Energy Efficiency/CO_2 Mitigation Case Study Series - Vol. 3: Allied Industries

A techno-economic investigation commissioned by the members of the

Carbon Dioxide Capture and Conversion (CO_2CC) Program

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2 INTRODUCTION:

The scope of this report covers GHG reduction technologies and activities in three key industries: cement, iron and steel and mining

This report highlights that there are many approaches which can be utilized to lower industrial emissions. Methods broadly break down to the following:

(1) Preventing emissions through energy and process efficiency improvements and recycling of waste materials back into the process

(2) carbon capture and utilization (CCU), carbon capture and storage (CCS) and a combination of the these two (CCUS)

The allied industries including cement, iron and steel production, as well as mining are high profile greenhouse gas (GHG) emitters and are under increasing pressure to decarbonise their operations.

- **There are many issues around decarbonization in each sector of the allied industries.**
  - **Cement** is naturally conservative and must prioritise meeting specifications for critical infrastructure over formulation changes. More radical moves e.g. to alternative cement chemistries (outside of Belite-rich systems) will face more of a challenge in terms of acceptance. The industry's preference is to continue with engineering and process improvements such as oxyfuel burners. The direct separation reactor (DSR) is also very rapidly being proven and there are significant industry backers for two European Union consortium projects utilising this type of approach - LEILAC and its successor LEILAC II. The necessity of CCS for the cement sector is becoming clear if carbon penalties and a continued negative public image are to be avoided.
  - In modern **iron and steel** plants, energy in the integrated flowsheet of a steel plant is based on coke oven gas (COG), blast furnace gas (BF gas) and basic oxygen furnace gas (BOF gas). The heat management is optimised through exchange of these gases, and in addition there is the possibility to capture CO2 and to reuse it or capture and store it underground. Lanzatech for instance has been very successful in working with steel companies to implement its Steelanol gas fermentation technology for production of alcohols and aviation fuels.
  - At the heart of decarbonizing the **mining** sector is the production of low-carbon electricity. Reductions in the industry's carbon footprint have thus far largely been realised as a result of the economic and competitive benefits that come with adoption of best available techniques (BAT). Methane abatement has been a relatively low-hanging fruit for the industry and the payback on recovered heat and power has provided good techno-economics, in particular for the more concentrated coal mine methane (CMM) and coal-bed methane (CBM) streams. Ventilation air methane (VAM) which is as dilute as 1% in air have been developed – e.g. Johnson Matthey's COMET™ VAM oxidation technology in conjunction with AngloCoal

DRIVERS:

Each industry's progress and plans for further decarbonization include:

(1) Industry characteristics and landscape

(2) Sources of GHG emissions

(3) Relevant GHG mitigation techniques, including carbon capture and utilization (CCU) and carbon capture and storage (CCS)

(4) In addition, a combination of the these two (CCUS) in these sectors

- **Reduction of GHG Emissions**
  - The 2015 Paris Climate Change agreement set a target of limiting global temperature increases to 1.5 °C with an absolute threshold of 2 °C over pre-industrial levels in order that significant social, environmental and financial consequences can be avoided
  - In the EU, the Emissions Trading System (ETS), sets a cap on emissions from industrial activities including those from heat and power, cement, iron and steel, oil refining and aviation. There is a fourth ETS trading period, set to begin in 2021, at which point carbon allowances will have been reduced and stricter penalties
- **Strategies for Reducing GHG Emissions**
  - There are three ways to tackle GHG emissions – prevent them in the first place, convert them into a non-GHG product, or capture and bury them permanently underground
  - Use of recycled materials also play a major role in lowering carbon intensity as well as providing security of supply – in particular for critical raw materials (CRM)
  - Carbon Capture and Utilization (CCU) and Carbon Capture and Storage (CCS) are brought together under the one umbrella of CCUS. Approaches for utilization include production of building materials, chemicals, plastics and fuels. Utilisation is a key method for monetising carbon capture.
- **Environmental and Economic Impact of GHG Emissions**
  - The body of published science and opinion points to increasing rates and severity of adverse weather events as a result of anthropogenic GHG emissions. The pattern of adverse weather events can be seen from data which looks at the frequency of events which are considered anomalies.
  - The stark difference between global surface temperatures in the late 19th century compared to today are notable. Temperature data has undergone independent analysis by NASA and the US National Oceanic and Atmospheric Administration (NOAA). The data shows that 2019 was the warmest year on record, with temperatures reaching almost 1 °C higher than the 1951 to 1980 mean. Furthermore, every decade since the 1950's has been warmer than the one before

Each of the report's chapters sets out an introduction to the industry and its decarbonisation challenges, then goes on to profile the technologies which can be employed and the progress made to date. This report highlights that there are many approaches which can be utilized to lower industrial emissions

SCOPE OF REPORT: CEMENT

In the cement sector, much has been achieved already for decarbonization.

