of fossil fuels, whose availability is limited, by up to 40%. Due to the expenditure of energy on CO_2 capture, transport and storage, CCS requires considerably more fuel per produced unit (for example, kilowatt hour of electricity). This additional expenditure of energy not only depletes fossil resources more quickly, but in fact also increases CO_2 emissions and lays further claim to nature and landscape for additional mining and other upstream operations.

As far as possible effects on the environment and human health are concerned, it has not yet been clarified whether, and to what extent, the emission fractions of other atmospheric pollutants will change, compared to a power plant with the same electrical power but without a CO_2-capture installation. The additional fuel consumption for the capture and transport of CO_2 increases the quantity of atmospheric pollutant emissions. We do not assume that this additional CO_2 will be stored together with captured CO_2, since regulations demand, and power plant operators strive for as pure a CO_2 stream as possible, especially for the purpose of avoiding corrosion damage in the CO_2 transport network. From the point of view of environmental quality standards it is essential that pollutant emission fractions caused by the application of CCS technology do not exceed the emissions of conventional energy conversion.

24 The geological and geochemical binding affinities of

3 Storage capacity

- Secure and sufficiently large storage sites in close proximity to capture plants are a pre-condition for the climate protection efficacy of CCS. Were there to be insufficient secure storage sites, all efforts towards further development of CCS would be dispensable.
- In the choice of storage sites, great demands have to be made on impermeability, in order to ensure their integrity.
- Quantification and localization of storage capacities in Germany, the EU and globally have up to now been too imprecise.

Storage capacity is a fundamental pre-condition

The extent to which CCS actually contributes towards climate protection is determined – apart from the applicability of capture technology – above all by the capacities of suitable storage sites that are actually available. Disposal – that is, the permanent geological storage of CO_2 – is the key component of CCS; emission reduction can only be achieved insofar as CO_2 is permanently and securely stored.

In contrast to capture plants and transport facilities, storage sites are defined by natural conditions. Natural CO_2 deposits, as well as crude oil and natural gas deposits that have partly contained CO_2 over long periods, show that there are geological formations that are able to retain CO_2 underground. Crude oil and natural gas deposits can be more favourable storage sites than other formations such as aquifers containing salt water, since besides their proven impermeability they are also more thoroughly investigated and might have fewer side effects such as displaced water. It is foreseeable, however, at least as far as Germany is concerned, that crude oil and natural gas deposits will be insufficient. The question concerning available capacities of suitable storage sites is therefore still unanswered. Here, the regulation in the CCS bill could be helpful, which provides for analysis and assessment of storage potentials in Germany by the Federal Ministries of Economics and the Environment.

Besides their geotechnical suitability, the size, location and temporal availability of storage sites must be matched to the respective emission sources – that is, to power plants during their total lifespan. A power plant that emits 10 million tonnes of CO_2 per year requires, over its service life of 40 to 50 years, storage sites with a capacity of about 400 to 500 million tonnes. On the grounds of economic and energetic efficiency, emission source and storage site should not lie too far apart, since recompression of CO_2 is expensive and involves great expenditure of energy.[25]. This issue could influence decisions on the location of future power plants.

Finally, a storage site must be available at the time required. A crude-oil or natural-gas field, which is still in operation, is available for permanent storage of CO_2 only under certain conditions. The practice, primarily in the USA, of using CO_2 for enhanced oil recovery (EOR) does not guarantee the acceptance of quantities arising at the emission source, since in this case the quantity of applied CO_2 is orientated towards production requirements. There is also the risk that CO_2 will re-enter the atmosphere with produced hydrocarbons, should it not be removed from the hydrocarbon stream and re-injected. The prerequisite for subsequent use as a CO_2 storage site is that the infrastructure – that is, boreholes, conveyor systems and, possibly, pipelines – is still intact. Particularly in the case of sub-seabed crude-oil and natural-gas deposits, the period between the end of production and the dismantling of drilling rigs can be quite short. The cost of reconstruction would in this case make the storage site more expensive, and give rise to further adverse environmental effects through the consumption of resources and expenditure of energy.

Demands on the selection of storage sites

The careful selection of storage sites is decisive for the security and efficacy of CCS. Storage security depends essentially on the site-specific characteristics of geological formations. Furthermore, the question of the long-term security of bore plugs is of key importance. Each potential storage site requires detailed characterization in order to ascertain not only its suitability but also the probability of leakage. At the same time, it has to be considered that drilling into storage sites and the large-scale injection of CO_2 involves the risk of triggering seismic events, which – for example through the formation of cracks – increase the risk of leakage, independent of prior geotechnical and tectonic conditions. CO_2 and other contaminants contained in the gas stream react with the rocks of the storage site‘s geological formations and can further impair storage security. The central instrument for assessing the suitability of a geological formation as a storage site is modelling of its characteristics. The insights thus gained must flow into the approval of storage operation.

The appropriate selection, operation and monitoring of storage sites are of great importance, also because specific opportunities for repair – for example, to seal discovered leakage – at present hardly exist. Furthermore, less ambitious standards and possible leakages at a storage site would jeopardize general acceptance of CCS. In each case, the storage of CO_2 should only take place following official authorization of the storage site and approval of the storage process. The requirement to obtain a permit is accordingly laid down in the EU CCS Directive[26] and in the German CCS bill.

