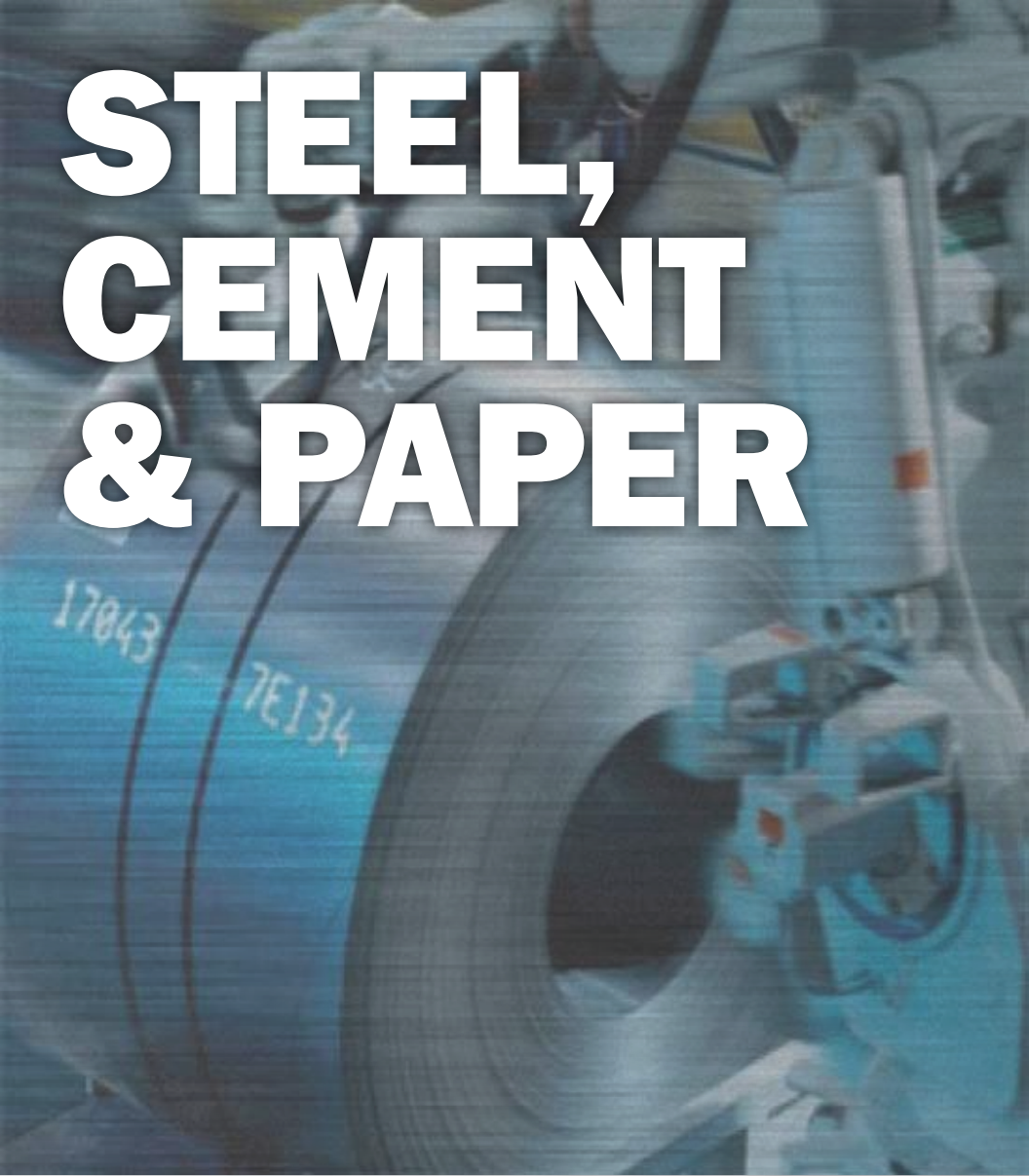


HORIZON 2050



STEEL, CEMENT & PAPER

Identifying the breakthrough technologies
that will lead to dramatic greenhouse gas
reductions by 2050

CAN
Europe

The vision of Climate Action Network Europe is a world striving actively toward the protection of the global climate in a manner that promotes equity and social justice between peoples and sustainable development. Climate Action Network Europe unites 130 European environmental and development NGOs to work towards this vision.

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A complete list of references can be found in the CE Delft report (see right under "Background information.")

Background information

This paper uses the information in the background report "*Technological developments in Europe: a long-term view of CO₂ efficient manufacturing in the European region*" (July 2010) produced by CE Delft for Climate Action Network Europe. The report can be found at www.climnet.org and www.cedelft.eu

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DISCLAIMER: the report "Technological developments in Europe: a long-term view of CO₂ efficient manufacturing in the European region" by CE Delft and its technical summary as presented in this brochure (p. 4-9) do not necessarily reflect the position of Climate Action Network Europe and its members.

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INTRODUCTION



“Mankind is divided into three classes: those that are immovable, those that are movable, and those that move.”

Benjamin Franklin

Shaping the 2050 climate policy Horizon

Avoiding dangerous climate change will, according to the latest climate models, require global greenhouse gas emissions to be cut by 50-80% by 2050. For developed countries and regions this means reductions of 80 to 95%.