Table 1 summarises the case studies in the cement sector included in this report. The main difficulty of CCS is cost, as it incurs an energy penalty on the plant – in particular if a more commercialised amine technology is adopted. Membranes come at a lower cost, however there are many technical hurdles to overcome and these are unlikely to have much impact in the short-medium term. Other technologies such as calcium looping, and the aforementioned DSR have more potential

Table 1. Case Studies for Decarbonisation in the Cement Sector

Company/Project	Technology/ Project Name	Decarbonisation Approach
CNBM		Waste heat recovery, energy from waste, low clinker content
Cemex	Climafuel	Waste fuel
Lafarge	Cement2020 Geocycle	Biomass Waste fuel
Siemens	Sciement	Digitalisation
Schneider Electric	Ecostruxure	Digitalisation
LEILAC	Direct Separation Reactor	New calciner with integrated CO_2 separation
Hanson	EcoPlus	Clinker substitution
CarbonCure	CarbonCure	CO_2 curing
Heidelberg	Brevik	Variety of CCS technologies

Monetization of the captured carbon i.e. CCUS may be a possibility for overcoming cost hurdles – and one where industrial emitters are investing significant time and resources. Combinatorial approaches with process, formulations and CCUS are likely to be adopted going forward

SCOPE OF REPORT: IRON & STEEL

The iron and steel sector has many synergies with that of cement in terms of making efficiency improvements

Table 2 summarises the approaches of companies with technologies for decarbonising iron and steel included in the case studies for this report. CCUS approaches are particularly popular and several of the projects in the list are in this category

Table 2. Case Studies for Decarbonisation in the Iron & Steel Sector

Company	Process/ Technology	Improvement
ArcelorMittal	Siderwin	Raw materials – Process using electrowinning of iron ore with renewable energy
ArcelorMittal	Carbon2Value	CCU – Separation of off gases for production of several value-added chemicals
ArcelorMittal	TORERO Biocoal	Raw materials – Use of biomass-derived fuel within blast furnaces
Baowu/Rio Tinto/Tsinghua	Various Innovations	Energy efficiency – Improved technical performance of conventional blast furnaces
LKAB-SSAB-Vattenfall	HYBRIT	Raw materials – Direct reduction of iron using renewable-derived hydrogen
Tata Steel	Combined Heat & Power	Energy efficiency – Recovery of waste heat for generation of low-grade heat and power
Lanzatech	Steelanol	CCU – Use of off gases for production of bioethanol
ULCOS Consortium	HIsarna	Energy efficiency – Modern furnace design that avoids shortcomings of conventional blast furnace
MIDREX	Al-Reyadah Plant	CCS – Direct reduction of iron using fossil-derived hydrogen with downstream storage
STEPWISE Consortium	SEWGS	CCU – Use of off gases toward production of a syngas or hydrogen.

Access to economic sources of decarbonised electricity is a necessity for many of the more environmentally sound iron and steel production methods

SCOPE OF REPORT: MINING

Mining has not had the same level of focus on GHG emissions as have iron and steel, or cement.

The mining industry is so expansive – with over 700 companies globally covering production of fossil fuels as well as ferrous and non-ferrous ores. It has a high electricity burden, emits both CO_2 and the more potent GHG methane.

Table 3. Case Studies for Decarbonisation in the Mining Sector

Company/ Project	Process/ Technology	Improvement
AngloAmerican	Mechanical/Advanced Fragmentation	Improvement to mechanical treatment for higher operations efficiency
Goldfields	PV Solar	Integration of renewable electricity
Rio Tinto	Aluminium Smelter	Direct GHG replacement and integration of renewable energy
JX Nippon	Biomining	Switching from conventional to biomining
Goldcorp's Borden Lake	Electrification	Electrification of plant operations
MEG Energy	SAGD	Increase in material efficiency
Anglocoal	Methane Abatement	CCUS
BHP Billiton	Methane Abatement	CCUS

Production of mined materials is expected to soar, in line with increased use of transportation and electrification. The move to a sustainable society, requires that the mining industry finds a way to provide the necessary critical raw materials (CRM) without shifting the environmental burden into its own backyard

