

# Statement on Carbon Capture and Storage

## by the Energy Committee at the Royal Swedish Academy of Sciences

### Introduction

The global annual release of about 30 Gton CO<sub>2</sub> to the atmosphere is strongly coupled to the consumption of fossil fuels, which today constitutes 81% of the world's commercial energy supply. While the development of cost-effective, sustainable energy production remains a top priority, time is of the essence. Most projections suggest that fossil fuels unfortunately will globally remain the major source of energy for the foreseeable future [1]. This is problematic as recent reports suggest that the resilience of the Earth to tolerate even moderate additional CO<sub>2</sub> concentrations is limited [2]. Carbon capture and storage (CCS) is identified as one of the few viable options for significant reductions of CO<sub>2</sub> emissions in a relatively near future [3, 4]. In addition, CCS combined with biofuel combustion could also be an important carbon sink. The concept of CCS to mitigate CO<sub>2</sub>-driven climate change is simple; CO<sub>2</sub> is captured at main point sources, such as power plants or other industry with large CO<sub>2</sub> emissions, transported to and deposited at locations with negligible release to the atmosphere for a sufficient period of time. The situation in Sweden differs in several important aspects from most other countries in Europe and globally. The focus globally on CCS is to use this technology on large power plants, releasing in excess of 10 Mton CO<sub>2</sub> annually, while the largest point sources in Sweden are large industries, e.g. steel and cement factories, that release between 0.5 and 2 Mton CO<sub>2</sub> annually.

This statement has been elaborated for the Energy Committee by a working group consisting of Gia Destouni, Lennart Bergström, Niklas Hedin, Jerker Jarsjö, Karl-Göran Mäler and Dick Hedberg. The statement has been approved by the Energy Committee on 22 June 2010.

### Key points

#### 1. Capture

Carbon dioxide can be captured at a large point source using different technologies. The three dominating options are post-combustion capture, pre-combustion capture, and oxyfuel capture. The current energy infrastructure is based on regular combustion of fossil fuel; this structure makes post-combustion capture the straightforward approach to CCS in the near term. While pre-combustion and oxyfuel capture have distinct advantages relating to the ease and cost of CO<sub>2</sub> capture, they require large investments in new power plants. The capture processes developed for post combustion are mature but costly. Today the commercial technologies use amines to capture CO<sub>2</sub>. These absorption-reaction processes are associated with large thermal losses, as well as corrosion and environmental issues [5]. Technologies that can offer a significant reduction of the costs associated with capture include new amine-based liquids, adsorbents and membranes.

#### 2. Transport

Large quantities of CO<sub>2</sub> are already being transported in pipelines for injection in oil fields for enhanced oil recovery (EOR). Hence, the technology for transport in pipelines of CO<sub>2</sub> is relatively mature. Although a large pipeline network for oil and natural gas already exists in Europe, pipeline authorizations are specific to the substance conveyed, and the licensing of re-use for existing pipelines is uncertain [5]. Hence, a new, dedicated CO<sub>2</sub> pipeline infrastructure will probably have to be constructed at a considerable cost.

There are also other options that e.g. include transport on ships from seaside or off-shore temporary storage sites. Such solutions may be attractive to handle smaller (non-power plant) point sources and/or point sources that are located in areas where building a pipeline infrastructure becomes prohibitively expensive.

#### 3. Storage

Ocean storage involves direct injection of CO<sub>2</sub> into the ocean at depths of more than one kilometer. The injected CO<sub>2</sub> can then form "lakes" on the ocean bottom, which would limit the rate of dissolution into surrounding waters. Most countries do not consider ocean storage to be a viable option, not least because there is a risk of further ocean acidification. Another alternative is mineral carbonation, in which CO<sub>2</sub> is converted to solid carbonates. However, the transformation processes that are currently being investigated are too slow for large-scale applications.