It is often argued that such deep emissions reductions are technically impossible or that they would harm the economy and create unemployment. This fear has been holding back appropriate climate action in Europe and other parts of the world. This publication is based on two assumptions. The first is the achievement of emissions reductions of more than 80% by 2050 in Europe. The second is the concurrent presence of a strong and modern manufacturing sector in Europe.

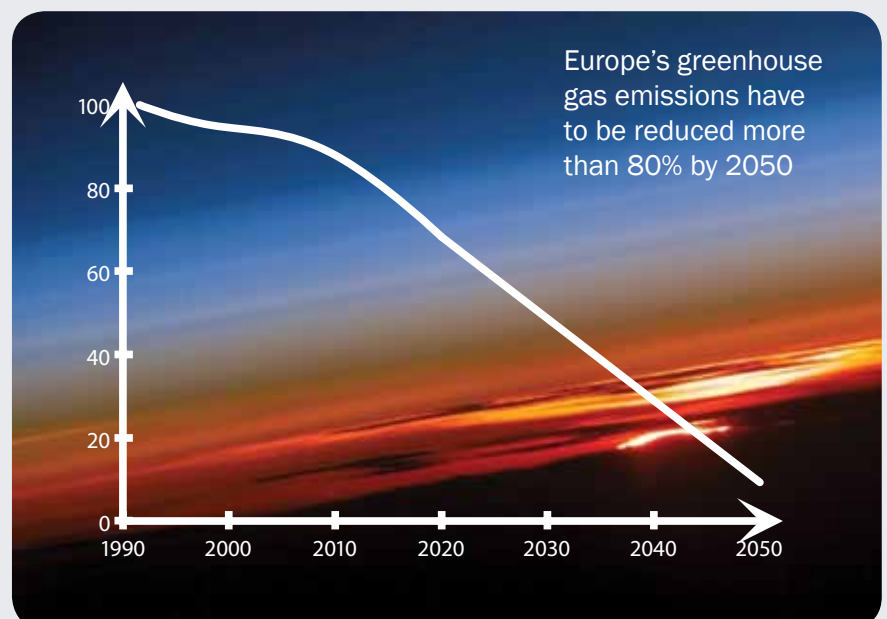
To find out if these scenarios are possible, in the spring of 2010 CAN-Europe asked CE Delft to look at the feasibility of such emissions reductions by 2050 in three of the most important manufacturing sectors in Europe: steel, cement and paper. The prime question was whether or not we currently possess the technologies (at least in the pilot stages) which could, when applied on a large scale, sustain both the assumptions noted above. To have EU-wide application those technologies would need to reach commercial maturity by 2020. CAN-Europe used the results of this research to formulate specific policy recommendations to be implemented within the next decade, as laid out in the last section of this document.

The research of CE Delft has led to some interesting results and insights. To find out whether these scenarios are possible within the three sectors, you need only begin reading.

Matthias Duwe

Director

Climate Action Network Europe



MAIN FINDINGS

The technological potential to take us beyond 80% reductions in important manufacturing sectors exists

In all three sectors examined in this document, CE Delft identified technologies that are able to reduce greenhouse gas emissions by 80% or more. Most of those technologies are in pilot phase or close to being applied in small scale demonstrator projects. According to the best estimates available to CE Delft, most of those technologies will reach market maturity between 2010 and 2030. In the following sections, we look at each of those sectors in more detail.

For the **steel sector**, the public/private partnership under the umbrella of the Ultra Low CO₂ Steel (ULCOS) project is leading to some very promising technological innovations. The most advanced and promising technology is the Hisarna coke free steelmaking process, which will be able to reduce greenhouse gas emissions from steel production by 80% (in combination with Carbon Capture and Storage (CCS) and 20% without CCS) compared to the current reference steel plant. This technology is expected to reach market maturity around 2025. Both the capital investment and operational costs of this type of steel production look promising.

In the **cement sector** there are two technological roadmaps that will lead to dramatic emission reductions. A new advanced cement kiln process in combination with CCS will be able to reduce emissions by 80% compared to a reference (Portland) cement plant. The most exciting development is the use of MagnesiumOxide cement clinker. This new type of cement has the ability to become a net CO₂ absorber or reduce more than 100% after being applied. Both of these technologies will most likely become available commercially available around 2025.

For **pulp and paper production** the most promising technology roadmap relates to the efficient use of byproducts generated in the pulp making process. Black liquor, a biomass-based by-product with a high energetic value, can be turned into a useful synthesis gas (syngas). This gas can be used to deliver the necessary heat to the pulp making process. If the CO₂ emissions of this process are captured and stored the net emissions of the paper sector can be negative. Ideally this has the potential to fully off-set the emissions from the entire European pulp and paper sector. This technology is expected to reach commercial maturity by between 2010 and 2030.

Of course proving the viability of innovative technologies in these sectors is only a first step. To fully reach the necessary emissions reductions and drive a modern and productive manufacturing industry in Europe, **a solid vision and policy roadmap is required**. On both fronts the European Union right now is dropping the ball. The current EU emissions trading system (ETS) will by no means guarantee reaching these goals. Weak 2020 reduction targets, low carbon prices and the lack of political will to recycle auctioning revenues into innovation research, development and deployment (RD+D) of new technologies create the risk of having a high carbon lock-in together with stranded assets in a post 2020 European Economy.


