Alliance Nationale de Coordination de la Recherche pour l'Énergie

Decarbonization Wedges Exercise

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CO_2 MITIGATION TECHNOLOGIES IN THE CEMENT INDUSTRY

1. State of the art and current development in different world regions

Portland clinker, the most common type of cement, is produced through a combustion process: first calcium carbonate is calcined ($CaCO_3$ -> CaO + CO_2), then the calcined limestone is combined with clay to produce clinker. Eventually gypsum (or any other calcium sulfate) is added to the clinker in order to make what is called Portland cement.

There are two types of CO_2 emissions: when calcium carbonate ($CaCO_3$) is calcined into limestone, CO_2 is emitted —this accounts for 66% of production sites emissions; the other source of CO_2 emissions is through heat generation —heat is required for calcination and combustion.

In the end the cement industry accounts for 6.5% of anthropogenic CO_2 emissions.

Technology 1: Performance levers

"Addition ratio" to Portland clinker (c/k)
Further additions can be made to the cement in order to produce blended cements. The percentage of added products can go up to 95% for some special applications of the cement. This lever is called the cement-to-clinker addition ratio (c/k). The usual addition products are: ground blast furnace slag, fly ash, ground limestone, ground pozzolans, etc.

The total cost is deeply affected by logistic costs depending on the distance between the cement plant and the steel plant —for blast furnace slag— or the coal power plant —for fly ash.

Kiln-specific heat consumption reduction
The heat yield of the clinkerization process is 60%. However not all the excess heat is lost, it is eventually used to dry the raw materials coming from the quarry as well as the fuels —e.g. coal, petroleum coke, alternative fuels, etc. In the end it is not possible to reduce dramatically heat consumption of this process just by improving the combustion because the enthalpy of the chemical reactions is conditioned by thermodynamic laws.

- **Fuel switch to alternative fuels**

Burning fuels that come from biomass is considered as neutral in terms of CO_2 emissions. Burning alternative fuels decreases CO_2 emissions related to heat generation. However biomass resources are not always available everywhere and all the time.

Technology 2: New low-CO_2 products development

Low-CO_2 hydraulic product (- 30% of CO_2) as compared to Portland clinker
Innovations are possible concerning several phases of cement manufacturing: lower burning temperatures, optimization of the grinding process, etc. Due to low CO_2 price value, economic circumstances are currently limiting this method to only few high added value market segments.

The reduction of CO_2 mitigation depends on whether the market for the low-CO_2 product method will be limited to *niche* applications or if it will develop for mass applications.

Mineral carbonation products
This new method involving mineral carbonation products is a significant radical innovation compared to Portland cement and concrete. Indeed although its composition differs from Portland clinker —i.e. less limestone—, mineral carbonation products are manufactured using a carbonation process —not using hydration. Furthermore burning conditions are optimized, leading to the reduction of th energy consumption. This leads to a decrease in CO_2 emissions in addition with CO_2 consumption during the curing process.

Techno 3: CO_2 capture technologies

Post-combustion amine scrubbing

CO_2 can be captured at cement plant stack with an amine solvent. The capture by amine scrubbing is less integrated in the cement plant process than in coal power plant processes as no steam is available in the cement plant. This results in a higher cost of CO_2 captured.

In any case it is important to keep in mind that once captured, CO_2 still has to be shipped to storage locations or to EOR[1] or operation sites. This means that the cost of the full capture-shipping-final use chain will be even more expensive —e.g. > 120 €/t CO_2.

Oxycombustion

Of the total CO_2 emitted by a cement plant, 80% is produced at calciner stage. This technology is better integrated to cement manufacturing process. Furthermore oxycombustion avoids nitrous oxide formation during combustion stage at pre-calciner stage because no nitrogen is admitted for combustion (air is replaced by oxygen and recycled CO_2). The resulting gas mix is therefore only made of O_2 and CO_2, which eventually makes CO_2 easier to further concentrate and purify.

Separated calcination

This technology is underpinned by the fact that 66% of the CO_2 emitted by the cement process is linked to limestone calcination. Indeed separated calcination processes keep the calcination CO_2 pure until plant outlet by keeping CO_2 separate from combustion gases. Besides the hot CO_2 is then cooled down while producing electricity, which makes the cement plant self-sufficient in terms of power consumption.

CO_2 capture technologies will only be implemented in selected sites where conditions will be favorable —i.e. when some CO_2 applications are possible close to the cement plant: e.g. EOR, algae growth, greenhouse, chemicals, etc.— or when pooling to ship and storag is possible and where local funding opportunities are available. No stand-alone business model can currently support CO_2 capture and storage.

2. Maturity level and technological perspectives

Maturity of CO_2 mitigation Technologies in the Cement Industry

<u>*Methodological information:*</u>

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
Performance levers	5	5	5	5	5
Low CO_2 products	3	3	4	5	5
Post-combustion capture	5	5	5	5	5
Oxycombustion	2	2	4	5	5
Separated calcination	2	2	3	4	5

<u>**Technology 1:**</u> the performance levers mentioned are mature enough and quite used. Investment is high for BAT cement kilns with low return on investment which is thus limiting the deployment of the technology. Concerning alternative fuels, the idea of burning wastes that become more difficult to burn implies new investments.

<u>**Technology 2:**</u> these low-carbon products are actually in the demonstration phase and will likely gain maturity. The low-CO_2 hydraulic product will *a priori* be limited to *niche* applications with high added value. However mineral carbonation displays a good potential development and can contribute to 1 to 2% of total CO_2 emissions reduction, which is similar to what performance levers can achieve. This product is expected to divide specific CO_2 emissions in the cement industry by at least a factor of 2.

