Capturing carbon to tackle climate change

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A non-technical summary of *Carbon capture and storage in Europe*, a report by the European Academies Science Advisory Council (EASAC)

The oldest continuous set of measurements of atmospheric levels of carbon dioxide (CO_2) comes from the monitoring station at Mauna Loa Observatory on Hawaii. On May 9, and for the first time since measurements began in 1958, the daily reading there reached 400 parts per million (ppm) of CO_2. In the 19th Century, before the Industrial Revolution, the global average was about 280 ppm. The last time our planet experienced a concentration of atmospheric CO_2 similar to today's is believed to have been about 4.5 million years ago.

From a press release issued by the US National Oceanic and Atmospheric Administration in May 2013

Introduction

In recent decades the greenhouse effect has become one of the most familiar of the insights of basic physics. It tells us that most of the heat from the Sun falling on the Earth's surface is not radiated back into space but becomes trapped by the gases forming our atmosphere. Some of these gases, carbon dioxide (CO_2) in particular, are more effective than others in trapping heat. One of the hallmarks of industrial societies that rely for most of their energy on burning fossil fuels is an outpouring of CO_2. Hence the predicament in which we now find ourselves: climate change will have major impacts on the natural resources and weather patterns on which modern societies depend.

Hence too the continuing discussion over what should be done, from radically changing our lifestyle to developing renewable or carbon-free energy sources. Another possibility – the topic of this report – is continuing for the present to use CO_2-creating energy sources, but preventing the CO_2 so generated from entering the atmosphere by capturing and storing it: a process called 'carbon capture and storage' (CCS).

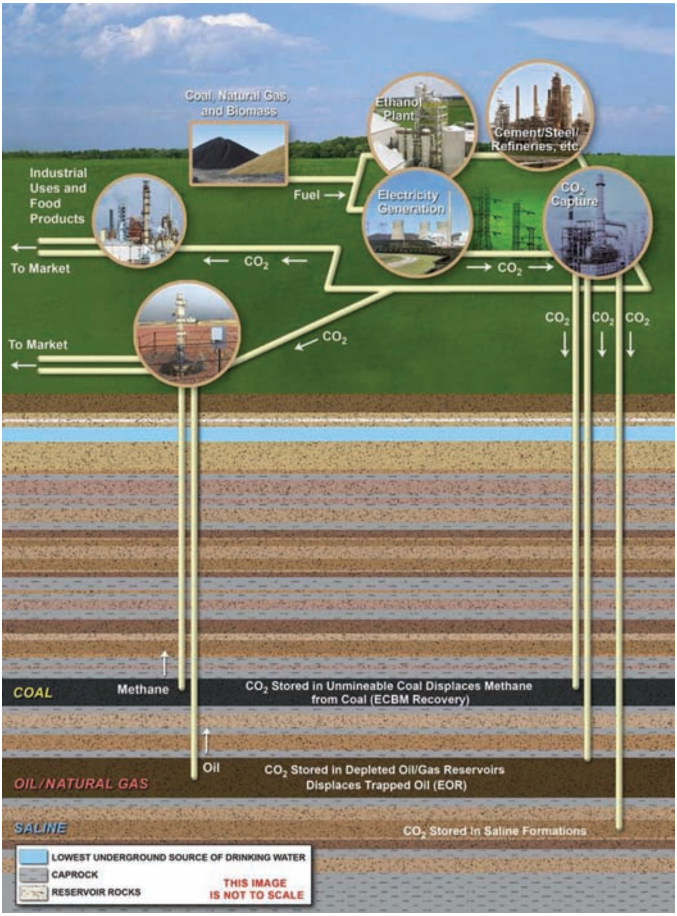
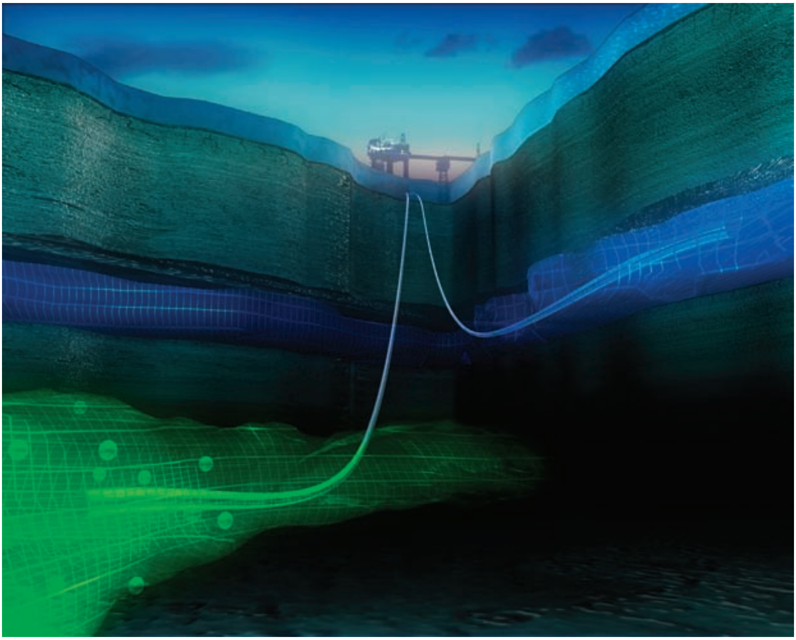