By comparison, geological storage of CO<sub>2</sub> is a technologically mature and economically relatively feasible CCS option. It implies that CO<sub>2</sub> is injected as a supercritical, fluid-like phase into depleted oil reservoirs, coal beds or deep aquifers. The latter formations are porous, permeable, and typically saline at the great depths (700 m or more) that are being considered for CO<sub>2</sub> containment. A main issue regarding geological storage, which is not yet fully addressed, is to account for the relatively high uncertainties about CO<sub>2</sub> leakage from potential storage sites back to the ground surface and the atmosphere.

For mitigation of climate change, the IPCC reports that about 90 to 99% of the injected mass must remain separated from the atmosphere during a 100 year period, or 60 to 95% during a 500 year period [3]. Adverse effects of leakage on soil and water systems near the surface must also be avoided. Since CO<sub>2</sub> is a weak acid, it can change groundwater chemistry and for instance increase the mobility of metals. This can affect groundwater quality in the vicinity of the storage site, which emphasizes the need for addressing potential impacts of return flows at candidate storage sites. Local escape routes through connected high-permeability formations (such as fracture zones) are important for groundwater quality effects, while the larger-scale, overall functioning of the storage site will govern its efficiency for mitigation of climate change.

#### **4. Reducing the cost and energy penalty for capture**

The CO<sub>2</sub> capture constitutes the most expensive step of the CCS technology. Reducing the costs and energy penalties associated with this step is essential for achieving CCS to play a considerable role in stabilizing the atmospheric levels of CO<sub>2</sub>. Technologies that can offer a significant reduction include new amine-based liquids, adsorbents and membranes. Most of today's technologies for separating CO<sub>2</sub> from N<sub>2</sub>-rich gases rely on absorption in aqueous solutions of alkanolamines. Alkanolamines have a saturated hydrocarbon back bond and amine and hydroxy groups. In the absorption processes, CO<sub>2</sub> acts as a solute and reacts chemically with alkanolamines at low temperatures, although the N<sub>2</sub> does not. Relatively pure CO<sub>2</sub> is then released on raising the temperature. Sterically hindered alkanolamines have the potential to replace the alkanolamines used today (monoethanolamine (MEA) and similar). MEA appears to have among the best properties. The alkanolamine solutions are corrosive and needs to be diluted, which leads to a large thermal loss on heating and cooling the solvent. New nanostructured solids, e.g. adsorbents or membranes, could be employed in swing adsorption processes, or in membranes units, to separate CO<sub>2</sub> from mainly N<sub>2</sub>. Adsorption technologies may separate CO<sub>2</sub> from N<sub>2</sub>-rich flue gases, at a much-reduced cost compared with the current technologies if more CO<sub>2</sub> selective sorbents can be developed.

#### **5. Suitability of geological storage sites**

Target formations for geological storage need to have relative high porosities, in order to contain large quantities of CO<sub>2</sub> within well-defined regions, where any CO<sub>2</sub> migration after injection can be subject to measurement and monitoring programs. Furthermore, the permeability of the formation needs to be sufficiently high to avoid unsustainable pressure build-up during the injection.

The suitability of oil and gas fields for geological storage is generally ensured by the already proven existence of structural or stratigraphic traps of low permeability formations above such fields; the so-called cap rock. This prevents upward migration of hydrocarbons. However, oil and gas fields do not exist at all places where CCS needs to be applied and their total storage capacity is insufficient for the large volumes of CO<sub>2</sub> that need to be injected for CCS to stabilize the atmospheric levels of CO<sub>2</sub>.

Globally, deep saline formations have the largest storage capacity and can be found in most of the world's sedimentary basins, which is a clear advantage in terms of CO<sub>2</sub> transport from emission sources. Formations of sandstone and possibly chalk are most suitable from a storage perspective. Pristine saline formations are immediately available for CO<sub>2</sub> disposal, contrary to many petroleum reservoirs. A main concern is that many of these aquifers can be overlain by more permeable rock strata, which may not trap CO<sub>2</sub> as effectively as the cap rock of oil reservoirs.