Storage site capacities should be explored

Specific geological exploration is not far enough advanced to allow reliable statements on the capacities of suitable storage sites. The Federal Institute for Geosciences and Natural Resources (BGR) is currently working on a register of possible storage sites in Germany[27]. The register, together with further investigations – such as the investigative drilling of possible geological formations – should allow more precise estimates of Germany's storage potential than those previously made by the BGR (22 ± 8 billion tonnes of CO_2) and the localization of storage sites.[28] Up to now, such quantification has merely concerned theoretical potentials, and the extent to which these will be reflected in more realistic scenarios on usage is still unclear. These investigations must also consider the long-term or even

[25] In the case of natural-gas transportation, it has to be assumed that recompression is essential after about 150 to 200 km.

[26] EU, 2009a

[27] BGR, 2008

[28] By comparison: Power plants subject to emissions trading emit about 350 million tonnes of CO_2 per year.

permanent use of storage sites and possible competition with other uses (cf. Capital 4).

The Federal Environment Agency recommends that large-scale CO_2 capture be pursued only on the basis of the most thorough evidence of suitable storage sites. Only then will it be possible to assess how much CO_2 emission can actually be reduced by CCS technology. This assessment would help to avoid misdirected capital expenditure in capture technology and transport infrastructure.[29] Time schedules for possible large-scale introduction of CCS must take account of the time required for geological exploration of storage sites.

4 Competing uses

- The permanent storage of CO_2 may not hinder or restrict sustainable uses such as geothermal heat and power production.
- Spatial planning is required to avoid conflicts concerning the use of geological formations between CCS and other, above all sustainable forms of use.

The use of extensive subterranean spaces for permanent storage of CO_2 over thousands of years can restrict or preclude other future uses for energy supply, such as geothermics and compressed-air or natural-gas storage, and consumes a limited resource. There is the additional risk of adverse environmental effects (cf. Chapter 2), not least that leakages could represent future sources of CO_2. In this respect, a conflict arises between the potential benefits of CCS for climate protection and compatibility with sustainable energy policy and, in particular, the principle of generational equity.[30]

Prioritization of geothermics over CO_2 storage

The storage of captured CO_2 will be carried out preferably in former crude-oil and natural-gas fields, as well as in deep saline aquifers at depths of 1,000 to 5,000 metres. Certain geological regions, such as the North German Basin[31], are suitable in many places, due to their characterization, not only for CO_2 storage but also for geothermal use. A study carried out by the Office of Technology Assessment at the German Bundestag (TAB) estimates the technically utilizable supply potential for deep geothermics in the North German Basin at a total of 20,200 TWh electricity and 62,800 TWh heat[32]. The sites for economically and ecologically optimized utilization of geothermic potential in the North German Basin have still to be investigated. In wide areas of this region, however, the development of geothermics and CO_2 storage, both of which enjoy political support, are mutually exclusive on legal (Federal Mining Law) and security (see below) grounds.

Competition for the permit for prospecting a particular site could be resolved by subterranean spatial planning and the allocation of subterranean space on the basis of varied geological, infrastructural as well as economic and ecological criteria. Taking account of the principle of prioritization of sustainable uses put forward by the Federal Environment Agency, such subterranean spatial planning would have the result that sites suitable for geothermal heat and power production would not be accessible, or only of limited accessibility for the storage of CO_2.[33] Moreover, a safety clearance would have to be provided for, in order not to endanger other real or potential uses, such as geothermal reservoirs, groundwater resources or thermal-water wells. Injection of CO_2 into the storage horizon leads to wide-ranging subterranean pressure changes, so that minimum clearances between CO_2 storage sites and other uses would be essential for safety reasons.[34]

Due to safety demands on cap rocks above potential CO_2 storage formations, concurrent use of deep geothermics and CO_2 storage at diffe-

29 In the present debate, the argument is often heard that one could build "CCS-ready" or "capture-ready" power plants, and initially operate them without CO_2 capture, yet at the same time design them in such a way that CO_2 capture, on becoming technically available, could then be retrofitted. The "capture-ready" concept is unsound, however, since even if capture were to be realized, the storage and transport of CO_2 might prove to be impossible. Verification of "capture readiness" must therefore cover not only corresponding facilities at the power plant, but also proven, secure and adequate storage potential as well as substantiated transport infrastructure. Such evidence cannot presently be put forward. Irrespective of that, "CCS-ready", precisely defined, provides no guarantee that, even with given feasibility, retrofitting will take place regardless of its economic efficiency.

30 UBA, 2006

31 The North German Basin constitutes a large geological formation, which stretches from southern Lower Saxony into the North and Baltic Seas as well as into neighbouring countries to the east and west. The spread in northern Germany largely corresponds to the North German Plain.

32 Büro für Technikfolgenabschätzung, 2004

33 WI et al., 2007

34 Rutqvist et al., 2007

rent depths above each other must be ruled out. For stored, supercritical CO_2 would disperse over a wide area underneath the cap rock formation. With the storage of large quantities of CO_2 the result would be CO_2 concentration in a layer of low thickness but wide range.[35] Deep subterranean formations on a large-scale would thus become unavailable for other uses for an unforeseeable period of time. The accelerated development of geothermal electricity and heat production – that is desired on the grounds of climate protection – in regions used for CO_2 storage would thus no longer be possible. The subsequent penetration of CO_2-filled horizons with geothermic boreholes would involve a high risk of leakage and substance mobilization, and could therefore not be undertaken. The basic possibility of drilling around a CO_2 storage site could not be considered, for the risk of compromising storage site integrity would be considerable, and the greatly increased technical investment as well as the resulting substantial increase in costs would prevent or greatly restrict the building of geothermal power plants.[36] Furthermore, the great technical effort involved would impair the environmental performance of the construction phase of a geothermal power plant.