The European Union must develop a climate-proof long term vision of the future of its manufacturing industry. This vision must be backed up with a mix of solid policy instruments which include full carbon pricing, the use of EU ETS auctioning revenues to develop and deploy new technologies and, last but not least, a regulatory framework that phases out all obsolete high carbon production sites between 2020 and 2050.

SUMMARY



“Innovation distinguishes between a leader and a follower.”

Steve Jobs

OVERVIEW	STEEL	CEMENT	PAPER
	Reductions of 80% are possible	Reductions of 100% are possible	Reductions of 100% are possible

Source: CE Delft, Technological Developments in Europe, July 2010.

STEEL SECTOR



Sector profile

Over recent decades, global (crude) steel production has grown rapidly, amounting to 1330 million tonnes in 2008 compared to 790 million tonnes in 1999. Production has especially increased in emerging markets such as China. This country is the largest producer, covering nearly 38% of the market, followed by the EU with a share of 15%. Current turnover in the EU steel sector is approximately € 150 billion. The sector employs 410,000 people, representing 1.25% of the total employment in EU manufacturing.

Trading accounts for about 40% of global steel production. Although such trade mainly takes place within regions, there is also some trade between different regions. Because of differences in the types of steel being produced in different regions globally, the EU in recent years had become a net importer. However, in 2009, because of the economic crisis, the EU27 exported more steel than it imported.

Today the EU is the world's third largest exporter but also its largest importer. China is the biggest supplier followed by Russia and Ukraine. The EU also imports more than 90% of its needs of primary raw materials, which are mainly iron-ore and coking coal. The European steel sector's main customer base is found within its home markets, particularly in the high-end segments. Its main competitive strength is based on high quality products, product innovation and technological development, efficiency and a skilled labour force.

The production of steel is among the most energy- intensive and, consequently, CO₂ emitting sectors. It accounts for an estimated 5.2% of total global greenhouse gas emissions and 21% of total EU industrial CO₂ emissions. About 80-90% of these emissions are related to the blast furnace converter process.

Public/private partnerships generate important results

The steel sector is at an advanced stage of piloting technologies that would lead to dramatically lower CO₂ emissions in steel production. Most of these technologies and pilot plants are originating from the ULCOS (Ultra Low CO₂ steel production) project supported by the European Commission and major steel making companies.

Most of the emissions in steel production are the result of the reduction of iron ore in the blast furnace using cokes. Right now on average the production of one tonne of hot metal in the EU results in 1.65 tonnes of CO₂ emissions. Current best practices come close to 1.4 tonnes of CO₂ per tonne of hot metal produced.

To reduce emissions further there are broadly 3 potential technological directions taken often in combination. They include: designing a new process that is intrinsically more energy efficient and/or carbon-neutral; the use of carbon reducing agents and fuels with a low(er) carbon content; and CO₂ emissions capture and storage.

Blast Furnace top gas recycling

Blast furnace top gas recycling (TGR) is a technology that recycles the energetic

content of blast furnace gas. Top gas recycling has been demonstrated at the LKAB research plant in Sweden. It is an option for new plants and a retrofit option for existing blast furnaces. The final CO₂ emissions can be purified for deep geological storage. This process does not give a net reduction in energy consumption as reduced coke consumption is balanced by an increased electric power requirement for CO₂ separation. Greenhouse gas emissions are reduced if CO₂ is sequestered and can lead to up to a 50% reduction compared to the current EU average specific emissions. The technology is expected to be ready for market deployment by 2020.

The Fastmelt process

The Fastmelt process is a technology that uses a complete redesigned blast furnace in the form of a rotary hearth furnace that is more efficient in reducing iron ore. Direct energy consumption of the process is 10% lower on average as compared with an EU blast furnace. CO₂ emissions are 55% lower when the process is combined with Carbon Capture and Storage (CCS). The technology is capable of processing a wider spectrum of ores (including ores of lower quality) compared to the blast furnace process. It does not require coke as a reducing agent. Both characteristics result in

Technology	Main advantages compared to average EU blast furnace (reference)	Potential drawbacks compared to reference	Technological maturity
Coke-free steelmaking (Hisarna)	<ul style="list-style-type: none"> • 80% CO₂ reduction compared to average blast furnace with CCS, 20% without CCS • Lower investments and operational costs due to broader range of available inputs 	Needs replacement of existing blast furnaces	2010: Pilot phase (NL) 2025: Market deployment
Fastmelt process of direct reduction	<ul style="list-style-type: none"> • 55% CO₂ reduction compared to average blast furnace with CCS, 5% without CCS • Lower operational costs due to broader range of available inputs 	<ul style="list-style-type: none"> • Needs replacement of existing blast furnaces • Higher investment costs 	2010: Market deployment
Top gas recycling with CCS	<ul style="list-style-type: none"> • 50% CO₂ reduction compared to average blast furnace • Expected to be the standard for newly built plants (retrofit option) 	• Higher operational costs	2010: Pilot phase 2020: Market deployment
Electrolysis	<ul style="list-style-type: none"> • Probably no carbon is needed in the production process 		2010: not developed (pre-pilot phase)

significantly lower operational costs. Energy consumption and CO₂ emissions are slightly lower to or comparable with the blast furnace process. Specific investment costs for the Fastmelt process and associated electric arc furnace are significantly higher compared to large integrated and blast furnace based steel plants. The Fastmelt process without CCS is on the verge of market deployment.