Many countries have inland formations suitable for CO<sub>2</sub> storage. In Denmark and Germany, for instance, possible storage sites are located near main emission sources. In Sweden, suitable sedimentary basins are limited to two locations; one in Southwest Scania (Skåne), and one below the bottom of the Baltic Sea, south of Gotland.

## **6. Quantifying and reducing the uncertainties of geological storage**

There is a large gap between the decadal time scale of the few CO<sub>2</sub> injection experiments that have so far been implemented and monitored and the centennial-millennial time scale during which the CO<sub>2</sub> must at least be separated from the atmosphere in order to mitigate climate change. Understanding of the fate of injected CO<sub>2</sub> in the deep aquifer storage systems during that large time gap requires scenario projections based on numerical models.

Models are thus essential scientific tools for assessing long-term storage site suitability and CO<sub>2</sub> performance, and quantifying main associated uncertainties. Two such main uncertainty sources are then:

- The highly uncertain parameter values (of, e.g., permeability and fracture networks) and their variability in the deep aquifer formations that are considered as potential CO<sub>2</sub> storage sites
- The uncertainties in the models themselves, such as the model assumptions about the governing geochemical reactions that will affect CO<sub>2</sub> after injection, or about the connectivity of fractures and other high-permeability features in and above the storage formation.

These uncertainties can be quantified through combinations of probabilistic and scenario analyses, analogous to the multiple model and scenario projections of climate change considered by the IPCC [6], probabilistic assessments of climate sensitivity [7], and combined probabilistic and multi-scenario analyses of subsurface pollutant spreading and associated pollution risks [8]. Such quantification is necessary to direct the new studies needed to reduce the most important uncertainties, and to account for remaining uncertainties in climate and environmental policies and decisions [9].

## **7. Incentives for CCS implementation**

Incentives to make it profitable to undertake investments in Carbon Capture and Storage must be designed in a way that it is more profitable to store carbon instead of releasing it into the atmosphere. A simple carbon emission tax will not do that if it is based on the generation of CO<sub>2</sub> (for example if the tax is based on the amount of carbon burnt) and not the final fate of carbon dioxide. On the other hand the tax system can easily be modified to handle this problem. One example would be a deposit and refund system. In this system, the CO<sub>2</sub> producer would have to pay a tax on the production, corresponding to the marginal damage from the emission of carbon dioxide emissions. However, if the producer can show that all or part of CO<sub>2</sub> generated will be captured and stored (for at least some time), the producer would be entitled to a refund of the tax paid. The size of the refund would be based on the expected storage time, the damage from an accidental big release of the greenhouse gas (which may be different from the damage of continuous emissions of carbon oxides because of crossings thresholds etc.). Such a system can be designed in a manner that the producer has enough incentives to reduce emissions, either by capturing and storing the carbon in a safe way or by reducing the generation of carbon oxides by, for example, changing energy technology.

## **8. Conclusions and summary**

Despite existing uncertainties connected with the risk of leakage from storage sites CCS in increasing degree today appears a realistic tool for fair-sized reductions of anthropogenic emissions of carbon dioxide to the atmosphere.

There are three main methods for capturing carbon dioxide at the source: pre-combustion capture, post-combustion capture and oxyfuel capture. Capture is the most expensive link in the CCS concept and should be the subject of increased R&D efforts.

Storage of the captured carbon dioxide can take place either in the ocean or the earth's crust, into depleted oil or gas reservoirs, coal beds or deep, porous and permeable aquifers. So far, ocean storage appears less attractive. R&D efforts should be focused on risks of leakage of the carbon dioxide from wells, bedrock and soil, as well as on topics related to how the carbon dioxide will react with surrounding elements, in what way it will be dissolved in water and how it will behave in dissolved form.

Finally, it can also be mentioned that the Royal Swedish Academy of Sciences, in co-operation with the Royal Swedish Academy of Engineering Sciences, in 2004 carried out a project on Carbon Capture and Storage [10].

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