5 The role of CCS in climate protection

- Germany can attain its climate protection targets, also in the long term, without CCS; namely, with substantial energy savings, increases in energy efficiency[37] and the systematic use of renewable energy sources.
- The objective of energy policy must therefore be the sustainable and thus climate-compatible development of the energy system. This may not – as is laid down in the EU CCS Directive[38] – be curtailed through development of CCS. The use of fossil fuels would not be sustainable even with CCS technology.
- CCS could become significant as a bridging technology for a transitional period, in order to attain national climate protection targets, should measures for an increase in energy efficiency and greater use of renewable energy sources not produce the desired effects.
- Countries with large coal and crude oil reserves, and countries whose general set-up does not allow a rapid switch to sustainable development, or whose energy requirements are greatly increasing, also set great hopes in CCS for the reduction of CO_2 emissions. For realization, however, they are dependent on technology transfer.

Sustainable development of energy systems – savings, efficiency and renewable energy sources

Sustainable development[39] of energy supply and use can be achieved by 2050 on the basis of the following basic principles:

1. Energy demand is dependent on the energy service; that is, the energy required for the intended effect.
2. Societal behavioural patterns (for example, consumer behaviour and development planning, such as land-use regulation as well as infrastructural and building measures) are critically examined in terms of energy consumption and modified. At the same time, it is not the standard of living that is on trial, but rather its energy intensity.
3. Energy is converted and transported as efficiently as possible and utilized with efficient techniques; as a result of which substantial energy-saving potentials arise as well as cost benefits for society.

35 Ennis-King and Paterson, 2003

36 Frick et al., 2007

37 An increase in energy efficiency implies combining the chosen energy services (for example, light or heat) with the least possible use of primary energy; that is, cutting back losses across the entire conversion chain. Beyond that, energy savings can also be achieved by a reduction in energy needs, by making use of fewer energy services (for example, by not heating or leaving lights turned on in unoccupied rooms).

38 EU Directive on Geological Storage of Carbon Dioxide (EU, 2009a), Recital 4.

39 Here, the comprehensive approach of sustainable development applies, which seeks to realize the principle of generational equity by way of equal consideration of environmental factors – such as climate protection – and social or economic factors, in order to be permanently sustainable (Nationale Nachhaltigkeitsstrategie, Bundesregierung, 2002). The Federal Environment Agency described in detail in its CCS position paper (UBA, 2006) the extent to which CCS can satisfy the guiding principles of sustainability (Enquete-Kommission, 1998). Due to the additional use of fossil resources and the finiteness of storage capacities, CCS violates the principle of economical, efficient and conservative treatment of scarce, natural resources. Sustainable development demands that natural assets be not utilized to an extent greater than their ability to regenerate or provide substitute resources (Bundesregierung, 2002). Uncertainty and lack of experience of the possible adverse effects of CCS on the environment and human health endanger the basic principle of precaution, which is intended to guarantee that we do not burden the ecosystem with more pollutants than it can bear, and to avoid dangers and unwarranted risks to human health (Bundesregierung, 2002). Generational equity would be at risk were CO_2 storage sites to become significant sources of CO_2 in future.

4. Energy demand, markedly reduced in accordance with principles 1 to 3, is basically met with renewable energy sources. The conversion of fossil energy sources is dominated by cogeneration of heat and power.

Were these basic principles to be put into effect parallel to demands for essential CO_2 emission reduction, the operation of additional coal-fired power plants and thus CCS would be dispensable. The 'Lead Study 2008' of the Federal Environment Ministry (BMU)[40] put forward possible scenarios for such a development in Germany, while retaining the statutory phasing out of the use of nuclear energy in Germany. Setting the course of future energy policy in a consistent manner, and the equally consistent implementation of decisions taken on the basis of the above basic principles, are the prerequisite for such a scenario. The success of this course of action will require great efforts on the part of policy-makers, industry and consumers, including continuous re-examination of underlying scenarios with regard to the probability of their realization, forecast potentials and achieved progress or suffered set-backs.

CCS – a complementary climate protection measure

Should it not be possible, on technical, economic or political grounds, to maintain necessary progress in energy policy and the dynamics of realization of a sustainable energy system, or should new scientific findings show that more ambitious climate targets are required, policy-makers – also in Germany – will have to consider additional climate protection measures.

Countries with their own coal reserves, emerging countries with rapidly increasing demand for energy and countries with large reserves of crude oil frequently set other political priorities, and will continue in the long term to make use of fossil energy resources. Where the basic conditions for consistent transition to sustainable development of the energy system are lacking, it will be necessary to secure climate protection targets by strengthening existing measures or by employing additional CO_2 mitigation measures and, above all, by reducing the CO_2 intensity of power plants.

CCS is also to be considered as a potential emission reduction measure. Although CCS comes too late for realization of the necessary turnaround to a worldwide reduction in greenhouse gas emissions in the coming years,[41] it could later support the declining trend, should this technology actually become available.

Availability of CCS requires utilizable and secure storage sites of sufficient size and abundance (cf. Chapter 3), which do not compete with the sustainable development of the energy system (above all, with geothermics) (cf. Chapter 4). Furthermore, capture technology has to be sufficiently developed, economically efficient and available in time. The development of the technology offers opportunities for export to countries with corresponding needs.

The environmental effects of all three process steps of CCS should be evaluated in a life-cycle analysis, including upstream chain, storage site exploitation and post-storage activities (cf. Chapter 2). Only against the backdrop of the results of such an environmental performance evaluation could it be decided whether CCS can play a role, and if so, what role. Since not only fossil resources but also geological storage sites are finite, even with a positive assessment CCS is in any case a possibility only for a transitional period.