Case Studies: Cement

- The LEILAC project (LEILAC Consortium, 2020) is aiming help the company Calix to commercialize their “Direct Separation Reactor” (DSR), the design of which inherently captures a stream of high purity CO2 (~95 %) by physically isolating the calcination reaction from the combustion processes used for heating
- Overall, the DSR is claimed to be able to capture the majority (~60%) of total CO2 emissions during manufacturing without large additional financial or energetic costs

Case Study 1: LEILAC (1 of 2)

Direct Separation Reactor (DSR)

In essence, it is a large, externally heated tube through which the ground limestone falls, calcining along the way, with the CO2 being produced from the top of the reactor. The residence time is around 20 s. The concept was originally developed in Australia and trialed in a pilot plant / small industrial unit in Bacchus Marsh, VictoriaAn EU project. The LEILAC project (Low Emissions Intensity Lime and Cement) has demonstrated the process at large pilot scale (Hodgson, et al., 2018), and a second project has been approved in the last few months (“Leilac-2 CCS project to begin in April 2020,” 2020) which will demonstrate the process at the scale of 100,000 tons per year, after receiving 16 million euros from the EU’s Horizon 2020 scheme

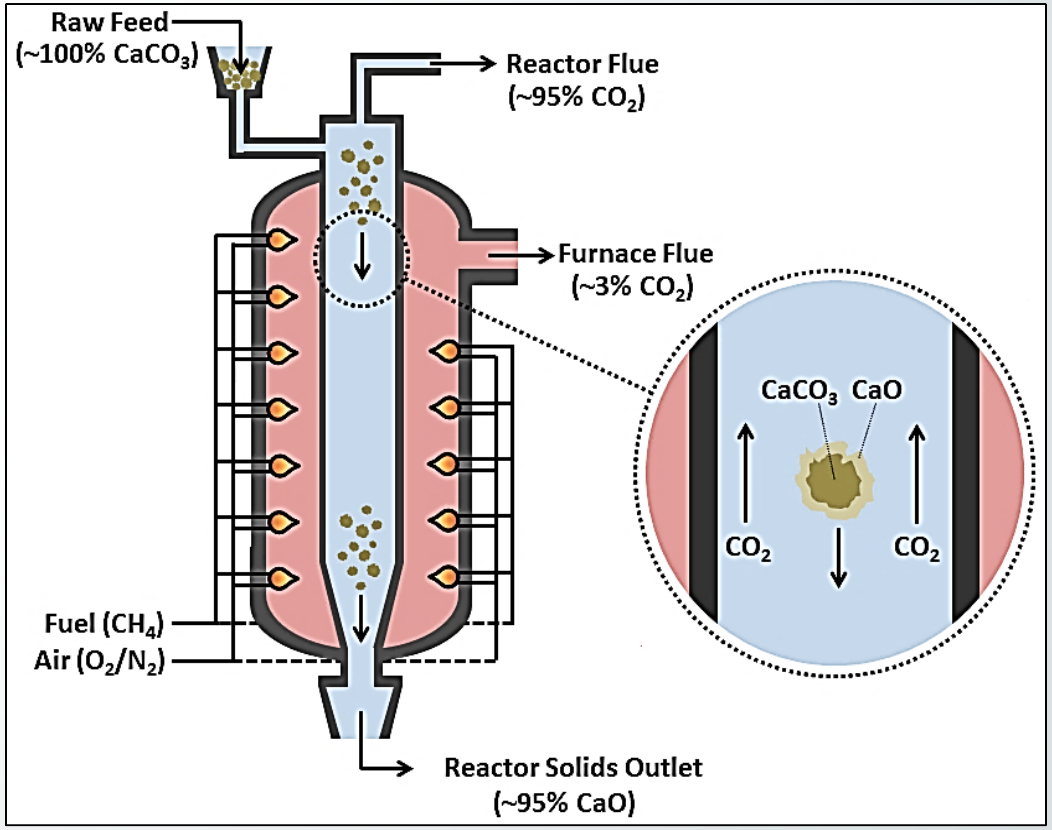


Figure 1: Schematic illustration of the direct separation reactor concept for the direct capture of CO2 evolved during calcination. Configuration shown for a limestone feed (CaCO3) with heating by natural gas (CH4) Source: Adapted from Hodgson et al., 2018

Case Studies: Cement

Case Study 1: LEILAC (2 of 2)

The technology has been successfully demonstrated with a magnesite feed on a commercial plant (Bacchus Marsh, Australia), from which a working model was developed (i.e. heat transfer, mass transfer, reaction kinetics) and validated against plant data