Electrolysis

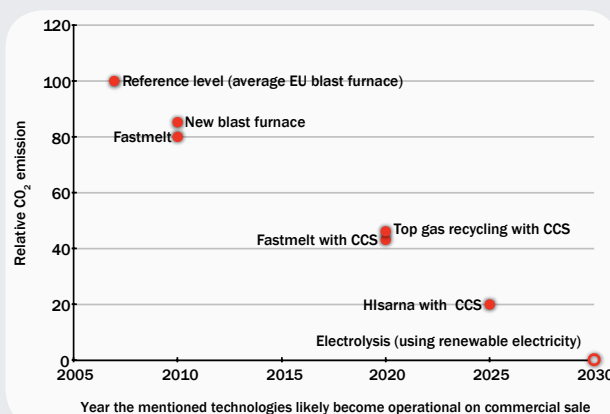
Steel production based on Electrolysis would reduce iron-ore by the addition of electrons to iron supplied by electricity. This theoretically allows for complete carbonneutral steel production (if the applied electricity is produced without generating CO₂ emissions). However, although the principle of the process has been proven, the technology is still in the early stages of development and might require another 20 years of development before the first commercial scale production facility could become operational. There is still a lot of basic research that has to be conducted to get a better understanding of the process. On the other hand, given the possibilities for very significant CO₂ emissions reductions without the need to combine it with CCS, electrolysis would appear to be the preferred technology for enhancing sustainable development in the steel sector. This may be an argument for extra incentives to develop this technology.

Hisarna coke free steelmaking

The Hisarna Coke-free steelmaking technology seems to be the most promising route to low carbon steel making at the moment. In this process there is no need for the production of coke from coal and iron ore sintering. Therefore the process is approximately 20% more energy efficient and produces less greenhouse gas emissions per tonne of hot metal compared to current average blast furnace technology. This technology is being developed and piloted by the ULCOS project. It will first be demonstrated in a 60,000 tonnes/annum pilot installation currently being built at CORUS IJmuiden (the Netherlands) and planned to commence operations in the beginning of 2011. Further development may include a 700 ktonne/annum commercial scale plant, which will be designed in 2015-2016

(based on the experiences with the pilot plant) and constructed between 2017-2018. Full scale market deployment of this technology is expected by 2025. Ultimately, the Hisarna technology will probably be applied on the market at a 500– 1,000 ktonne/annum scale, which complies with the requirements for medium scale and flexible production capacity in the steel sector.

With respect to environmental performance, implementation of Hisarna technology is expected to yield a CO₂ reduction of 20% compared to the average blast furnace in Europe. When combined with CCS, reductions of up to 80% of emissions are expected to be achievable.



Looking at economic aspects, Hisarna will require significantly lower capital investment costs (CAPEX) and will produce semifinished products with the same quality as current breakthrough technology at significantly lower operational costs (OPEX), including reduced energy consumption. Hisarna will be capable of utilising a wider range of (lower quality) inputs.

A potential practical drawback is that the penetration of Hisarna in the EU steel sector might be limited as increases in steel consumption in the EU are marginal and can still be met by increasing the productivity of existing blast furnaces. Furthermore, steel producers tend to overhaul the existing blast furnaces every 15 years or so to increase plant's lifetime. Costs amount to approximately 50% of the investment for a new blast furnace. As a consequence of both mechanisms, under current policy frameworks, the rate of replacement of existing facilities is expected to be slow and determined by existing blast furnaces reaching the end of their lifetime. Without policy

changes, opportunities for new plants will mainly be related to substitution of blast furnaces in existing integrated steel plants where one of the individual plants is at the end of its lifetime and further overhaul possibilities exist. Increasing the pace of replacement will require additional legislation, e.g. tightening the best available technology standard for oxygen steel production after the Hisarna technology has been proven to be commercially mature.

	Current EU average blast furnace	Coke free steel making (Hisarna)
Production capacity (Mtonne pulp/annum)	0.5–5.0	0.5–1.0
Energy consumption	100% (± 17 GJ/tonne HM)	80%
Electricity	100% (= 680 kWh/tonne pulp)	≈125%
CO₂ emission tonne/tonne HM		
• With CCS:	1,650	330 (-80%)
• Without CCS:	1,650	1,320 (-20%)
CAPEX		
• Greenfield	100%	75%
• Brownfield	-	65%
OPEX (incl. energy, excl. depreciation costs)	100%	90%

CEMENT SECTOR



Samples of Magnesium Oxide cement

Sector profile

The global cement market produced 2.55 billion tonnes in 2006 (IEA and WBCSD, 2009). China is the main player, accounting for approximately 50% of world production, followed at some distance by the EU with 10%. In the EU-27 region, total tonnage produced amounted to just over 267.1 million tonnes in 2006 at a value of € 19 billion. Output in 2007 is estimated to have reached 272 million tonnes. This represented approximately 0.5% of total value added and 0.25% of total employment in manufacturing.

Demand for cement is cyclical, depending entirely on building and infrastructure requirements. Employment has been decreasing steadily over recent years. In 2006, it is estimated that there were 56,500 direct jobs (EU-27).