6 CCS and emissions trading

- As provided for in the amendment of the EU Emissions Trading Directive[42], CCS is to be integrated into the EU emissions trading system with effect from 2013.
- Operators of power plants should surrender emission allowances for all CO_2, including captured CO_2, produced by these plants.
- Power plant operators will be issued with CO_2 emission credits only for successfully and permanently stored CO_2, since only then will a climatic benefit arise.
- Control of the CO_2 stream in CCS process chains has not yet been adequately regulated.
- CO_2 and other substances of climatic relevance must be treated as emitted as soon as they pass through the cap rock of the storage site. Upper limits of estimates of CO_2 leaked from storage sites take account of uncertainty factors.
- Monitoring costs for integration into emissions trading have to be borne by operators.

40 BMU, 2008

41 WI et al., 2007

42 EU, 2009b

Emissions trading as an economic incentive mechanism

CCS does not yield a profit, but gives rise to additional costs for the capture and storage of large quantities of CO_2, as well as from increased demand for primary energy from plants as a result of this technology. Additional costs would be borne by plant operators only were statutory requirements to compel them to do so, or additional economic incentives exist.

Economic incentives are provided by CO_2 emissions trading, by means of which CO_2 emitted into the atmosphere is given a price. The inclusion of CCS in emissions trading enables plant operators to adequately account for securely stored – that is, non-emitted – CO_2.

This way, CCS technology becomes an option for the reduction of CO_2 emissions. It should, however, rank equally with other technical mitigation options utilized by companies to reduce CO_2 emissions, such as measures for an increase in plant efficiency or fuel switching. CCS would become accepted, were CCS-related additional costs to be lower than the cost of other measures for CO_2 emission reduction, or the cost of purchasing emission allowances.

Emissions trading or regulatory control?

As an alternative or complementary to the economic incentive system of emissions trading, legislators could make CCS mandatory. The mandatory introduction of CCS was also the subject[43] of debate on the EU Climate Package,[44] but was ultimately rejected. The Federal Environment Agency is opposed to the prescribing of CCS capture, since it is not yet foreseeable whether large-scale utilization will be possible, or whether evidence of sufficient and secure storage capacities can be provided. A CCS obligation would lead to commitment to a technology that, against the backdrop of uncertainties and gaps in knowledge, would be premature, and would contribute, moreover, to privileging an option that is not yet fully developed. Furthermore, the environmental effects and their possible avoidance, have not yet been sufficiently investigated (cf. Chapter 2). The danger of a breach of safety and environmental demands on CCS would therefore arise. Instead, we support the role of emissions trading in the realization of CCS technology, where market participants take a decision, based on entrepreneurial considerations, on how they fulfil their emission reduction obligations in line with a specified limit ("cap"[45]) on emissions. The prerequisite, however, is that emissions trading offers a long-term perspective on periods of time that correspond with the capital expenditure cycle in the power-plant sector, and that a steadily-reduced cap likewise projects long-term and ambitious climate goals.

Legislators should limit their role at the present stage to regulating demands on the employment of CCS and, in particular, to laying down environmental demands, with a view to enabling market participants to employ CCS, but at the same time leaving the decision on CCS to them (cf. Chapter 8).

Should it in future become apparent that the market is not implementing emissions trading signals, or should EU emissions trading not impose a cap that is appropriate to climate protection targets, in order to considerably reduce power plant emissions it would be up to legislators to adopt other necessary measures for the attainment of climate protection targets. These could include an obligation to make use of CCS technology.

Fundamental system variables of emissions trading with CCS

From our point of view, the planned inclusion of all installations for the employment of CCS in the EU emissions trading system from 2013 – with the exception of integration of the entire transportation network – is justified. From the environmental point of view, detailed specifications have to be set for integration of CCS into emissions trading, which, however, are not laid down in the legislation.

All installations that burn fossil energy resources for energy conversion, and thus produce CO_2, have basically to be treated equally in emissions trading. At present, this means that from commencement of the third trading period in 2013 operators of such plants, in so far as these produce electrical energy, will not receive free allocation of emission allowances, but will have to purchase allowances (certificates) on the market or at auction. This also applies to installations for the capture, transport and storage of CO_2.

43 Davies, 2008, p. 76: Amendment 126

44 EC, 2008b

45 Here, the total quantity of emission allowances applicable throughout the EU, which is laid down for greenhouse gas emissions covered by EU emissions trading.

This view is also shared by the European Commission and is to be welcomed.

Legislators should make emissions trading predictable on the part of all involved parties, and not encumber the system by cutting the cap – beyond the already planned flat rate of 1.74% per year – in line with the coming into operation of functional CCS installations. For the putting into operation of CCS installations was already take into consideration in projections of greenhouse gas emissions with the apportionment of emission reduction contributions to the emissions trading sector and remaining sectors up to 2020[46]. Moreover, the ex ante principle applicable in emissions trading speaks against subsequent adjustment of the cap as a reaction to certain technological developments, since this would impair the planning ability of involved parties and introduce substantial uncertainties into the system. The specified cap should project climate policy goals, irrespective of the technology employed for their realization.

Reduction of system and implementation costs through the balancing of CO_2 streams

On examining the CCS process chain, it has to be ensured that future regulations keep the cost of implementation on the part of companies and authorities effective and efficient. This applies, above all, to monitoring. The recording of CO_2 emissions during transportation from the source to the storage site could result in very high bureaucratic and operative costs. Based on a likely complex network of pipelines connected with several CO_2 sources and storage sites as well as varied responsibility of different parties for individual pipeline sections, CO_2 streams would have to be measured and documented at every transfer point; otherwise, emissions could no longer be clearly assigned.