- The project is a collaborative undertaking with €21 million in funding running from 2016 to 2020. As of 2018, a pilot plant (Lixhe, Belgium) was commissioned with raw material feeds of either limestone (~190 t/day) or cement meal (~240 t/day), which targets high overall calcinations (~95%). The high concentrations of CO_2 in the DSR mean the near-equilibrium kinetics are conceivably of particular importance
- There is also scope for the injection of superheated steam within the DSR, which achieves several beneficial effects.
    - Firstly, the addition of superheated steam necessarily reduces the partial pressure of CO_2, thereby shifting the thermodynamic equilibrium toward the forward reaction and accelerating calcination at lower temperatures.
    - Secondly, there is evidence to suggest that the presence of steam intrinsically accelerates the calcination reaction, even when accounting for the accompanying reduction in partial pressure of CO_2
    - Finally, having achieved these advantageous effects within the DSR, steam can be separated from the exiting flue gas with relative ease by conventional processes (e.g. condensation) that also allow heat integration without large financial costs

Otherwise, future iterations of the DSR technology could realize additional reductions in emissions. For instance, coupling the technology with an ASU such that heating occurs by oxyfuel combustion would mean the gases generated in the outer furnace were of similarly high purity (~90 %)
Alternatively, similarly aligned projects have examined the use of concentrated solar power (CSP) as a source of renewable energy, wherein an adjoining solar field concentrates thermal energy for heating directly (i.e. central reactor tower) or indirectly (e.g. heat transfer fluids).
Despite conceivable design constraints (e.g. reactor height, outer reactor surface, solar field size) and process limitations (e.g. intermittent availability, process control), the concept nevertheless has potential if applied to decarbonised production of cement

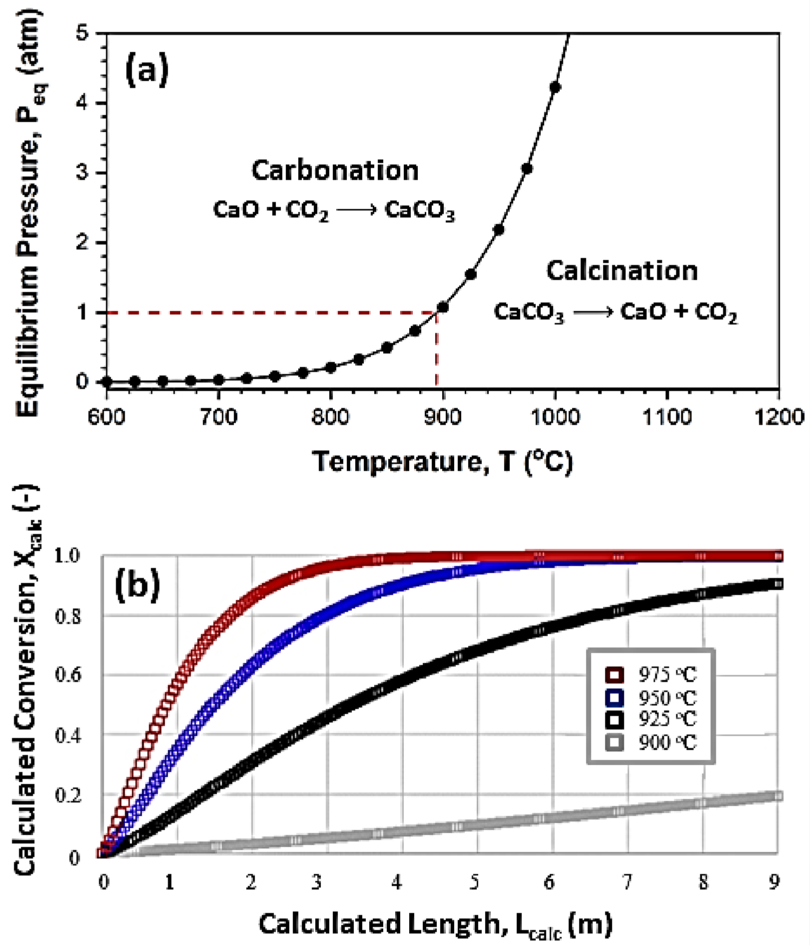


Figure 2: (a) Equilibrium pressure of CO_2 during calcination of $CaCO_3$, and (b) Calculated isothermal conversion of $CaCO_3$ in a DSR-type reactor. Source: Adapted from Valverde et al., 2015 and Lisbona et al., 2020

> **"In the future we could look at electrification, allowing effective use of renewables. As the process can load shed and switch between fuels – very good for the future." (Hodgson, 2020)**

