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Technology note

Carbon Capture and Storage

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What is it?

Carbon dioxide Capture and Storage (CCS) refers to a set of technologies which can be installed for the reduction of carbon dioxide (CO_2) emissions in power generation and industrial processes. The process consists of the separation of CO_2 from large industrial and energy-related point sources, subsequent compression, transportation to a storage location and long-term isolation (i.e. storage) from the atmosphere. The large point sources of CO_2 include large fossil fuel or biomass power plants, major CO_2-emitting industries (steel and cement production), natural gas production, synthetic fuel plants and fossil fuel-based hydrogen production plants. CO_2 can be stored in geological formations (e.g. oil and gas fields, unminable coal beds and deep saline aquifers), in the ocean (direct release into the ocean water column or close to the deep seafloor) and via industrial fixation in inorganic carbonates (Figure 1). Alternatively, CO_2 can also be used as an input to other industrial processes.

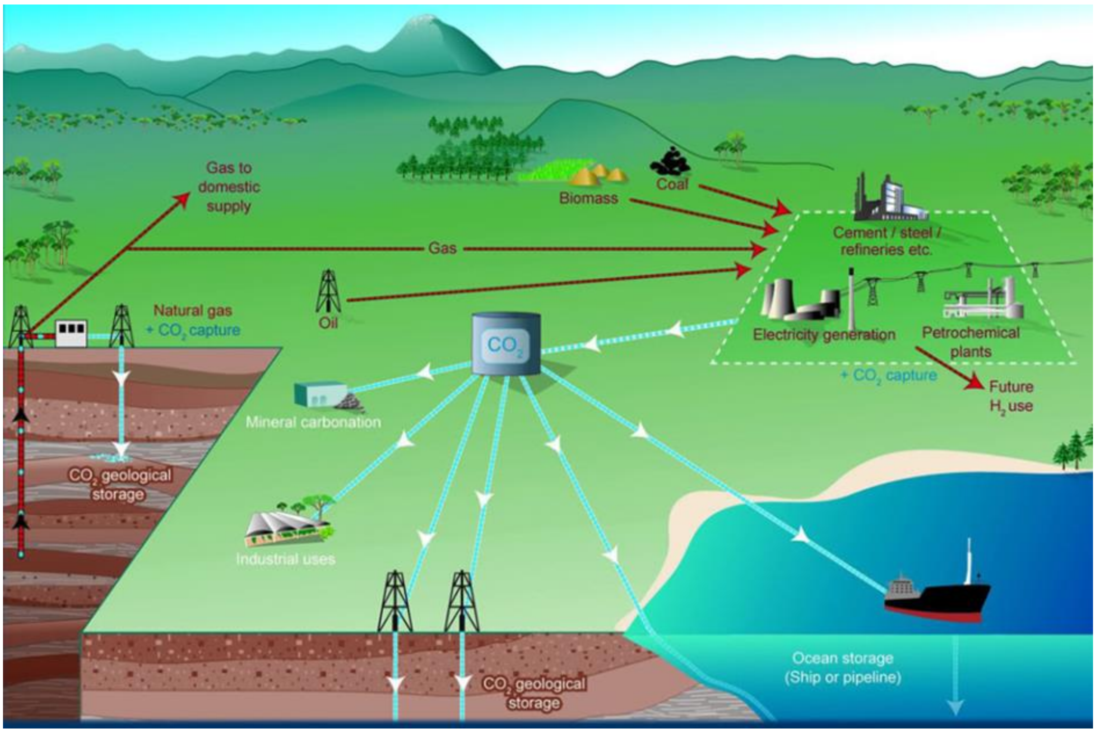

Figure 1: Schematic diagram of possible CCS systems showing the sources for which CCS might be relevant, transport of CO_2 and storage options (IPCC 2005).

How does it work?

- Capture: There are three different types of CO_2 capture technologies: post-combustion, pre-combustion and oxy-fuel combustion. The selection of the capture system mainly depends on the plant design (e.g. concentration of CO_2 in the flue gas stream, pressure and temperature of the gas stream, retrofitted or newly built plant).
- Transportation: Pipelines are preferred for transporting large amounts of CO_2 onshore. For larger distances oversea, the use of ships could be economically more attractive.