We regard it as proper that CO_2 producers (for example, power plants) have to surrender emission allowances for all CO_2 produced, whether captured or emitted into the atmosphere, and that this is therefore treated as released. In return, storage site operators should receive emission allowances for stored CO_2 in the amount of the verified, permanently stored quantity. Costly monitoring of pipeline networks or other transport systems could thus be dispensed with. Only compressor stations operated for the transportation of CO_2 would have to be integrated into emissions trading. This approach is adopted approximately in the CCS bill with its "storage-site receipt approach"; according to which, a primary producer of CO_2 can only assert a claim, within the framework of emissions reporting, to the quantity of carbon dioxide that has been verifiably and securely stored. In this case, too, extensive control of the transport pipeline is unnecessary. Since pursuant to the CCS bill, however, emission allowances are not issued to a storage site operator, but instead a reduction of the primary producer's obligation to surrender emission allowances effected in the amount of the stored quantity of CO_2, clear assignment of storage site and power plant must be possible, which would hardly be possible in the case of a potentially complex pipeline network.

Beyond that, it would have to be ensured that CO_2 is not transported beyond EU borders, in circumvention of the obligation on the part of plant operators to surrender emission allowances, or contracting states subject to obligations under the Kyoto Protocol. Transboundary CO_2 transportation must not lead to a weakening of the requirement for the surrendering of emission allowances by plant operators responsible for CO_2 emission. EU regulations deal inadequately with this latter circumstance, and thus endanger the cost-efficient reduction of greenhouse gas emissions that is intended with emissions trading.

Combination with biomass – consideration of stored CO_2 from biomass combustion

A reduction in the total quantity of CO_2 in the atmosphere can be connected with the capture and storage of CO_2 from the combustion of sustainably produced biogenic fuels (negative emission).[47] The IPCC also demands[48] that CO_2 from the combustion of biogenic materials, which is captured and stored, not only leads computationally to negative emission in the total system, but has also to be accounted for in the CO_2 balance. The issuance of emission allowances to storage site operators for the secure storage of CO_2 – in the manner proposed by the Federal Environment Agency – rewards the application of CCS in biomass combustion, since the particular primary energy source, from which CO_2 derives, is irrelevant to the issuance of emission allowances.

[46] EC, 2008a

[47] WBGU, 2006, 2008

[48] IPCC, 2005

Determination of CO_2-leakage from storage sites and the treatment of uncertainties

The precise quantification of leakage of greenhouse gases from storage sites is of decisive importance for sound integration of CCS into emissions trading. Established measurement technology presently allows only imprecise quantification. It has therefore to be ensured that for the integration of CCS into emissions trading not only all emissions – including expected leakage from storage sites – but also uncertainties in the quantification of released greenhouse gases are considered in determining the quantity of emission allowances that have to be surrendered for the storage site. Adjustments to reported emissions for uncertainties, on the basis of which the requirement to surrender emission allowances ultimately results, have to be measured in such a way that they comply with the maximum permissible 1.5% uncertainty – demanded for large power plants in the monitoring guidelines for emissions trading[49] – in determining the quantity of allowances to be surrendered[50]. Uncertainties in excess of 1.5% should therefore entail an increase in the quantity of emissions allowances that have to be surrendered, in the form of a conservative adjustment of the initially determined emission quantity[51]. This way, it can be guaranteed that emissions are not underestimated.

Were actual CO_2 leakage from storage sites to be undervalued, this would amount to unjustified support of large power plants that capture CO_2. In the end, they would be at least indirectly absolved from part of the environmental pollution for which they are responsible, and would then come to enjoy a financial privilege that operators of power plants that – for instance, on economic grounds – renounce the use of CCS technology could not take advantage of.

Monitoring has to take place at the cap rock of a storage site; otherwise, diffuse leakages could remain undetected and result in storage site operators remaining (wrongfully) exempt in part from the existing requirement to surrender greenhouse gas emission allowances. With direct measurement at the cap rock, the storage site operator might receive no emission credits for released greenhouse gases that ultimately, however, do not reach the earth's surface and enter the atmosphere. In view of the otherwise threatening unjustified advantage, and the resulting weakening of the pollutant-pays principle, we regard this as justified.

Displaced greenhouse gases must be adequately considered in emissions trading

The greenhouse gases to be accounted for include not only injected CO_2, but also, where applicable, other gases – such as methane – that are displaced from the storage reservoir by this CO_2. The greenhouse effect of one kilogram of methane over a period of 100 years is 23 times greater than that of one kilogram of CO_2. The storage of CO_2 must not lead to the situation that the climate is additionally polluted with displaced methane.

In the case of "displaced greenhouse gases", the responsible storage site operator would have to accept these equivalent greenhouse gas emission loads in the form of a requirement to surrender emission allowances. EU statutory requirements have not yet addressed this issue. Insofar as displaced methane is verifiably and completely recorded and utilized, the storage site operator is not required to surrender emission allowances. Were the methane not to be utilized, it would have to be ensured that the storage site operator surrenders an equivalent quantity of emission allowances. As in the case of the measurement of CO_2, uncertainties in quantification would be at the operator's expense.

7 Questions of liability

- Ambitious liability regulations are required for the employment of CCS technology.
- Potential damage is widely varied and not yet adequately researched.
- Regulations must contain provisions on dealing with such damage.