Case Studies: Cement

- CarbonCure Technologies was founded in 2007 in Halifax, Canada.
- The company's key activities are in producing mineral carbonation equipment for sequestering CO_2 in the form of nanosized calcium carbonate particles into otherwise conventionally produced concrete. CO_2 is added to enhance the curing of concrete
- Supplementary Cementitious Materials (SCMs) are not a problem for the process
- Initially the technology was for the pre-cast market (Carboncure, 2017). However, ready-mix concrete technology is now available

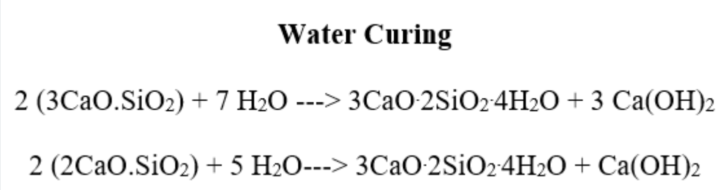
Case Study 2: CarbonCure

Cement Curing Chemistry

In conventional cement curing, calcium silicate phases react with water to form calcium hydroxide and hydrated silicate structures which bind the structure resulting in hardened concrete. Cement can also be cured by a mix of water and CO2 which results in the formation of calcium carbonate rather than calcium hydroxide in the final product.

In the **CarbonCure system**, waste CO_2 is collected from local cement facilities, purified and delivered in bottles by local gas suppliers to concrete producers where it is precisely injected into the concrete mixers during the production stage using CarbonCure's proprietary injection and delivery system. CO_2 is delivered to the equipment as a gas in one stream and separately as a liquid, which phase changes into solid and gas within the mixing zone.

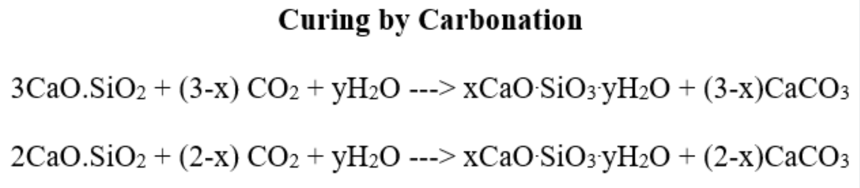
The process is carried out in batches under computer control with feedback from several sensors and actuators situated at various points of the system. The sensors continually measure moisture, temperature, pressure, CO_2, mixing, flow and proximity.



Water Curing

$$2\,(3CaO.SiO_2) + 7\,H_2O \text{ ---> } 3CaO\cdot 2SiO_2\cdot 4H_2O + 3\,Ca(OH)_2$$

$$2\,(2CaO.SiO_2) + 5\,H_2O \text{---> } 3CaO\cdot 2SiO_2\cdot 4H_2O + Ca(OH)_2$$



Curing by Carbonation

$$3CaO.SiO_2 + (3\text{-}x)\,CO_2 + yH_2O \text{ ---> } xCaO\cdot SiO_3\cdot yH_2O + (3\text{-}x)CaCO_3$$

$$2CaO.SiO_2 + (2\text{-}x)\,CO_2 + yH_2O \text{ ---> } xCaO\cdot SiO_3\cdot yH_2O + (2\text{-}x)CaCO_3$$

CarbonCure states that the CO_2 reacts with calcium ions present in the concrete mix to form nanoparticles of calcium carbonate. These accelerate hydration and strengthen the concrete structure by up to 10% for ready mix concrete (as well as reducing cement requirement by 5-8%). A neutral or small positive contribution is seen for masonry concrete when compared to the control.

The CarbonCure website states that there is a reduction of around 15 kg of CO_2 per m^3 of cement (around 47 kg/ton, depending on the exact composition) produced from the use of Carbon Cure technology. The company now claims to have treated "more than 1 million cubic yards" of cement.