Illustration of CCS. Source: US Department of Energy, 2012a.

The energy policy of the European Union (EU) already includes objectives for climate change, notably a compulsory 20% reduction by 2020 in greenhouse gas emissions (compared with 1990 levels), and a longer-term target of an 80–95% reduction by 2050. These are ambitious goals.

After several meetings at which the members of an EASAC Working Group heard evidence from leading authorities on CCS, they concluded that this approach does have the potential to contribute to Europe's efforts to decarbonise its electricity production system and several industrial processes. However, as EASAC's president Sir Brian Heap emphasises in his foreword to the report (*Carbon capture and storage in Europe*, available from the EASAC website at www.easac.eu), 'at present the economics of CCS are not viable, and strong policy actions are needed urgently'.

The full report, of which this document is a non-technical summary, reviews the current position, and suggests some of the actions and policy decisions that need to be taken if CCS is to play a full part in helping the EU to meet its own targets.

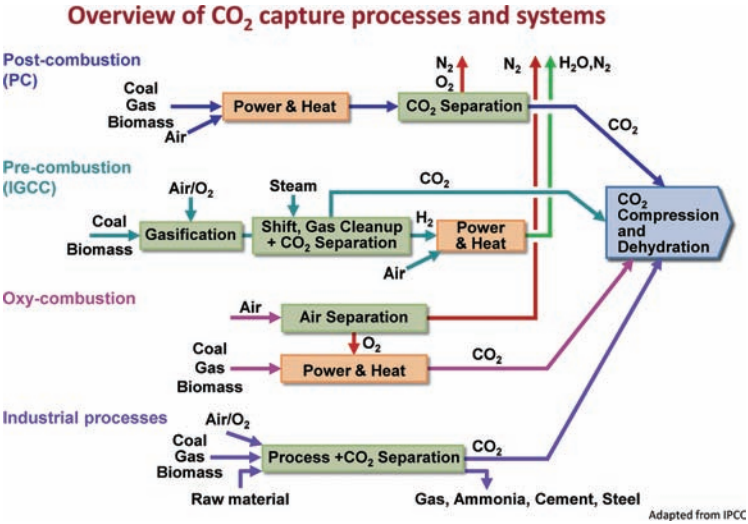


Credit: Alligator film/BUG. Copyright: Alligator film/BUG - Statoil.

Carbon storage at Sleipner.

The scale of the problem, and the remedies

Natural gas and coal-fired power stations with a generating capacity of 500 megawatts of electricity create, respectively, some 180 and 400 tonnes of CO_2 every hour. The challenge in capturing this CO_2 lies not only in its quantity, but in its dilution with other gases. The flue gas emitted by a coal-fired plant is about 14% CO_2 by volume; that from a natural-gas plant may be just 4 per cent. Capturing the CO_2 is not therefore a straightforward matter of collecting and compressing all the gas that emerges; the first step is to extract the CO_2 from the mixture. Doing this is neither easy nor cheap. Engineers have devised three methods.



Overview of CO_2 capture processes and systems. Adapted from IPCC, 2005.

- Post-combustion capture. This is the use of an add-on separation process to remove the CO_2 from the flue gas before its release to the atmosphere.