The operator must ensure remediation of damage and bear the resulting costs

Those who employ CCS are responsible for possible damage, which we have described in Chapter 2. This follows from the polluter-pays principle. In the case of damage to private property and environmental assets – such as soil, ground-

[49] EC, 2007

[50] This is in accordance with the current discussion in the EU on the treatment of uncertainties in the quantification of storage site leakage.

[51] Emissions to be reported are determined as follows: reported emission = measured emissions*(1+actual uncertainty-0.015)

water and other water bodies as well as biodiversity – the operator of the responsible facility (power plant, transport system or storage site) must carry out reasonable remediation, irrespective of the question of fault, and also bear the resulting costs. The Federal Environmental Liability Act (Umwelthaftungsgesetz), for example, provides for such fault-free liability (so-called strict or absolute liability) for the realization of risk exposure in the operation of particular installations. Both the Federal Mining Act (Bundesberggesetz) and the Federal Genetic Engineering Act (Gentechnikgesetz) contain examples of strict liability. They already sanction risks emanating from a facility or behaviour that to some extent exhibits great damage potential. The idea rooted in these regulations is applicable to a CO_2 storage site. In cases involving damage to the private property of third parties it is necessary, furthermore, to ease the burden of proof concerning the causing of damage; for example, in the form of presumption of cause. This makes it easier for those affected by damage to enforce their claims. Here, too, the three above-mentioned Acts, with their presumption of cause (in particular Article 34 of the Genetic Engineering Act and Article 120 of the Federal Mining Act), could serve as a model on account of their stringency.

Responsibility of the state at the earliest 50 years after closure of a storage site

Following cessation of storage operations the operator should remain responsible for the closed storage site. He must, above all, continue the monitoring of leaked CO_2 and other such substances. The closure of a storage site alone does not relieve the operator of his responsibility. Ultimately, responsibility for a storage site – with monitoring and possible remediation obligations – should pass to the state, but only if CO_2 and other substances remain permanently and completely contained in the storage site, so that no climatic effects can develop and no adverse local environment effects threaten. The site operator could otherwise shuffle off too many risks to the state and thus the taxpayer. The state should only take on long-term responsibility for a storage site. We advocate the transfer of responsibility only after expiration of a relevant period of time – at least 50 years during which no leakage has been detected – following closure of a storage site. Site closure on the one hand and transfer of responsibility on the other are dependent on proof of storage-site integrity. These demands guarantee that responsibility may only pass to the state in respect of a storage site for which the operator has substantiated impermeability over a prolonged period of time. It is also important to lay down that in the case of gross negligence or wilful intent the operator may be held liable for the occurrence of risk or damage even after expiration of that period of time.

Create adequate financial security for risks

The storage site operator has to deposit adequate financial security for the financing of necessary measures, from site monitoring to the surrendering of emission allowances for leakage and remediation of damage. This lowers the risk (for example, that associated with insolvency) that the respective operator will not be in a position to financially compensate damage.

Such security may only be completely released at the moment of transfer of responsibility to the state, and not already on closure of the site. Damage can occur after cessation of storage or following closure of the site. It should be ensured that the period from cessation of CO_2 injection to transfer of responsibility to the state is sufficiently long, in order, on the basis of experience gathered during this period, to be able to guarantee storage site impermeability with as much certainty as possible.

The site operator should compensate the state for its assumption of responsibility. This compensation is linked to the financial security mentioned above. Payments should flow into a liability fund, out of which the authorities can meet costs incurred in connection with post-closure maintenance, and also take appropriate account of the risk of damage. Payments can be made regularly during operation of the storage site, or in a single sum on the transfer of responsibility to the state.

8 Statutory framework

- he statutory framework should enable environment- and health-compatible CCS projects; it should not, however, promote them.
- The precautionary and the polluter-pays principles must apply.
- The entire CCS process chain requires regulation.

Objective of a statutory framework

A statutory framework[52] for CCS should solely enable CCS projects that meet stringent demands concerning environmental, climate and health protection. The statutory framework should serve neither to hinder nor to promote CCS projects. It must pursue an approach that encompasses all environment media, since the effects of CCS technology can affect the climate, atmosphere, water and soils. The precautionary principle has to apply, above all in view of considerable uncertainties concerning environmental effects and the long periods during which CO_2 is to be stored. Pivotal, too, is the polluter-pays principle. Those who employ CCS technology in order to fulfil their emission reduction obligation within the framework of emissions trading must bear its risks and its costs, and they may not load them onto the general public.

Key demands on a statutory framework for CCS

The following demands on a statutory framework for CCS technology from an environmental protection perspective are derived from the preceding chapters.