Case Studies: Steel

- The Carbon2Value project is an ongoing collaboration being principally led by ArcelorMittal and Dow Benelux as part of the EU's Interreg2Seas programme
- The project began in January 2017 and has received around €10.4 million in direct funding for research to be conducted until January 2021
- The synthesis principally occurs by hydrogenation reactions; however the formation of water also results in the occurrence of the backward reverse water-gas shift (RWGS) reaction
- Due to the different compositions of the various off gas streams, there are proposed to be two general scenarios for operation, where one utilises a mixture of both COG and BFOG/BOFOG streams (Scenario 1), and the other solely utilises BFOG/BOFOG with additional enrichment of H2 (Scenario 2)

Case Study 3: ArcelorMittal – Carbon2Value

The aims of the project generally include to reduce emissions by 30-45% across the steel industry, to be achieved by initial separation of the CO/CO2 content within off gases, then allowing their conversion by CCU into valuable chemical products. The two candidate valued-added routes primarily studied by Carbon2Value include fermentation to ethanol (i.e. a drop-in transportation fuel) and Fischer-Tropsch synthesis of naphtha (i.e. an existing chemical building block)

Industrial Application

As of March 2019, a CO/CO_2 separation pilot line was commissioned (Ghent, Belgium), where separation is fundamentally based on pressure-swing adsorption (PSA). ArcelorMittal is similarly engaged with **IFPen** in the construction of a €20 million pilot plant (Dunkirk, France) designed to utilise low temperature waste heat for the capture of CO_2 at a rate of 0.5 t CO_2 per hour with DMX solvent

- The Carbon2Chem project has principally focused on the production of methanol using a ternary Cu/ZnO/Al2O3 catalyst, with a pilot plant (Duisberg, Germany) having since commenced operation in late 2018

Analogous projects include the Carbon2Chem project principally managed by **Thyssenkrupp**, which are funded with €60 million through FONA/BMBF to conduct research initially between March 2016 to May 2020. The project claims to be able to reduce net CO2 emissions by around 20-50%

Challenges to Overcome

There are justifiable concerns about the technical feasibility and economic competitiveness of such CCU processes.

- For instance, the presence of contaminant species in the off gases from steel mills (e.g. SOx, NOx) which are known catalyst poisons warrants concern about the overall performance of these processes under actual plant conditions
- The cost(s) of replacing deactivated catalyst and/or removing contaminant gases will need to be considered on top of the existing cost for separation of CO_2.
  - Overall, this drives up the production cost of the chemical product and necessitates the introduction of carbon tariffs to allow competition in the market against conventional fossil-derived products

Techno-economic analyses examining methanol synthesis from COG/BFOG report production costs between \$0.29-0.57/kg, averaging somewhat higher than the market price (between \$0.29-0.31/kg in April 2020)

Case Studies: Steel

- Another project within the EU’s Horizon 2020 programme is the ‘STEPWISE’ project, which was run between May 2015 and April 2019 by the Energy Research Centre (Petten, Netherlands) with a total budget of €13 million

Case Study 4: STEPWISE – Hydrogen and CCUS

The project successfully commissioned and operated a pilot plant (Luleå, Sweden) adjacent to nearby steel facilities operated by SSAB, with the overall process reported to offer significant reductions in carbon intensity (by 85%), energy consumption (by 60%) and avoidance cost (by 25%)

The process is founded on the water-gas shift (WGS) reaction (Equation 3.14), wherein CO from steel off gases (i.e. BFOG) is reacted with H2O to effect the formation of H2 and CO2. However, the true novelty of STEPWISE is based on subsequent processing by sorption enhanced water-gas shift (SEWGS), wherein further reactions occur in the presence of a potassium-promoted hydrotalcite (K-HTC) adsorbent

$$CO + H_2O \leftrightarrow CO_2 + H_2 \qquad \Delta H_{R^\circ} = -41\ \text{kJ/mol} \qquad 3.14$$

$$CO_2 + \text{K-HTC} \leftrightarrow CO_2 \cdots \text{K-HTC} \qquad 3.15$$

$$H_2O + \text{K-HTC} \leftrightarrow H_2O \cdots \text{K-HTC} \qquad 3.16$$

At moderately high temperatures (300-500 °C) and pressures (10-40 bar), the K-HTC adsorbent selectively removes CO2 from the gas phase, offering several additional advantages compared to conventional WGS

Firstly, the removal of CO2 from the gas phase shifts the chemical equilibrium toward further product formation, producing a stream with high calorific value (i.e. H2, CO) whilst ensuring higher conversion of the BFOG (van Dijk, et al., 2018). **Secondly**, after removal of this product stream by injection of steam, the CO2 adsorbed onto the K-HTC can be separately desorbed to produce a flue stream with high CO2 concentration suitable for downstream CCUS

The use of nine columns working in an eleven-step cycle allows semi-continuous operation. Although such a design will inevitably invoke higher equipment costs (i.e. increased CAPEX), it also achieves higher efficiency and minimises pressurisation costs (i.e. decreased OPEX).