- Storage: Currently, storage of CO_2 in geological formations represents the most realistic option for large quantities of CO_2. If CO_2 is injected into suitable saline formations or oil or gas fields at depths of 800 m, physical and geochemical trapping mechanisms prevent it from migrating to the surface. An essential physical trapping mechanism is the presence of an impermeable caprock. Ocean storage as well as mineral carbonation of CO_2 are subject to large uncertainties and at the early stage of research, respectively.

How mature is it?

All three steps in the CCS chain, i.e. capture, transport and underground storage of CO_2 are as such mature today and several CCS projects are in operation worldwide (Global CCS Institute 2014, 2015). Frontrunner countries are the US, Canada and Norway. However, existing CCS projects are implemented in sectors where, as part of the industrial process, CO_2 is routinely separated from other gases or CO_2 is produced in a relatively pure stream. Large-scale implementation in the power sector and in iron and steel industries is still to be demonstrated. CO_2 is most often used for enhanced oil recovery (and hence, stored) or stored in rather small-scale geological sites. Storing substantial quantities of CO_2 in dedicated geological formations such as saline aquifers still requires considerable additional research effort. However, available evidence suggests that, worldwide, there is sufficient technical potential for CO_2 storage in geological formations.

In general, the current delay in CCS implementation is primarily for two reasons. Globally, costs of CO_2 emissions are still not internalized on an international level and prices of CO_2 certificated within the EU are very low; therefore, CCS is not economically attractive. Secondly, experience has shown that large-scale implementation of CO_2 storage can fail due to public opposition in certain regions of the world, especially in Europe.

How disruptive is it?

Latest results from energy, economic and climate modeling (e.g. Luderer et al. 2013, Bertram et al. 2015) show that integration of CCS in the power sector as well as in industrial processes by 2030 will facilitate achieving stringent climate goals in an economic way. CCS can significantly contribute to the stabilization of atmospheric GHG concentrations at levels around 450-500 ppm, which correspond to limiting global warming to 2°C with a reasonable likelihood. The scenarios analyzed also show that further delay of large-scale CCS implementation (like any other measure for climate change mitigation) will impede cost-effective climate protection. CCS can be regarded as disruptive technology in the sense that it can substantially help in reducing the GHG intensity of industries with high carbon emissions and of electricity generation, particularly in countries with high shares of fossil power plants, and also due to the option of retrofitting existing infrastructure.

What are the impacts?

Along with the benefit of reducing GHG emissions, CCS does have some potential drawbacks: cost increase compared to plants without CCS are considerable, public acceptance might be difficult to gain due to perceived risks, and increased environmental burdens other than GHG emissions are inevitable. Depending on power plant technology and fuel costs, CCS would increase the cost of electricity of the order of 40% (Figure 2). However, economic evaluation indicates that CCS, once commercialized, will be cost-competitive with other low-carbon sources of electricity. Local health impacts, safety and environmental risks of CO_2 transport and geological storage are comparable to the risks of current activities such as natural gas transport and storage, enhanced oil recovery and deep underground disposal of acid gas. Permanent storage of CO_2 must be ensured with an appropriate site selection based on available subsurface information, a monitoring program, a regulatory system and the appropriate use of remediation methods to stop or control CO_2 releases.

From a life-cycle perspective, i.e. considering the complete energy chain from fuel extraction to power generation, CCS allows for a reduction in CO_2 emissions from fossil electricity production of between 70-90% (Figure 3). Biomass power plants can even lead to negative CO_2 emissions if biomass is harvested in a sustainable way. However, due to the increasing fuel consumption per unit of electricity generated due to CCS, more primary resources are required, which in turn can increase their associated environmental burdens.