- The statutory framework should not require employment of CCS in existing or new power plants (cf. Chapter 6).
- Subterranean spatial planning should undertake the allocation of subterranean space on the basis of varied geological, infrastructural as well as economic and ecological criteria. Such subterranean spatial planning is appropriate for preventing the endangering of other, in particular sustainable uses of subterranean formations (cf. Chapter 4).
- In deciding on the approval of operation of a CO_2 storage site, the competent authority should be given scope in the weighing of interests. We welcome the fact that the CCS bill provides for this. The manifold public and private concerns that speak for and against a CCS project can thereby be considered and weighed up in the decision-making process. Should subterranean spatial planning not be undertaken, competing sustainable use should be included in the weighing up of interests with its respective weighting.
- The statutory framework must set high demands on the security of CO_2 storage sites in the interest of the environment, the climate and health protection. It should rule out leakage that endangers the climate benefit or involves a risk to human health and the environment for an infinite period. The climatic benefit of CCS from a technical point of view would not be guaranteed, were the rate of annual CO_2 leakage to exceed 0.01%. Compliance with demands is to be substantiated with a forecast based on geological characterization of the storage site in line with the state of science and technology.
- In order to avoid local adverse environmental effects, a still-lower leakage threshold could be necessary. The laying down of precise limit values is, in part, not possible, since the technology is still being developed and fundamental knowledge on environmental effects is lacking (cf. Chapter 2). New insights have to be followed in future by enforceable demands.
- The statutory framework should set high demands on the purity of CO_2 streams intended for storage. The CO_2 stream may contain no substances and substance concentrations whose storage raises the fear of adverse effects on the security of the storage site, or on human health or the environment. The statutory framework should also prohibit the disposal of wastes and other materials with the CO_2 stream.
- In line with EU and German legislation on water bodies, the discharge of salty groundwater displaced from the CO_2 storage site into aquifers containing fresh water must be prevented.
- Operators must be required to ensure a high level of protection during operation of the storage site. The statutory framework should require operators to take precautionary measures to guard against risks to human health and the environment during storage operations that correspond to state of science and technology. We welcome the fact that the CCS bill provides for dynamization. Should leakage, risks of leakage, dangers or risks to man or the environment occur – regardless of the substance or event that gave rise to them – the statutory framework must require operators to remedy the cause and bear the resulting costs up to the transfer of responsibility to the state.
- The statutory framework must oblige operators of storage sites to provide effective monitoring and formulate specific demands for this purpose. These demands should be of a dynamic nature, so that operators adopt technical advances in monitoring and adjust their existing monitoring measures accordingly.
- Operators should be required to submit detailed concepts during approval procedures for

[52] See the final section of this chapter on the Federal Government's bill.

storage-site operation, measures for the prevention of dangers and risks, as well as for monitoring, storage-site closure, and post-closure maintenance, and to update such concepts in line with the state of science and technology.

- Besides laying down pre-conditions for the long-term responsibility of the state for a storage site, and the creation of reserves for contingent liabilities (cf. Chapter 7), the statutory framework should also provide for liability in respect of such damage as does not have to be remediated pursuant to the EU Directive on Environmental Liability. This concerns, for example, flora and fauna that do not fall under EU law on the protection of species.

Development of a statutory framework

International agreements on the protection of the marine environment (OSPAR, London Protocol) prohibit CO_2 storage in the ocean water column. Sub-seabed storage is basically permitted, but high demands are set on the protection of the marine environment. The European Parliament and the Council of the European Union have adopted the Directive on the Geological Storage of Carbon Dioxide[53], which came into effect on 25 June 2009. The directive creates new legislation on CO_2 storage. Among other things, it lays down a requirement for approval of CO_2 storage sites, material demands on their selection and operation as well as post-closure measures. The directive further regulates access to the CO_2 transportation network and adapts existing EU legislation, including the Environmental Impact Assessment Directive, accordingly.

German law has to regulate the entire CCS process chain comprising capture, transport and storage. It has to take into account the requirements of international agreements on the protection of the marine environment as well as EU requirements, and it must fill the gaps in such requirements. In so doing, the objectives mentioned in this chapter have to be pursued and key demands on a statutory framework have to be met.

With CCS technology, climate and environmental protection are of prime importance, so that regulations under environmental law must form the focus of the German statutory framework. Due to the novelty and the risks of CO_2 storage, a specific statutory framework is required.

We regard orientation towards the Federal Mining Act as inappropriate. On account of its purpose, the Federal Mining Act does not lay down environmental law, and environmental protection is not given the consideration in its specific provisions that is necessary for the regulation of CCS.

The Federal Environment Agency therefore welcomes the fact that the Federal Government's CCS bill has the intention of regulating the storage of CO_2 in a separate Carbon Dioxide Storage Act. Besides storage, the CCS bill also regulates the other steps in the CCS process chain, namely capture and transport. Among other things, it

- provides for a planning approval procedure with latitude in the weighing of interests,
- requires submission of proof of security by operators, with which the long-term security of the storage site, the averting of danger and required precautions in line with the state of science and technology have to be substantiated,
- requires operators to readjust activities and installations in such a way that long-term security, the averting of danger and precautionary measures are ensured in accordance with the latest developments in science and technology,
- requires adjustment of the concept, according to which the operator monitors the storage site, and of concepts for storage-site closure and post-closure maintenance, in line with the state of science and technology, and
- requires legislators to regularly examine whether regulations concerning demands on the storage of CO_2 need to be amended to take account of the state of science and technology.

[53] EU, 2009a

9 Research on CCS – Emphases and funding

- Before wide use of CCS becomes an option, technological development is required and critical questions concerning environmental protection and the statutory framework have to be clarified. For this purpose, the promotion of research is necessary.
- Financial support must not hinder the promotion of energy efficiency measures and the further development of renewable energy sources.
- With CCS, storage-site exploration, investigation of effective monitoring and post-closure maintenance as well as the relation to other uses (for example, geothermics) should be the main focus of research.
- Proceeds from the auctioning of CO_2 emission allowances should be used to fund research.
- Allocation of additional emission allowances within the framework of emissions trading is not an appropriate funding instrument.
- Global transfer of technology and knowledge is essential.

Clarification of the suitability of CCS as a climate protection measure

In order to attain climate protection targets, all CO_2 emission reduction options have to be examined. Rapid clarification of technical viability and the required statutory and economic frameworks should be undertaken, in order to judge whether CCS could be a complementary climate protection measure. The specific environmental effects of the entire life-cycle of large-scale realization and resulting ecological demands are of decisive importance for the assessment of CCS. A fundamental condition for promotion of research is, however, that it does not hinder prioritized research and development of sustainable climate protection options (technologies and other measures); in other words, it should be in due proportion to the promotion of sustainable options such as renewable energy and energy-saving schemes.