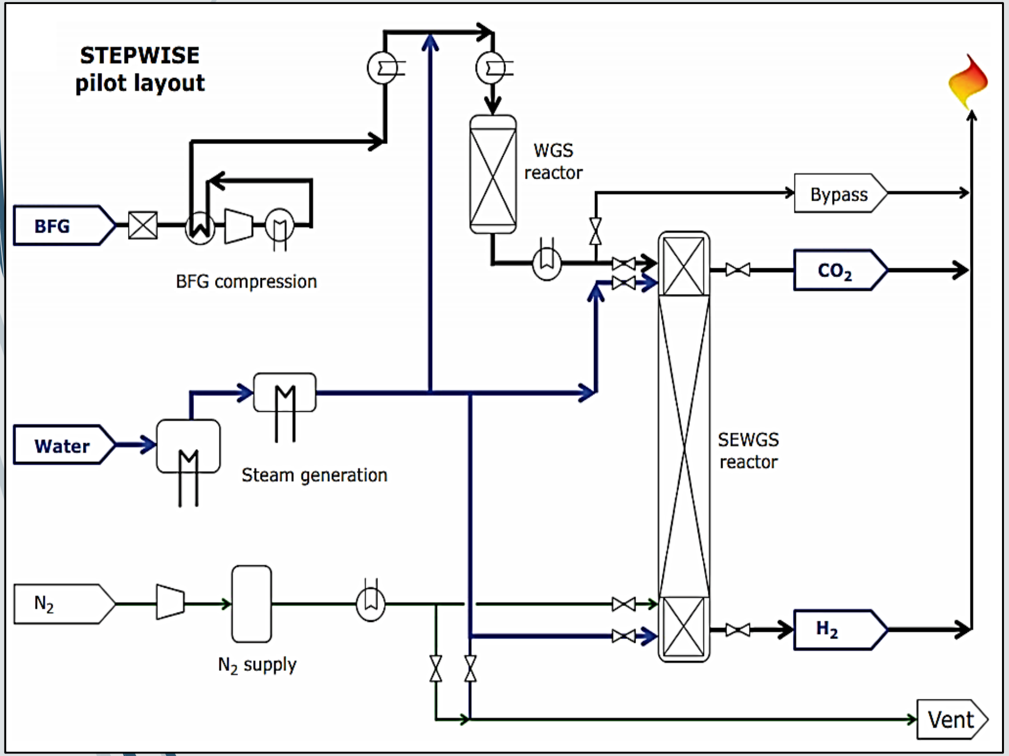


Figure 3: Schematic overview of the sorbent enhanced water gas shift (SEWGS) technology developed to utilise blast furnace off gases (BFOG) from the steel industry as part of the STEPWISE project . Source: van Dijk et al., 2018

Case Studies: Mining

- Rio Tinto is one of the world's largest metal and mining corporations
- The aluminium industry accounts for as much as 1 % of global GHG emissions
- Processing alumina into aluminium is a highly energy and carbon-intensive process, especially at smelters that source power from coal
- Rio Tinto developed a more efficient aluminium smelter that lowered its costs and emissions while improving productivity by 40%

Case Study 5: Rio Tinto Aluminum Smelter

- Rio Tinto and Alcoa announced the world's first carbon-free aluminium smelting process
- The larger scale development and commercialisation of the new process will be advanced from ELYSIS, a joint venture company formed by Alcoa and Rio Tinto
- A technology package is planned for sale beginning in 2024. The new process produces oxygen and replaces all direct GHG emissions from the traditional aluminium smelting process. When fully developed it will strengthen the closely integrated Canada-United States aluminium and manufacturing industry.
- In Canada, if fully implemented at existing aluminium smelters in the country, the technology could eliminate the equivalent of 6.5 million metric ton of GHG emissions. That represents an amount roughly equal to taking nearly 1.8 million light-duty vehicles off the road
- In the short-term Rio Tinto also ensures aluminium smelters are powered from renewable energy - Rio Tinto's wholly owned hydro power facility. Rio Tinto is now offering independently certified, responsibly produced aluminium from its smelters in Australia and New Zealand that predominantly use hydro-powered electricity.
- Canada and Quebec are also each investing $60 million (CAD) in ELYSIS and Apple is providing an investment of $13 million (CAD).
  - The company helped facilitate the collaboration between Alcoa and Rio Tinto on the carbon-free smelting process, and Apple has agreed to provide technical support to the JV partners.

Economics (costs) remain a driver in the decision to include renewable energy projects into mine development, and for energy efficiency projects to appeal to the mining industry, the total financial benefit need to be monetised.

