Alliance Nationale de Coordination de la Recherche pour l'Énergie

Decarbonization Wedges Exercise

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CARBON CAPTURE AND STORAGE

1. State of the art and current development

Technology 1: CO_2 capture

CO_2 capture can be applied either on power generation units or on industrial processes such as steel making processes, cement industry, refineries, etc. These technologies fall into 3 methods: capturing CO_2 in post-combustion, in pre-combustion and in oxycombustion. In post-combustion, CO_2 is captured with an amine solvent. In oxycombustion nitrogen is first extracted from air. After combustion, the flue gases that are recycled to be burnt again are only made of O_2 and CO_2 —the latter being easier to capture as there is no more nitrogen in the air. Pre-combustion is only used with coal-fired power plants and involves extracting nitrogen from air too. After coal has been gasified with steam, there is only CO_2 and H_2. Eventually CO_2 is extracted and electricity is generated with H_2.

Technology 2: CO_2 geological storage

CO_2 geological storage builds partly upon the know-how acquired in CO_2 Enhanced Oil Recovery processes. Two main techniques, onshore geological storage and offshore geological storage, are being considered. Whereas short term injection issues are well under control, what remains to be assessed is permanent CO_2 storage in the long term. Dedicated monitoring techniques and remediation methods need to be validated: this should be achieved when operating demonstration projects.

2. Maturity level and technological perspectives

Maturity of elementary technologies associated with CCS

Methodological information:

The maturity level is the TRL, reduced to 5 levels with market deployment enclosed in the higher TRL classes; maturity level scaling: 0 = none; 1 = fundamental research; 2 = R&D; 3 = demonstrator; 4 = low deployment; 5 = large deployment.

	2015	2020	2030	2040	2050
Capture[1]	3	3	4	5	5
Onshore geological storage	2	3	4	4	4
Offshore geological storage	2-3	3-4	4	5	5

For the time being large scale demonstrators are being developed to demonstrate the efficiency of capture technologies at the industrial scale. Storage is not mature yet and will not be present in the short term, notably because of the bottlenecks mentioned in section 3.

Offshore storage is much more accepted despite higher costs and this technology will probably develop faster than onshore storage. The deep offshore storage (i.e. using a 'self-sealing process') may be a long term option even if it is much less mature compared to onshore and offshore standard storage.

[1] The maturity level is the mean maturity level of the 3 combustions methods —i.e. pre-combustion, oxycombustion and post-combustion. The maturity level assessment for CCS is thus different than the one used in the template on low-carbon steelmaking.

Potential development of technologies related to CCS

Methodological information:

Potential development is measured as the percentage of the technology's contribution to environmental protection. This means evaluating, in terms of carbon emissions and of carbon emissions reduction, to what extent this new technology can contribute to limiting temperature increase to 2°C above pre-industrial level according to the time horizon considered in this study. Potential development scaling: 0 = not significant; 1 = significant (i.e. more than 1% of global emissions reduction) in some countries; 2 = significant on the global scale; 3 = very significant on the global scale (i.e. up to 3% of global emissions reduction); 4 = major technology vs. climate change (i.e. more than 3% of global emissions reduction).

	2020	2030	2040	2050
Capture	0	1	2	4
Geological storage[2]	0	1	2	2-4

These technologies have not yet reached maturity and they will not contribute to greenhouse gas emissions reduction until 2030. After that, they should develop rapidly.

Globally the IEA is still expecting CCS to contribute to 13% of the total abatement target by 2050 in order to comply with the 450 ppm scenario.

CO_2-Enhanced Oil Recovery (CO_2-EOR) is taken into account in this assessment during the first period (2020). Beyond, CO_2 storage in saline aquifers should become dominant.

3. Technological, economic and social bottlenecks

Methodological information:

The following table ranks the bottlenecks according to their impact on the development of the technology. A bottleneck ranking at 6 on the scale will hinder or stall the deployment of the technology compared with bottlenecks ranking at 1; conversely, a bottleneck ranking at 1 will hinder the deployment of the technology much less than bottlenecks ranking at 6. Note that the ranking is relative, meaning that a bottleneck ranking at 6 is not necessarily hard to remove; conversely, a bottleneck ranking at 1 is not necessarily easy to remove. Technologies rank according to: research, finance, regulations, resources & environment, security and acceptability. The table also contains keywords associated with each bottleneck.

It must be stressed that the ranking of such different factors must be considered with caution; as an expert's judgement, not a quantitative assessment.