- Oxy-combustion capture. This is a method of concentrating the CO_2 in flue gas (so making it easier to remove) by substituting oxygen for the ordinary air that would normally be used for burning the fuel.

- Pre-combustion capture. This is the pre-treatment of fuel to remove its carbon component before combustion, and under circumstances in which it is far more concentrated and so easier to capture.

Post-combustion capture. This method can be applied to newly built power plants, or fitted to existing ones. Fuel is burned in the usual way, but the exhaust gases are then passed through a solvent which extracts the CO_2. The solvent is heated to drive off the gas, which is then collected and compressed. Systems like this will typically remove around 90% of the CO_2 in a flue gas.

Although research into carbon capture has focused mainly on power plants, the technology will also need to be applied to other large point sources of CO_2 production such as the cement, steel, and oil and gas refining industries. It is thought that post-combustion capture with appropriate modifications could be added on to such plants.

As with the other two carbon capture technologies, the next step will be to build demonstration plants to test the feasibility of integrating it with power generation and industrial production. Issues to be examined include the feasibility of operating under conditions in which the demands placed on the system vary according to fluctuations in the requirement for power.

Oxy-combustion capture. In oxy-combustion, 95% pure oxygen rather than air is used for burning the fuel. This produces a gas consisting mainly of CO_2 and water which, after purification, removal of the water and compression, is ready for transport and storage. The technology is used in several pilot projects either starting or already operating. One obvious drawback is that first extracting the required oxygen from air requires a process that itself consumes substantial amounts of power.

Oxy-combustion's reliability, efficiency and integration have yet to be tested on an industrial scale. Because the carbon capture element is an integral part of the system, exploring these and other issues will require a purpose-built power plant. The technology development path for oxy-combustion may therefore be more costly than that for either pre- or post-combustion capture.

Pre-combustion capture. Pre-combustion CO_2 capture is mainly applied in what are known as 'integrated gasification combined-cycle' (IGCC) power plants. Here the fuel, usually coal, is first 'gasified' by heating it with pure oxygen. The product is a mixture comprising mainly hydrogen, carbon monoxide, CO_2 and water, which is further treated to create a stream of hydrogen for combustion in a gas turbine to generate power, and CO_2 for transport and storage.

Although not widely used, IGCC technology without carbon capture is in commercial operation in several plants around the world. Pre-combustion capture within such a plant is therefore regarded as (near) commercial technology. CO_2 capture cannot easily be added on to an existing

IGCC system, but experience is now sufficient for a commercial-scale demonstration plant to be built.

How will capture affect the environment?

At a rough estimate, carbon capture at a power plant should reduce CO_2 emissions by 85–98 per cent. But it has to be remembered that the addition of CO_2 capture technology itself creates an 'energy penalty' of perhaps 6–13% depending on the means used. Generating this extra energy will create additional direct and indirect pollution.

To assess the full environmental impact of carbon capture technology will take time, and will require studies that look well beyond the immediate locality of a plant. In addition to CO_2 emissions, the direct and indirect release of nitrogen oxides, sulphur, volatile organic compounds and particulate matter will have to be investigated. Much of the currently available information is only qualitative, and seldom based on actual measurements. More reliable data will have to await the findings from large pilot schemes.

How much will capturing carbon cost?

The overall cost of electricity generated by power plants with CCS will depend on their location, the type of fuel they burn and which technologies they use as well as on financial matters such as interest rates and fuel costs. One measurement often used to compare different power generation technologies is the 'levelised cost of electricity'. This represents its average price excluding profit, but including the cost of building the power plant, operating and maintaining it, fuelling it and financing it over its entire lifetime.

The several studies of this kind so far attempted have shown no clear cost difference between the capture technologies. In broad terms, using carbon capture when producing electricity will increase its cost by around 50 per cent. Modest improvements over the next 20 years could reduce this ballpark figure to 30–45 per cent. Further incremental improvements may be expected beyond that timescale, but any more substantial improvements based on radically new technologies remain speculative.