Cement manufacturing in the EU is a highly energy-intensive activity with high process emissions. It emits approximately 180 Mtonnes of CO₂ annually, thereby accounting for 16% of total industrial CO₂ emissions in the EU. It contributes about 3% of the total anthropogenic emissions of energy related CO₂ in the EU and about 5% of the global anthropogenic emissions CO₂.

The prospects for CO₂ neutral Cement production

Industry-wide research into further reduction of CO₂ emissions, in programmes such as the Cement Sustainability Initiative (CSI), focuses on three technology roadmaps: a new combustion process, fuels with lower carbon intensity and the development of Portland clinker substitutes.

Cement as currently supplied to the market is a mixture of Portland clinker mixed with a varying percentage of 'substitutes' such as blast furnace slag or coal-fired power plant fly ash. The percentage of Portland clinker in such mixtures may be as high as 95% or as low as 50%.

The specific emissions for clinker production amount to approximately 840 kg CO₂ eq./tonne clinker. The CO₂ emission consists of 40% energy related emissions and 60% process related emissions, caused by decarbonisation of the consumed lime stone raw material (calcinations). The most efficient clinker production in Europe leads to 780 kg CO₂/tonne clinker.

The main source of emissions in the cement sector is related to clinker production. Therefore, most efforts to realise abatement of CO₂ emissions are related to this part of cement production.

Utilisation of low carbon fuels is already part of current operational practices. In 2006 alternative fuels constituted 18% of fuel consumption

in clinker production across Europe. In Germany, however, alternative fuels made up 55% of total fuel consumption and in some specific kilns alternative fuels make up more than 80% of the fuel mix. Theoretically a kiln could be fired solely with a fuel mixture of biomass and natural gas. The use of low carbon fuels would be beneficial from an environmental perspective. Biomass firing as a CO₂ emission reduction measure only reduces fuel related emissions (40% of total clinker production is related CO₂ emissions). It does not impact raw material emissions. In addition, replacing all fossil fuels by biomass is not a realistic option because the availability of sustainable biomass is expected to be limited.

Oxyfuel technology

The new oxyfuel firing technology uses pure oxygen instead of air for combusting the fuel in a kiln. In order to limit flame temperature increases, the oxygen is diluted with cooled and recirculated flue gases that consist primarily of CO₂ and water vapour. The cleaned CO₂ is compressed to super critical pressure for transportation and storage. The use of oxyfuel combined with CCS is expected to reduce both process and fuel CO₂ emissions. At the moment, there has been no experience with oxyfuel configurations of cement kilns in practice. A pilot plant might be planned in the near future since the option is currently being further developed by the European Cement Research Academy (ECRA). With development into a proven commercial scale technology expected to require

Technology	Main advantages compared to average EU cement kiln (reference)	Potential drawbacks compared to reference	Technological maturity
Magnesium based clinker (Novacem)	<ul style="list-style-type: none"> Over 100% CO₂ reduction compared to average kiln (sink). Avoidance of process emissions, carbonisation of product (no CCS required) Same investment costs as alternative technologies and operational costs similar to average kiln 	There might be some issues with current market standards on product quality	2010: Pilot phase (UK) 2025: Market deployment
Oxyfuel firing with CCS	90% CO ₂ reduction compared to average kiln (almost complete CO ₂ capture)	Higher investment costs than alternatives and higher operational costs than average kiln	2025: Market deployment

at least 10 years, actual market deployment is only likely by about 2025. The exact timeline is, however, uncertain.

Magnesium Oxide based cement

Alternatives for Portland clinker based on inorganic elements other than calcium, silica and aluminium are actively being developed by small companies, such as Novacem in the EU, Calera in the USA and TechEco in Australia. Both Novacem and TechEco are developing magnesium based cements.

Before the widespread use of Portland cement in the 20th century magnesium oxide (MgO) and magnesium chloride based cements were widely used. Examples of structures built with magnesium based cements are The Great Wall of China, stupas in India and timber-frame buildings in Europe. This illustrates the durability of this kind of cement. Novacem is currently developing an MgO based potential breakthrough cement technology. The developments aim to deliver a cement which will have the same physical and economic properties of Portland cement but with a dramatically lower carbon footprint. The production process will use raw materials available on a huge scale.

Magnesium based cements are currently being offered as commercial products in the USA by, for example, The Bindan Company in Chicago and CeraTech.

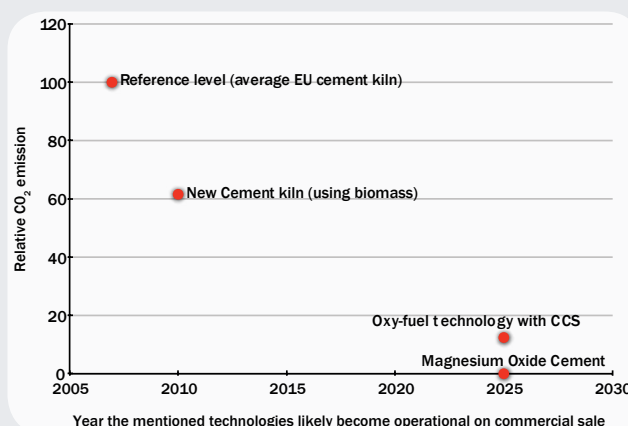
In the production process, conventional Portland clinker is substituted with magnesium based clinker. The product being developed by Novacem contains both magnesium oxide and magnesium carbonates.