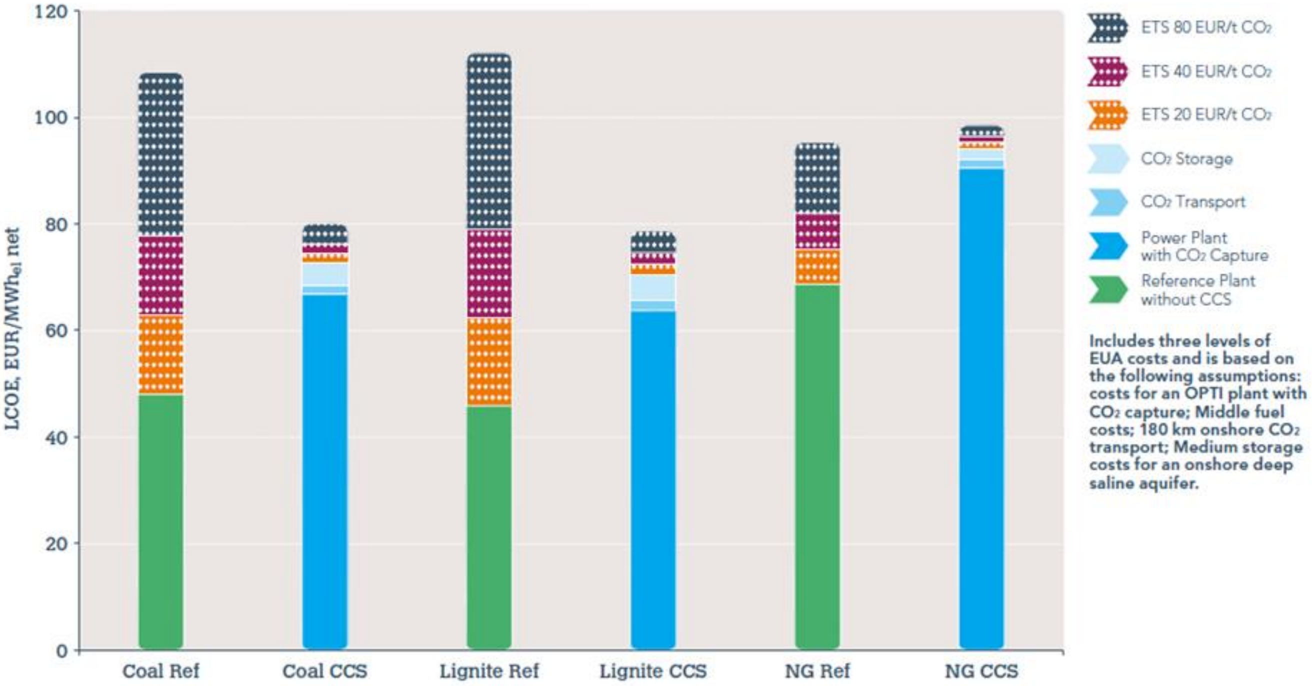

Figure 2: Levelised Cost of Electricity (LCOE) of integrated CCS projects (blue bars) compared to the reference plants without CCS (green bars) (ZEP 2011).