CO_2 capture in summary

Carbon capture for fossil-fuelled power stations and industrial processes is technologically feasible, but integrated operation of carbon dioxide capture, transport and storage on an industrial scale needs to be demonstrated, and its commercial viability remains to be determined. Because current electricity prices do not factor in the external costs of climate change, CO_2 capture is not yet economic. CO_2 capture will need to be more highly valued if industry is to be incentivised to pursue it. The next essential step in making a case for CCS is the construction of demonstration plants. Because lead times for major capital projects can be long, such demonstrations need to be started without delay.

How will CO_2 be transported to storage sites?

Capturing CO_2 is only the first step; it has to be compressed and then transported to a storage location. It is anticipated that this would be through specially constructed pipelines, although tanker vessels may be appropriate where storage is to be in relatively small and/or remote offshore facilities, or during the start-up phase of CCS schemes when flexibility is likely to be at a premium. The cost of transport by pipeline is determined largely by the capital investment required, and is proportional to distance. Shipping costs are less sensitive to distance. Consequently, there may be a break-even distance beyond which ship transport is cheaper than pipelines.

For offshore storage, combining pipelines and ships could be more cost-effective and less risky, especially in the initial stages of a new storage site when, for example, its capacity is still uncertain.

Because 6000 km of CO_2 pipeline are already installed and working in North America, this form of transport is often seen as the most 'mature' component of CCS systems. However, CO_2 transport in Europe will be through more challenging terrain (for example closer to urban centres or offshore) and will have to cope with higher levels of impurities and more variable operating demands. And pipe rupture, although improbable, could quickly release large quantities of CO_2 which, under unfavourable circumstances, might reach dangerous concentrations. Ship transport of liquid CO_2 is a proven technology, but experience has so far been with relatively small vessels carrying no more than 1000 tonnes of the gas.

With pipeline transport, instead of building many separate connections between carbon capture sites and storage points, it will be cheaper to install a network of trunk mains across Europe. This would have the added advantage of needing fewer planning permissions, which should make pipeline construction quicker. It is likely that governments would have to be closely involved in establishing any CO_2 transport infrastructure, possibly building the pipeline network and selling it to the private sector when risks became clearer.

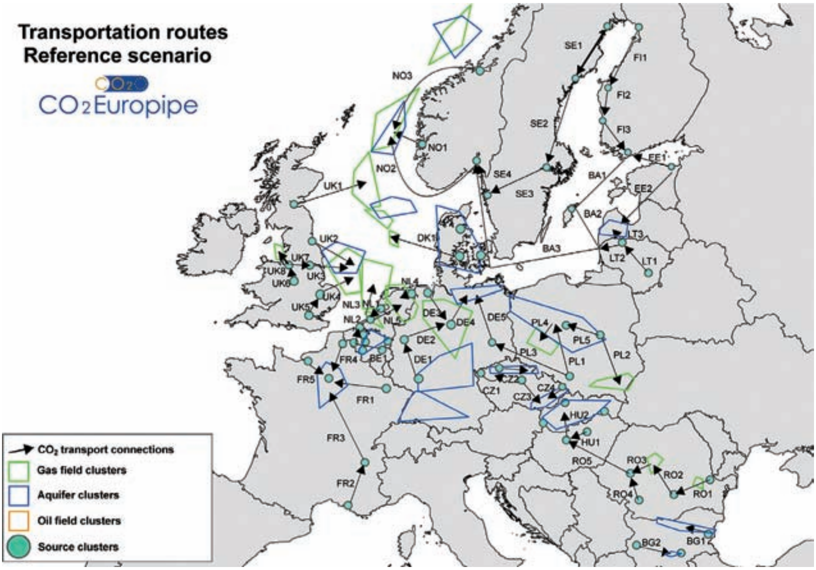


Illustration of possible future CO_2 transport network: the 2050 reference scenario for CO_2 transport network in Europe, from Neele et al., 2010.

If CCS is to make a major contribution to climate change mitigation in Europe by 2050, the CO_2 transport network will have to be on a scale comparable to that already established for natural gas distribution. The existence of this network shows that the task is feasible; however, it must be remembered that the financial incentives to construct the gas network were stronger, and many publics have since become less willing to accept major infrastructure works.

How will CO_2 be stored?

There are three geological settings in which CO_2 might be permanently stored: (1) mature or depleted oil and gas fields, possibly in conjunction with enhanced oil recovery in which CO_2 is pumped into the ground to drive out the remaining oil or gas; (2) deep aquifers containing salt water; and (3) coal beds considered uneconomic or impractical to mine. The first two appear to offer the most promise. Given their limited availability and various technical challenges, coal beds will make a lesser contribution.