Set the right emphases for research

CCS functions only in the process chain as a whole, from capture to transport and finally to storage. Research is therefore necessary on all three steps in the chain. It is particularly important from the climate protection point of view to clarify, to what extent secure and environment-compatible storage sites exist. Subterranean exploration should be designed in such a way that generally accessible knowledge of geological formations and their petrochemical and hydrochemical properties is improved, and thereby other uses – for example, geothermics as well as natural-gas and compressed-air storage – served. Further research should focus on appropriate monitoring methods and post-leakage measures. It has to be guaranteed, of course, that knowledge gained with the help of public funds should also be made and remain available to the general public.

Research funds from the proceeds of auctions of emission allowances

Proceeds from the auctioning of emission allowances within the scope of the European emissions trading scheme should ideally be wholly directed towards climate protection. In the third trading period from 2013 to 2020, annual proceeds of around 20 billion euros are to be expected from the auctions, depending on the price and volume of auctioned allowances.[54] Although only at least 50% of these proceeds, as provided for in the new Emissions Trading Directive, should be made available by Member States for the financing of climate protection measures, this is still equivalent to 10 billion euros per year, or a total of 80 billion euros of support funds over the third emissions trading period. A reasonable proportion of this amount, on the basis of the above-mentioned prioritization, should be made available for research into the environmental effects of CCS and for the development of diverse CCS demonstration projects.

Grounds for rejecting the funding of demonstration plants with emission allowances

Besides direct funding from auction proceeds, the EU Directive provides for special funding – beyond the crediting of stored CO_2 as “non-emitted“ – of CCS in emissions trading for up to 12 CCS demonstration projects. For this purpose, the Directive provides for up to 300 million emission allowances (EUA) from the “New

[54] This figure is based on the assumption that an annual EU-wide total of approximately 1 billion emission allowances will be auctioned at a price of 20 euros per tonne. This assumption is based on the impact assessment of the European Commission’s Climate Package of 23.01.2008 and on current information regarding both the final details of the new ETS directive 2009/29/EC and recent developments on the ETS market.

Entrant Reserve" [55] to be made available to operators of CCS demonstration projects. In addition, with these 300 million EUA, demonstration projects on "innovative renewable energy technologies" in the EU should also be funded.

Funding on this scale threatens to disturb the relation to other climate protection measures.[56] In every case, promotion should be limited to additionally required capital expenditure and should not subsidize operating costs. The Federal Environment Agency regards the described approach as inappropriate for two reasons.

Firstly, the proposed funding from the reserve for new installations contravenes the fundamental idea of emissions trading, namely that the market should discover, on a technologically neutral basis, the most favourably priced CO_2 reduction option. The Federal Environment Agency rejects explicitly the "overloading" of emissions trading with other tasks, such as the subsidization of particular technologies, for example CCS.

Secondly, the reserve amounts – at present estimates – to not more than 700 - 750 million EUA. The proposed funding of 300 million EUA therefore represents a substantial reduction in the amount of EUA available for new installations and capacity extensions. Whether the remaining 400 - 450 million EUA will suffice for the original purpose of gratuitous allocation for new installations and capacity extensions is at the very least uncertain.[57] Since a "reserve replenishment mechanism" does not exist, on depletion of the reserve no EUA would then be available for allocation to further new installations or capacity extensions. This could represent a considerable obstacle to such capital expenditure, not least because of competition from outside Europe.

Integration of CCS into the global carbon market – the present status of discussion

The clean development mechanism (CDM), a project-based instrument of the Kyoto Protocol, allows the offsetting of emission reduction in developing countries against reduction obligations in industrialized countries and companies. Certain countries strongly argue the case for compensating of emission reductions that have been achieved in individual projects with the help of CCS. Particularly those that have appropriate geological formations – above all, countries with crude oil and gas reserves – have a distinct interest in this. Many countries expect deployment of this technology within the scope of technology transfer agreed within the framework of the UN Framework Convention on Climate Change and the Kyoto Protocol. Other parties to the Framework Convention regard CCS as competition for more attractive CDM projects with renewable energy or energy efficiency, which make a greater contribution to the sustainable development of their countries. The EU supports recognition of CCS in the CDM, provided that the highest quality standards are met, and proposes pilot projects, restricted in both number and volume, in the period up to 2012. These should help to gain on-site experience with the planning and execution of such projects with the co-operation of national institutions. The UN conference of contracting states in Pozna?, Poland in December 2008 was unable to agree on basic admissibility of CCS to the CDM. The discussion will be continued in the period leading up to the next conference of contracting states in Copenhagen in December 2009.

The EU is among the few parties that can provide the funds required for the development of new technologies such as CCS, while emerging and developing countries will be dependent on technology transfer. This applies, however, also to sustainable development paths, whose support, in the opinion of the Federal Environment Agency, has priority.

[55] The original – and primary – purpose of the NER is to make available EUA for allocations to new installations and capacity extensions in the industrial sector and for defined plants for cogeneration of power and heat.

[56] For example, at an auction price of 20 euros per tonne, 300 million EUA are equivalent to 6 billion euros.

[57] Moreover, there is the possibility of a further reduction in the reserve due to the allocation for power plants in the Baltic States in connection with the closure of the Ignalina nuclear power plant in Lithuania.

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