Novacem claims that the magnesium based clinker product has the advantage that the final product absorbs more CO₂ than is emitted during the production process, thereby creating a net CO₂ sink. This advantage is mainly due to the use of magnesium silicates whereby no CO₂ emissions are created by the raw material. By contrast for every tonne of ordinary Portland cement produced, 400 kg of CO₂ is released from limestone. The new technology will

leave limestone, with its stored CO₂, in the ground.

The production temperature requirements are just 700°C, so low carbon content fuels can be used more readily.

Substitution of Portland clinker by magnesium based clinker would reduce both process related emissions and fuel related emissions. Cost figures are similar to a new cement kiln based on current technology.



Other potential benefits are that the cement is white, which allows it to be used for premium construction products, and that the cement can be recycled.

On the other hand, the cement still has to demonstrate performance and be accepted by the construction industry in the EU. This acceptance would be aided by a shift from composition-based standards to performance-based standards for cement. The technology is intended firstly to be applied in non-loadbearing prefabricated concrete building parts. After it is proven in these applications its use will be extended to other applications.

In addition to product development, production technology needs to be developed. Novacem is already operating a pilot plant in London. The company has already cooperated on the development of this plant with Laing O'Rourke, one of the largest UK construction companies, Rio Tinto, a global mining company, and large engineering partners. It expects to open a semi-commercial plant in conjunction with industry partners in 2012. The output from this plant will be used to get the first applications to market. The first full-scale production plant is set to follow in 2015. Novacem aims to licence its technology on a nonexclusive basis to ensure widespread adoption.

	Current EU average cement kiln	New EU cement kiln	Magnesium based clinker
Production capacity (Mtonne clinker/ annum)	2.0	2.0	0.5–1.0
Fuel consumption	100% (= 3.7 GJ/tonne clinker)	80%	50%
Electricity consumption	100% (= 110 kWh/tonne clinker)	80%	100–120%
CO₂ emission tonne/tonne clinker	0.88	0.79 (-10% less emission than EU average kiln)	≈-0.05 (a reduction potential of more than 100%: the process becomes a carbon sink)
CAPEX (Greenfield, M€)	Not relevant	260	≈260
OPEX (incl. energy, excl. depreciation costs)	100%	90%	100%

PAPER SECTOR



Sector profile

There is an international market for paper and pulp in which Europe represents a quarter of the world's production and consumption. The EU paper industry produces 99 million tonnes of paper and board and more than 90 million tonnes of pulp per year.

According to the latest structural data available, there were 756 firms employing 243,300 people in the pulp and paper sector in 2008, with turnover reaching € 78 billion.

Today, about half of EU paper production is based on recovered paper, a growth of 25% since 1998. Paper recovery and recycling, linked to increased processing efficiency, have allowed a substantial production increase without the need to use more new wood.

In 2007 the EU pulp and paper sector emitted 31 Mtonnes (Ecofys paper, 2009) to 41 Mtonnes CO₂ (CEPI, 2008), representing 4% of European industrial CO₂ emissions.

CO₂ neutrality is a viable option for the pulp and paper sector

The paper sector seems to have two technology roadmaps which lead to dramatic lower CO₂ emissions. One of them is advanced energy savings techniques and the other one is the downstream energetic valorisation of byproducts of the paper-making process in combination with CCS.

European pulp production is almost equally split between production from recovered fibre, i.e. secondary pulp, and production from wood, i.e. primary pulp. The production of primary pulp is dominated by chemical pulping (30%), with smaller shares produced by mechanical (6%) and thermomechanical (12% of production) pulping.

Almost all mechanical pulp mills and the majority of chemical pulp mills are integrated with paper making. On the other hand, paper and board mills are not necessarily integrated with primary pulp production. CO₂ emissions associated with pulp and paper production are mainly related to natural gas consumption in pulp processing into board and paper. The production of paper and board semimanufactured products requires significant amounts of fuel for the evaporation of the water applied in pulp slurry.

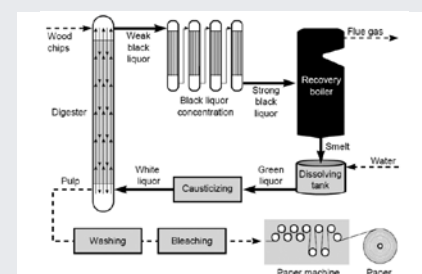
Advanced drying technologies

Advanced drying processes in paper and board semi-manufactured production, which reutilise the heat of vaporisation of the removed water, allow for a significant reduction in fuel consumption. The most notable examples of such technologies are airless drying and superheated steam drying. These technologies have the potential to reduce fuel consumption by 70-90% compared to conventional drying. Other innovative drying

technologies in the wet or dry end of the paper machine realise fuel savings of 10-20% but can be applied only for some types of semimanufactured goods. Though portrayed as a very promising technology in several studies, no recent information about applications in paper production have been found. This probably indicates that development as a paper drying technology has ceased or never been adopted. This suggests little probability that such a breakthrough technology with significantly reduced fuel consumption can be implemented in the paper industry on a largescale within the next one or two decades. On the other hand, both technologies have found ample applications in other sectors, primarily for batch-drying. It warrants further research on why this technology has not been further developed in the paper sector and if certain thresholds for its application could be removed.