Once pumped down into a saline aquifer or depleted oil field, the CO_2 will spread sideways and rise until it reaches a cap-rock or low-permeability sealing layer.

Deep saline aquifers offer by far the largest storage potential, and have attracted the most interest. However, not having been as closely investigated as depleted oil and gas reservoirs, they are correspondingly less well understood. The screening and licensing required before storage within the latter might therefore be quicker and cheaper. Europe has several large, abandoned or mature oil and gas fields offshore, although their combined CO_2 storage capacity falls well short of what is available in saline aquifers.

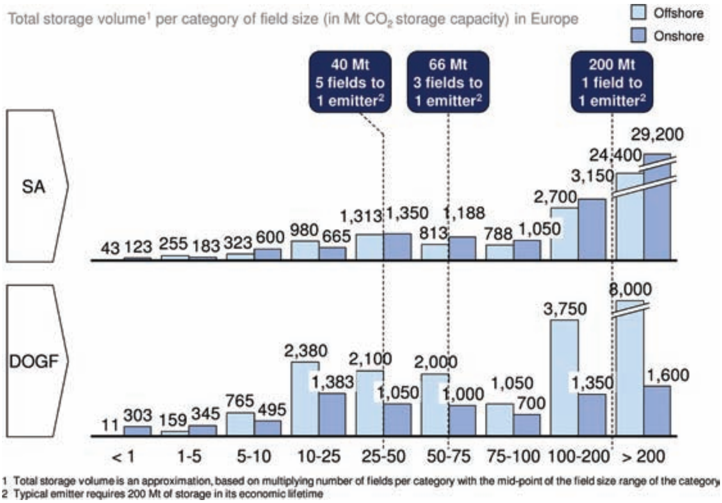
Among the factors that regulators will have to consider when assessing the safety of any particular site are the following: the risks of leakage and its possible consequences; the effects of pressure building up and perhaps compromising the integrity of the cap rock; and the possibility of induced seismic activity. Building confidence in our understanding of some of these issues could take years if not decades.

The current understanding of CO_2 storage comes from several continuing geological storage and research projects, the experiences of the petroleum industry, some underground gas and liquid storage facilities, and ancient natural underground reservoirs of CO_2. However, more needs to be known. Key questions about long-term storage at a site will include the following:

- How well are we able to demonstrate that injected CO_2 will stay within the designated storage site?
- Do we have monitoring techniques sufficiently sensitive to detect leakage or other undesired effects including seismicity?
- How can we estimate more accurately the capacity of potential storage sites?

How much storage space does Europe have?

One review of possible sites in Europe identified a total of 117.0 gigatonnes (Gt: 1 Gt = 1000 million tonnes) of potential CO_2 storage capacity, of which 95.7 Gt are in deep saline aquifers, 20.2 Gt in depleted oil and gas fields and 1.1 Gt in unmineable coal beds. For comparison, in 2009 Europe emitted 3.8 Gt of CO_2, of which around half was from large point sources creating more than 0.1 megatonnes (100,000 tonnes) of CO_2 per annum. Most of the anticipated storage capacity is in saline aquifers and offshore depleted oil and gas fields, which happen to be the more expensive settings; rather little is available in onshore depleted oil and gas fields.



Estimated distribution of CO_2 storage capacity in Europe. Source: ZEP (2011c) based on data from GeoCapacity (2009).

The full EASAC report offers a detailed list of research and development priorities for the future investigation of CO_2 storage.

How is CO_2 storage regulated?

The regulatory framework for storing CO_2 is set out in a 2009 CCS Directive from the European Commission. It includes criteria for characterising and assessing potential storage sites. The framework indicates that they should provide for permanent storage, and be environmentally safe and free of any negative effects on human health. The directive's guidelines suggest that confidence should be built through discussion between the site operator and the regulator and in consultation with the public. On balance, the EASAC Working Group considers the guidelines to be appropriate and helpful.

Although the scientific and economic viability of CO_2 storage depends on the definition of the terms 'permanent' and 'environmentally safe', the directive does not adequately define them. These issues are of great concern to the public whose support for CCS will depend on whether they consider the definitions appropriate. There is a pressing need for further consultation.