Technology		**Research & technological bottlenecks**	**Economy and Financial bottlenecks** (investment, risks)	**Regulation & institutional environment**	**Resources & environmental impacts** (including scarcity of raw materials, water, land, climate)	**Safety & security** (impacts on health, people and security assets)	**Socio-technical feasibility**
Capture	Rank	5	6	4	2	3	1
	Key-words	Cost, availability	High costs	Incentive CO_2 prices	Water use (for post-combustion capture)	Emissions Use of solvents	
Offshore storage	Rank	2	6	5	3	1	4
	Key-words	Remediation solutions to CO_2 leakage	Financial provision for assessing a CO_2 storage	Liability transfer to public authorities	Management of overpressured Water	CO_2 containment	
Onshore storage	Rank	1	2	4	3	6	5
	Key-words	storage capacity		Conflicts of use	Water resources	CO_2 containment	

CO_2 capture technologies are well established and have already been demonstrated on pilots (on power plants with producing ~30MWe and up to 120 MWe). R&D is still necessary to reduce even further the cost of capturing CO_2. Regarding public acceptance, demonstrations will have to prove that using solvent based CO_2

[2] This evaluation doesn't integrate the "deep offshore geological storage" technology. It means that potential of CCS could increase at the end of the period (by 2050). In general, the storage potential is uncertain, it is why a range between class 2 and class 4 is proposed (3 is used for calculation) that means a possible additional impact of CCS.

capture processes does not release spurious (i.e. carcinogenic) components into the atmosphere. Demonstrations will help establishing this conclusion.

Offshore storage will be easier to implement with regards to public acceptance but will be more expensive than onshore CO2 storage. Deep offshore storage could theoretically be considered as a safer but much more expensive alternative to onshore and offshore storages.

R&D is still necessary to provide efficient and robust surveillance systems that allow for early detection of any CO_2 leak and immediate actions to solve the problem. Remediation techniques still need to be assessed to prove that a CO_2 storage technology can be properly managed to insure safety, even in the long term.

Onshore CO_2 storage will be more difficult to deploy as the integrity of potable aquifers will be questioned and construction of pipelines to deliver CO_2 to the storage sites will need to get clearance from local communities. Evaluation of storage capacity needs to be reassessed by taking into account most recent geological information, storage experience and conflict of usage in land and underground use. The increasing pressure in aquifers is another issue with storage, especially in sedimentary basins.

Public acceptance is a key topic to enable the large deployment of the CCS technology. Recent examples of experiments of geological storage either onshore or offshore (e.g. in Norway, USA, Canada, Australia and Algeria) show that a proper management of safety and risks for standard CO_2 storage is available; therefore these potential environmental impacts could be limited to an acceptable level.

4. Potential radical and incremental innovations

Methodological information:

The following table lists the nature of innovations needed to overcome the bottlenecks mentioned earlier. There are two types of innovations: I stands for 'incremental innovation' (i.e. improving existing products and processes) and R stands for 'radical innovation' (i.e. developing new products and processes).

Technology		**Research & technological innovations**	**Economy and Financial innovations** (investment, risk)	**Regulation & institutional environment**	**Resources & environmental impacts** (including scarcity of raw materials, water, land, climate)	**Safety & security** (impacts on health, people and security assets)	**Socio-technical feasibility**
Capture	I or R	R	R	R	I	I	I
	Key-words	Oxycombustion and pre combustion	New financial rules	Public support			
Geological storage	I or R	I	R	R	I	I	I
	Key-words		Financial provisions	Operator responsibility			

Reducing the energy penalty due to CO_2 capture is still required. Drastically reducing it should require breakthrough innovations.

New financial rules involving public support could help develop the technology and speed-up its deployment. The long-term economic competitiveness to be achieved requires a ton of CO_2 avoided valued at approximately €50/ton of CO_2.

The EU Storage Directive[3] and the Guidance Documents associated to it are not detailed enough, neither on how to implement the transfer of liability from an operator to a public authority, nor on any financial provision that should be secured. If we consider that if 100 million tons of CO_2 were to be injected in the underground with a CO_2 valued at €100/ton, such a CO_2 storage would amount to 10 billion euros. Even 10% of this value as a financial provision for covering a gross leakage should constitute too high a financial risk when the technology is implemented.

Furthermore liabilities in the post-closure phase increase financial risks for storage bodies: injecting gas for 50 years, monitoring it for 20 and bearing prosecution risks for 30 years implies a century of risks —this is why few investors or storage bodies are interested in this technology. This system should change.

[3] EU (2009/31/EC): Directive on the geological storage of CO_2