Black liquor gasification

The most promising technology has been developed by the Swedish company Chemrec. It has uses a new black liquor gasification process. One commercial scale installation of this technology has been operational for a decade in the New Bern pulp mill.



Flowchart of chemical pulp production

Black liquor is the spent cooking liquor from the Kraft pulp making process. It is a liquid which contains more than half of the energy content of the wood fed into the digester.

Technology	Main advantages compared to average EU production process (reference)	Potential drawbacks compared to reference	Technologic al maturity
Black liquor gasification (Chemrec), with CCS	Over 90% CO ₂ reduction compared to average production	No impact on fossil fuel related CO ₂ emissions in the paper production process.	2015–2020: Market deployment
Paper drying innovations	Would affect the most important source of non-biological CO ₂ emissions in the sector		2010: not developed (pre-pilot phase)

Chemrec is currently demonstrating production of a biofuel via black liquor gasification in a pilot plant at the Smurfit Kappa Pitea Kraft pulp mill in Sweden, the largest Kraft pulp mill in Europe. The pilot plant gasifies 20 tonnes of black liquor per day. A second, large-scale demonstration plant is being built at the Domsjö pulp mill, also in Sweden.

The conversion of black liquor into transport fuels would obviously extract a large part of the fuels required for the pulping process, which might necessitate increased fossil fuel consumption in pulp production. The demonstration does, however, illustrate the possibilities of black liquor gasification and subsequent CO₂ capture. Part of the carbon present in the black liquor is rejected as CO₂ in the gas cleaning. Black liquor gasification offers the opportunity of precombustion CO₂ capture: the capture of all carbon as CO₂ from the produced syngas before it is burned.

At a pulp mill where the black liquor recovery boiler needs rebuilding, the boiler could also be substituted by a gasifier with subsequent gas cleaning reactor for conversion of CO into CO₂ and a CO₂ capture process. The remaining hydrogen-rich gas would be burned in a boiler for the production of the steam required for the pulping process. Electricity could be produced by combusting part of the remaining syngas in a gas turbine with a heat recovery boiler. Both applications of hydrogen rich gas have been proven at oil refineries.

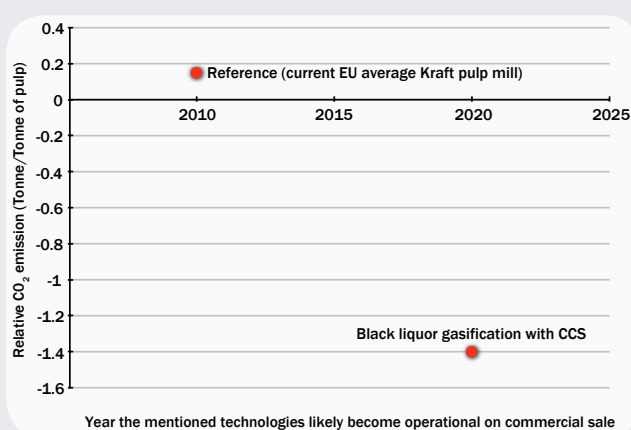
The amount of carbon in the fuel present in the black liquor is comparable to the amount of carbon present in the produced pulp (± 12.6 Mtonnes/year). Capture of 90% (a common capture rate) of the carbon present in the black liquor would mean removal of approximately 40 Mtonnes/year of CO₂, an amount equivalent to emissions from current fossil fuel consumption and decarbonisation of the entire pulp and paper industry. It would indeed be an option that would significantly reduce the CO₂ emissions of the combined pulp and paper industry. This process could change chemical pulp production into a carbon sink by capturing CO₂ from black liquor for geological storage.

As far as technical maturity is concerned, it appears that the black

liquor gasification process itself is the least developed part. Syngas treatment, shift of CO and CO₂ capture from syngas are all technologies applied in numerous industrial processes and oil and coal gasification processes around the world.

Market deployment of black liquor gasification is expected by 2015-2020. The investments costs for this technology are higher than the current average in Europe. This is probably true for operational costs, too.

Investment estimates made for a standardised pulp plant with a production of 2,000 tonnes/day indicate that a black liquor gasifier with a subsequent methanol production unit requires an investment that is approximately twice that of a recovery boiler – €345 million instead of €171 million. The plant would allow capture of approximately 1.2 Mtonne/year of CO₂. Supercritical CO₂ ready for deep geological storage could be captured at a cost in the range of €10-20 per tonne.



Chemrec black liquor gasification plant at New Bern pulp mill

	Current EU average Kraft pulp mill	Kraft pulp mill with black liquor gasification
Production capacity (Mtonne pulp/annum)	0.8	0.8
Steam	100% (= 12 GJ/tonne pulp)	100%
Electricity	100% (= 680 kWh/tonne pulp)	≈125%
CO₂ emission tonne/tonne pulp	0.18	-1.4 (a reduction potential of more than 100%: the production process becomes a carbon sink)
CAPEX black liquor processing M€ (brownfield)	170	± 345
OPEX (depreciation costs excluded)	100%	> 100% To be estimated



CAN-EUROPE POLICY RECOMMENDATIONS

The analysis presented here shows that Europe right now has the technologies available, in pilot stage, to reduce emissions significantly in the steel, cement and paper sectors. However, aside from technological improvements, better use of materials focusing on higher value with lower volumes, can reduce sectoral emissions dramatically as well.