In view of plans to revise the current directive, the Working Group lists several observations on the authorisation process. For example, boosting public support will be essential if CCS is to make a significant contribution to climate change mitigation, and there will have to be more emphasis on building confidence in the performance and safety of storage over hundreds or thousands of years. Such confidence needs to be high before authorisation is given to start CO_2 injection because the storage process is not easily reversible if the site subsequently turns out to be unsuitable.

The key chemical and physical processes that retain CO_2 in a storage facility depend on the geological setting and will evolve over time. Although these processes are broadly understood, uncertainties remain which need to be tackled to convince both regulators and the public that long-term storage will be safe. Pilot and demonstration plants will play a key role in developing this confidence.

Other ways of dealing with CO_2

Carbon capture and storage in geological formations is not the only method of sequestering carbon. Recent decades have seen many other suggestions including the storage of CO_2 in the deep oceans, its use as a chemical product or feedstock or for the cultivation of algae on non-cultivatable land or in the sea, and its conversion into stable carbonate minerals (in many ways the ideal solution, though not yet feasible). The Working Group considered all these and other approaches but, at this stage of their development, found most of them to be variously uneconomical, impracticable, environmentally damaging or simply unable to cope with the vast quantities of CO_2 needing to be stored. A few, such as biochar, biomass with CCS, waste carbonation, algal cultivation and CO_2 use in chemical processes, could, however, make a useful though limited contribution in the future.

Engaging the public

Surveys have generally revealed low levels of public awareness of CCS among Europeans. A 2011 Eurobarometer survey found that 52% of people in the Netherlands had heard of CCS and knew what it was. In other countries, however, the figure was between 3 and 13 per cent. This is unfortunate because public perception has emerged as a key factor in determining the prospects for CCS. Moreover, people who accept the reality of climate change and the urgency of tackling it tend to prefer options such as renewable energy technologies or reduced energy use.

Focus groups have sometimes characterised CCS as an uncertain technology that merely perpetuates our dependence on fossil fuels. Doubts have emerged that CO_2 could be stored securely for thousands of years, or be safe and without risk to the environment.

CCS developers need to offer truthful information, use open and fair decision processes, be accountable if things go wrong, and treat the local community fairly in the distribution of economic benefits. Public engagement should start early, be a two-way dialogue (not one-way messaging), be frequent and be informal as well as formal. The dialogue should include discussion of uncertainties, priorities, policy choices, alternative technologies and societal values. Public outreach should be an integral part of project management, and involve experts with whom the public can engage and who are perceived to be independent.

National and international public engagement is essential not only to establish how far people see CCS as playing a significant role in Europe's energy mix by 2050, but also to engender a more positive view of it as an option for climate change mitigation.

CCS in context: EU energy policy

The EU has set itself an ambitious programme. It aims to show global leadership, to provide a clear vision for the introduction of CO_2 capture and storage, to establish a favourable regulatory framework for its development and to invest more, and more effectively, in research.

The EU's energy policy is backed by binding legislation to secure delivery of targets – the 'climate and energy package' – agreed by the European Parliament and Council in December 2008. In 2010 more than a billion Euros were allocated to fund a series of power plants for demonstrating the integrated operation of CCS in all three CO_2 capture technologies, and in the main storage options.

At the time of publication of the EASAC report (May 2013), it had become clear that the proposed technology demonstrations were not on track. Over the past 5 years the initial intention to have up to 12 CCS demonstration projects operational by 2015 has been abandoned. Instead, three or four projects are viewed as a more realistic goal, with anticipated start-up dates tending towards 2020. This slippage is due in part to difficult economic conditions, but also perhaps to initial over-optimism of CCS proponents, researchers and policy makers. The European Commission itself identifies the lack of a long-term business case and the cost of CCS technology as the main problems. It also cites strong public opposition to onshore storage, the decision by some member states to ban CO_2 storage, and the lack of adequate CO_2 transport infrastructure.

Looking to 2050

Any calculation of the costs of CCS compared with those of other low carbon generating technologies will have to incorporate predictions, assumptions and estimates as well as firm data. All such calculations must be viewed with caution, but the EASAC report quotes figures from a 2011 study based on six recent comparative analyses. In this exercise the costs of coal- and gas-fired stations with CCS held an intermediate position in the range of current costs of the technologies considered. They showed up as more expensive than geothermal, hydropower, onshore wind, nuclear and biomass, but cheaper than offshore wind and solar technologies.