<u>**Technology 3:**</u> post-combustion is a mature technology, quite widespread in fertilizers manufacturing. However this technology needs to be scaled up. Oxycombustion is currently developing and is better integrated to cement manufacturing. However this does not contribute significantly to capture costs reduction. Separated calcination can help achieve electric self-sufficiency.

[1] EOR: Enhanced Oil Recovery

Potential development of CO_2 mitigation Technologies in the Cement Industry

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
Performance levers	1	2	2	3
Product development	0	1	1-2	1-2
CO_2 capture	0	0	0-1	0-1

CO_2 capture: this technology is not expected to develop in the coming years in the cement industry since other levers —new low-CO_2 products— can be used to mitigate CO_2 emissions. Deployment is conditioned by numerous external factors like funding, policy, regulation, public acceptance (regarding CO_2 storage) local opportunities, etc. The potential development is estimated at 3% for carbon capture storage in the cement industry and between 0.6 to 1.2% for mineral carbonation. Performance levers will achieve 2 to 2.5% of global CO_2 emissions reduction —the reference year is 1990.

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.

Technology		**Research & technological bottlenecks**	**Economy and financial bottlenecks** (investment, risks)	**Regulation & institutional environment**	**Resources & environmental impacts** (inc. scarcity of raw materials, water, land, climate)	**Safety & security** (impacts on health, people and security assets)	**Socio-technical feasibility**
"Addition ratio" to Portland clinker	Rank	2	6	4	5	3	1
	Key-words	Reached maturity	Price of added products	Standards compliance and CO_2 offset	Supply, available quantities		
Kiln-specific heat consumption reduction	Rank	5	6	4	3	2	1
	Key-words		Investment cost and renovation	CO_2 threshold	Emissions reduction		
Fuel switch to alternative fuels	Rank	1	6	3	4	2	5
	Key-words	Valorization of less energetic waste Cement quality	Pre-treatment price	Compliance with waste disposal standards	Availability of alternative fuels	Pollution and spreading risks	Waste issues
Low CO_2 product	Rank	6	5	4	3	2	1
	Key-words	Application properties Sustainability	Raw material prices	No product standard	Source of alumina		
Mineral carbonation	Rank	5	3	6	4	2	1
	Key-words	New applications to other market segments	Market CO_2 prices	Non-standard product/No CO_2 compensation	Limited CO_2 quantity available on market		
CO_2 capture	Rank	3	6	5	4	2	1
	Key-words	Maturity reached (for post-combustion)	Very high capture prices	No CO_2 compensation	High captured CO_2/avoided CO_2 difference, with resulting costs. Required LCA[2]		Favored closeness to CO_2-consumming facilities

There are often waste issues with switching to alternative fuels.

[2] LCA: life-cycle assessment

The development of CO_2 capture and storage in the cement industry should not be too significant except in case of a strong increase in CO_2 price. Capture is already expensive when compared to the cement market price. This means that the cement price will almost double when using CO_2 capture and storage.

The more the cement emissions are mitigated using performance, products and process levers, the lower the emissions of the cement plant, and thus the higher the specific cost of CO_2 from capture to storage. Direct CO_2 use for greenhouses, for algae growth and for mineral carbonation would be much more favorable.

The kiln specific heat consumption reduction through investing in the BAT is very capital-intensive and rarely produces an adequate return on investment, taking into account the local market conditions, especially in mature country where market is not developing anymore.

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 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
"Addition ratio" to Portland clinker	I or R	I	I	I / R	I	I	I
	Key-words	Percentage of added product		Implementation of product standards	Limited amount of available added product		
Kiln-specific heat consumption reduction	I or R	I	R	NA	NA	NA	NA
	Key-words	Reached maturity	Expensiveness Low ROI				
Fuel switch to alternative fuels	I or R	I	I	I	I	I	I
	Key-words				Limited quantities		Public inquiries
Low CO_2 product	I or R	R	R	R	R	I	I
	Key-words	Improvement of applications and emissions	Raw material prices	Implementation of product standards	Need for aluminum sources		
Mineral carbonation	I or R	R	I	R	R	I	R
	Key-words	New applications to other market segments		Implementation of product standards	Cheapness of CO_2 sources	Employment safety of CO_2 market segment	Acceptability from concrete clients
Post-combustion capture	I or R	I	R	R	R	I	R
	Key-words	Mature technology	High costs Introducing a CO_2 market	Implementation regulation	Specific need for CO_2 storage	Need to demonstrate storage safety	Storage public acceptance
Oxycombustion	I or R	R	R	R	R	I	R
	Key-words	Developing technology	High costs, CO_2 market	Implementing regulation	Specific need for CO_2 storage	Need to demonstrate storage safety	Storage public acceptance
Separated calcination	I or R	R	R	R	R	I	R
	Key-words	Developing technology	More affordable costs	Implementation of regulations	Specific need for CO_2 storage	Need to demonstrate storage safety	Storage public acceptance

All three performance levels usually pertain to incremental innovation —except when the levers require investing much or buying rare or expensive materials.

Low-CO_2 products that pertain to radical innovations are not necessarily more expensive to produce than Portand. However establishing standards and extending applications to other market segments pertain to radical innovations.

Carbon capture technologies are either too expensive or not mature enough. This is why CO_2 capture will only be carried out in the cement industry in selected areas (or countries) where plant locations and local conditions will be favorable. The energy involved within the capture technologies is quite high and will only be justified if coupled to rewarding applications.

Carbon recapture will be used in our industry primarily for the sake of mineral carbonation of new products, replacing the Portland in selected applications. New market segments are currently under development in order to increase the weight of this new CO_2 mitigation lever.