Some of the technologies mentioned in the CE Delft report have the potential to reach reductions beyond 80% compared to current reference processes. This conclusion implies that it is possible to achieve two goals at the same time: a dramatic reduction in greenhouse gas emissions and the safeguard of strong manufacturing and industrial capacity in Europe.

The main question is how innovative technologies can be further developed and deployed with the goal of complete EU wide deployment and substitution of the current production processes by 2050.

A strong and healthy policy mix

Europe's main industrial climate policy flagship, the EU Emissions Trading System, operational since 2005, introduced carbon

Uncertainties associated with Carbon Capture, Transport and Storage

In the report by CE Delft, Carbon Capture and Storage (CCS) is presented as one of the technologies that can lead to deep emission reductions in the concerned sectors. Indeed, in sharp contrast to the power sector, some of the manufacturing sectors do not at this time possess non-CO₂ emitting processes such as wind- and solar generated energy in the power sector. CAN-Europe therefore acknowledges the possible reduction potential of carbon capture and storage in the industrial manufacturing sectors concerned here. However, there are several thresholds and risks that stand in the way of its safe, sustainable and timely deployment.

CE Delft points out two uncertainties and possible disadvantages. First of all there is the lack of solid evidence of the

viability of long-term storage. Secondly, attention must be paid to the possibility that there may be limited storage capacity for CO₂ sequestration.

Other studies point to some of the other risks associated with carbon capture, transport and storage. A recent article identifies main carbon capture obstacles such as impurities in the gas, handling of large volumes of gases, handling toxic chemicals, greater losses in efficiency, and reduced ability to follow load (Hirschhausen et. al., 2010).

The costs of pipeline transport have large uncertainties, mainly due to the unknowns surrounding possible future network, which remains undefined and requires quantification and qualification of storage sites first (Herold et. al., 2010). Also many political and legal risks remain: according

to Boeuf (2003) a range of issues needs to be addressed before a proper structure of public-private partnership can be elaborated. Only a handful of operations for storage are underway (Sleipner Field, Salah). New studies find a strong decline in estimated storage potential (Gerlings et. al, 2010, Holler, 2010). Publications also point to high uncertainties with injection rates and required reservoir volume (Ehlig-Economides, Economides, 2009). Based on this and other literature and the current development rate full scale deployment by 2020 of both capture, transport and storage is disputable, and a 2030 date seems to be a more realistic timeframe.

Because of limited carbon storage space and the alternatives already available in the power sector, CCS should not be considered for the power sector.

pricing into production processes with mixed success. While the EU ETS and its price on CO₂ emissions should be a driving force for emission reductions in the EU, the instrument requires major changes and complementary policies and measures to achieve the dramatic industrial transformation as described above.

- To make the carbon price visible throughout the entire production and consumption chain **all EU ETS allowances must be auctioned**. Furthermore the EU ETS target or cap needs to be adjusted downward to mitigate the current drop in (projected) CO₂ allowance prices (due to the economic down-turn of the last 2 years) and hence the incentive to reduce emissions. Both actions will increase funding to RD&D through higher auctioning revenues.
- To push innovation and deployment to a larger scale, **a portion of the auctioning revenues of the EU ETS should go to an innovation fund dedicated to the further development and deployment of breakthrough technologies**. More than €10 Billion/year could be made available through such a system.
- Most of the installations in the sectors mentioned in this publication have a lifetime of more than 30 years. On the other hand, most of the technologies mentioned by CE Delft will reach commercial maturity between 2020 and 2030. To avoid a high carbon lock in and stranded assets, **complementary regulatory policies such as CO₂ emission performance standards and/or the application**



of Best Available Technologies in environmental permits must be introduced. This action would ensure that new production plants may only be built if they apply innovative low carbon technologies. This policy regime should happen by 2020 at the latest or earlier if one of these innovative technologies reaches commercial maturity sooner. In case of higher investment costs (CAPEX) for new technologies in comparison with high CO₂ alternatives, capital at low interest rates can be provided through the EU ETS innovation fund (see above).

- **After 2020 an expansion of the complementary regulatory provisions must provide for the phase out of high carbon production**

sites and their replacement with low carbon plants. This brownfield conversion must be supported by the above mentioned low interest loans and, if necessary, conversion funding. By 2050 all EU production sites must be converted.

Europe needs a long term and climate proof industrial vision

It is disturbing to see that the European Union right now is lacking a long term and climate proof vision on industrial development. Betting Europe's low carbon future on just one policy instrument such as the EU ETS contains a high risk because there are no guarantees that the carbon market on its own will ensure the development of the necessary breakthrough technologies. The costs, risks and other thresholds related to the development and early deployment of these technologies will not be surmounted by only putting a price on carbon. On the other hand it is encouraging to see that public-private partnerships such as ULCOS in the steel sector are leading to promising innovative technologies.

European Policy makers have less than 10 years to come up with such vision and its full implementation. We hope that this document and its background report show that a low carbon industrial revolution is possible and necessary in Europe.



Other recent publications by CAN-Europe



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