Many factors, from the state of public acceptance to unforeseen developments in technology, will influence the scale of CCS deployment in Europe over the four decades to 2050. It would therefore be foolhardy to predict the exact amount of CO_2 that will be captured and stored by that date. However, the picture already sketched is one of delays and downsizing in the proposed demonstration plants, of continuing challenges to the economic viability of CCS, and of difficulties with public acceptance, which may constrain the rates of development and locations of transport and storage infrastructure. Moreover, confidence in the safety of CO_2 storage will build only slowly, and will itself depend greatly on the success of those projects that are undertaken.

Given these circumstances the Working Group concluded that the 2050 share of EU power generation provided by fossil-fired power stations with CCS is likely to lie at the lower end of the 7–32% range identified in scenarios explored by the European Commission. The core of this contribution will come initially from CCS schemes in which circumstances –

good public acceptance, for example, and relatively close proximity of carbon sources to storage points – are most favourable and least likely to generate controversy. Carbon storage could also help to reduce the CO_2 footprint of key industrial sectors such as steelmaking and cement production, and might help Europe's chemical and gas industry in moving towards zero-emission production processes. Positioning CCS in this way might help to overcome opposition founded on the belief that its pursuit will be at the expense of developing renewable sources.

Recommendations in summary

The financial viability of CCS. Through the Emissions Trading Scheme and other relevant mechanisms, arrangements should be made to tip the economics of energy production in favour of CCS deployment. An immediate priority is the provision of adequate funding for three or four CCS demonstration plants, and the planning of a second wave of such plants. Carefully designed regulatory and financial measures may be needed to prevent carbon-intensive industries being driven to other regions where there are fewer restrictions. The EU should continue pressing for the introduction of comparable levels of environmental protection elsewhere in the world.

Storage. Fast-tracking several CO_2 storage facilities through the complete regulatory process would clarify it and boost confidence in the permanence and the safety of storage. In addition, the creation of five or six pilot-scale test sites for the injection of CO_2 should deliver useful results on a shorter timescale. To foster an integrated approach to the development of CCS infrastructure, Europe's CO_2 storage capacity should be located and characterised as soon as possible.

The development of CCS technology. The Working Group has identified the research and development activities necessary to achieve practicable carbon capture. The benefit of activities funded at EU level should be made available to all.

The transport of CO_2. The development of pan-European CO_2 transport infrastructure using ships and pipelines should receive policy attention and support equal to that already applied to the continent's electricity grid and gas pipeline network. Its funding should reflect an appropriate balance between the state and the private sectors. EU and national government funding may also be needed.

Public engagement. More open debates about the role of CCS in mitigating climate change will increase public awareness of CCS in relation to other technologies, and put decisions to proceed with it on a firmer footing. Pilot and demonstration plants should operate in such a way as to provide channels of communication with stakeholders.

Time to act

To achieve what is potentially possible by 2050 will require a sustained political will backed by concrete policy interventions to encourage investors' confidence. Failure to act soon will result in the partial or even complete closure of the 'window of opportunity' that now exists for CCS to act as a bridging technology en route to an energy economy founded primarily on sustainable sources. Without such action, CCS will play little part in European attempts to mitigate climate change over the next 40 years.

EASAC – the European Academies Science Advisory Council – is formed by the national science academies of the EU Member States to enable them to collaborate with each other in providing advice to European policy-makers. It thus provides a means for the collective voice of European science to be heard.

Through EASAC, the academies work together to provide independent, expert, evidence-based advice about the scientific aspects of public policy to those who make or influence policy within the European institutions. Drawing on the memberships and networks of the academies, EASAC accesses the best of European science in carrying out its work. Its views are vigorously independent of commercial or political bias, and it is open and transparent in its processes. EASAC aims to deliver advice that is comprehensible, relevant and timely.

The EASAC Council has 28 individual members and is supported by a professional secretariat based at the Leopoldina, the German National Academy of Sciences, in Halle (Saale). EASAC also has an office in Brussels, at the Royal Belgian Academies of Science and the Arts.

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