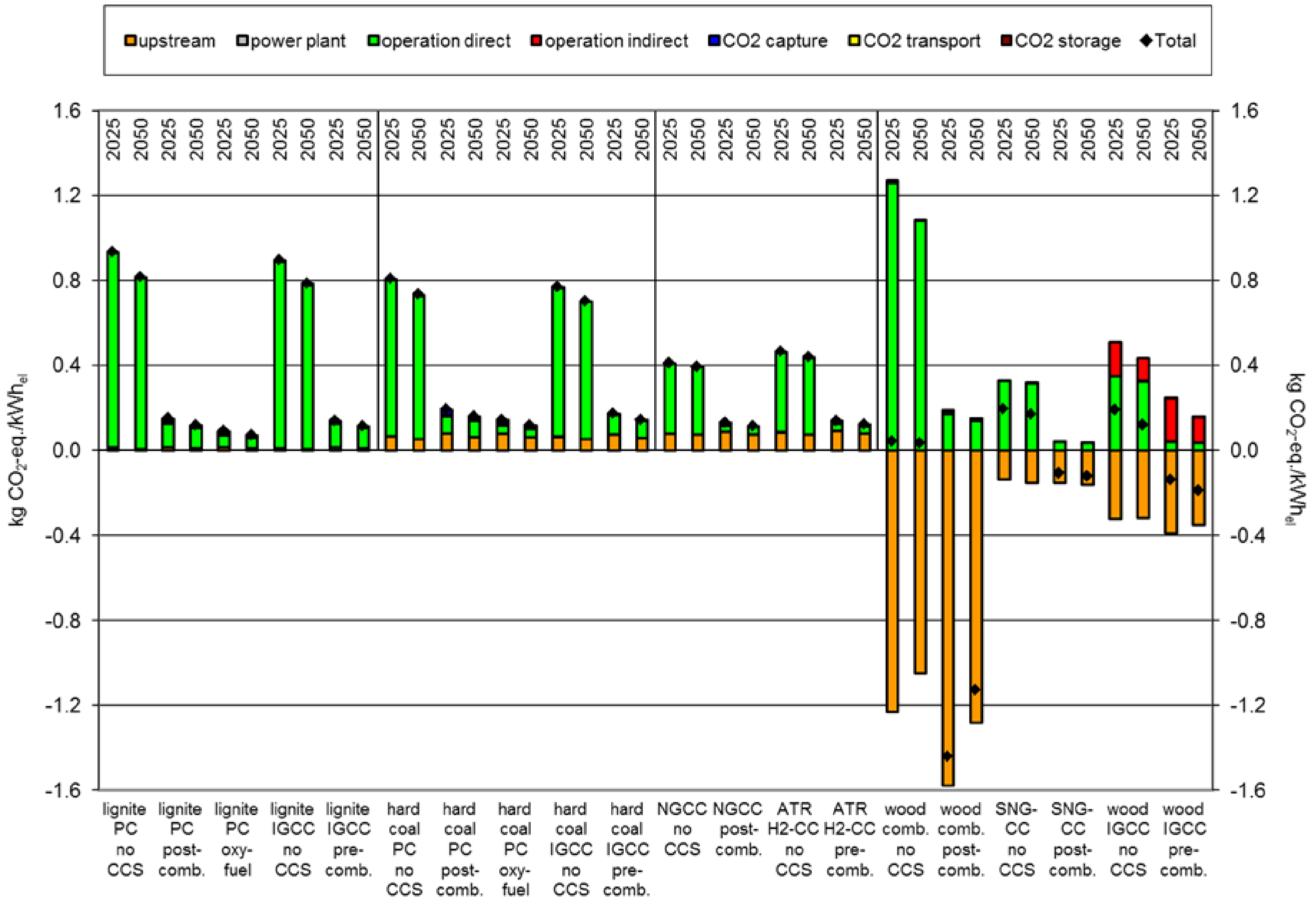

Figure 3: Life cycle GHG emissions of the electricity production in Europe from hard coal, lignite, natural gas and wood in 2025 and 2050 with and without CCS. PC, pulverised coal; ATR, auto-thermal reforming; SNG, synthetic natural gas (Volkart et al. 2013).

SWOT analysis

(objective: achieving reduction of GHG emissions with large-scale CCS implementation)

	Helpful	**Harmful**
Internal origin	**Strengths** - CCS allows for substantial reduction of CO_2 emissions in the electricity sector and in industry while simultaneously using (domestic and cheap) fossil fuels - existing power plants can be retrofitted with CCS - CCS can be applied to various CO_2 point sources: fossil and biomass power plants, steel and cement production, refineries, waste incineration, etc. - fossil power plants with CCS can generate base-load electricity with low carbon intensity as opposed to intermittent renewables - biomass combustion with CCS allows for negative CO_2 emissions	**Weaknesses** - CCS increases generation costs substantially - the complete CCS chain (CO_2 capture, transport, storage) has not yet been demonstrated in power sector - CO_2 capture reduces flexibility of power plant and increases complexity - CCS involves some accident risks, mainly in CO_2 transport and storage - CCS increases primary resource consumption - CCS implementation requires long planning horizons, mainly for storage site selection and its approval, testing and implementation
External origin	**Opportunities** - CCS is widely recognized as an important means for CO_2 reduction, substantially contributing to achieving climate change mitigation goals - CCS can be a business opportunity for traditional industries in the oil, gas and power plant industry as well as large utilities - CO_2 injection (i.e. storage) can be used for enhanced oil recovery	**Threats** - CCS is perceived as "high risk technology" - CCS might lack public acceptance due to various reasons - CCS requires appropriate legal boundary conditions, which still need to be established - CCS is (perceived as) competitor of renewables in terms of research funding and subsidies - CCS will only be economically feasible, if CO_2 emissions have an appropriate price on the international (or at least regional) level - CO_2 injection can trigger (minor) earthquakes

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