Case Studies: Mining

- BHP Billiton’s climate change strategy is focused on reducing operational GHG emissions (including methane), investing in low emissions technologies, managing climate-related risk and working with others to enhance global policy response
- In 2019, BHP Billiton announced a five-year, $400 Million investment programme to develop technologies to reduce emissions from their operations both upstream and downstream
- Fugitive methane emissions from BHP petroleum and coal assets make up 15- 18% of operational GHG emissions and are among the most technically and economically challenging to reduce
- VOCSIDIZER™ technology is made part of a steam boiler, which combined with a conventional steam turbine–generator system becomes like a conventional power plant but able to operate on less than 1% methane as fuel

Case Study 6: BHP Billiton – Methane Abatement

The world’s first commercial scale Ventilation Air Methane (VAM) project was launched by BHP and began operation in April 2007. The location is in its West Cliff Colliery in the Illawarra region of New South Wales – BHP Billiton Illawarra Coal

The West Cliff VAM Project or WestVAMP utilises 20% of West Cliff’s available mine ventilation air to achieve a reduction in GHG emissions of 200,000 tons CO2-e per year. In addition to cutting methane emissions, the project generates 6 MW of electricity from the steam turbine which will be a source of energy to be used within the West Cliff Colliery.

WestVAMP is based on VOCSIDIZER™ technology developed by Swedish emission control specialist MEGTEC System AB. The VOCSIDIZER™ technology coverts low concentration methane to carbon dioxide (CO2) and water vapour though an oxidation process.

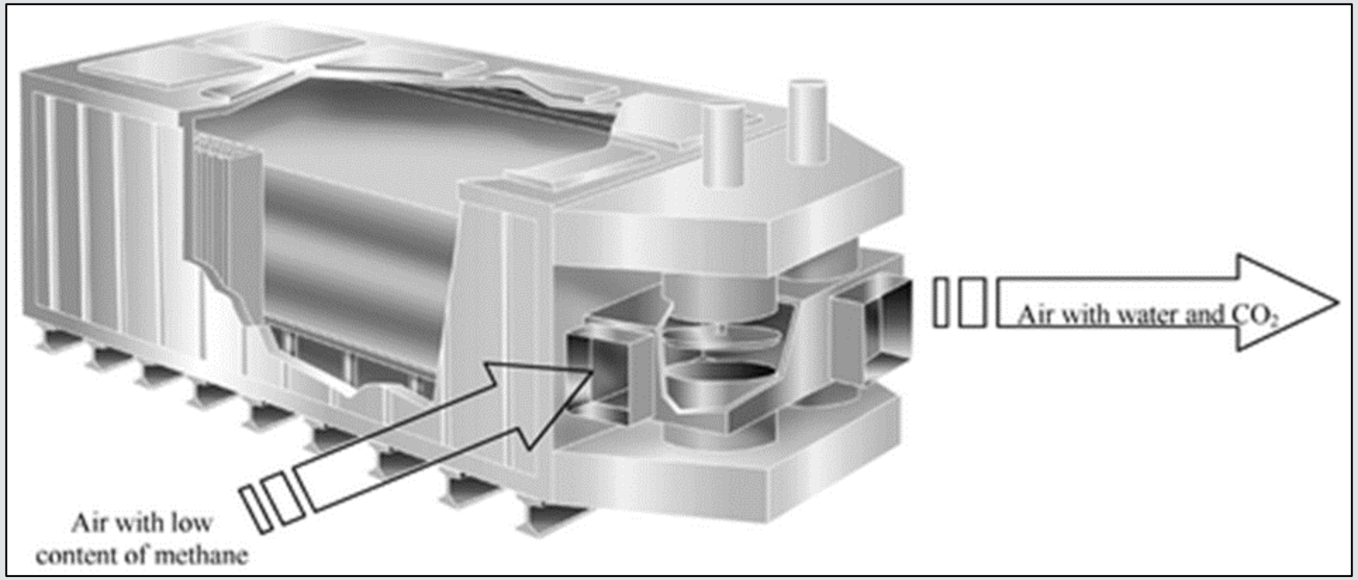


Figure 4: Illustration of the VOCSIDIZER™ technology. Source: Mattus, 2007

VOCSIDIZER™ technology consists of a well-insulated steel container, with a bed of ceramic material inside. There are two air plenums: on top and below the ceramic bed. Electrical coils heat the centre of the ceramic bed to 1000°C to start the system. The electrical coils are then turned off, before starting a fan to blow the coal mine ventilation air vertically through the ceramic bed. As the coal mine ventilation air passes through the bed, the air increases in temperature until the methane in the air is oxidized.

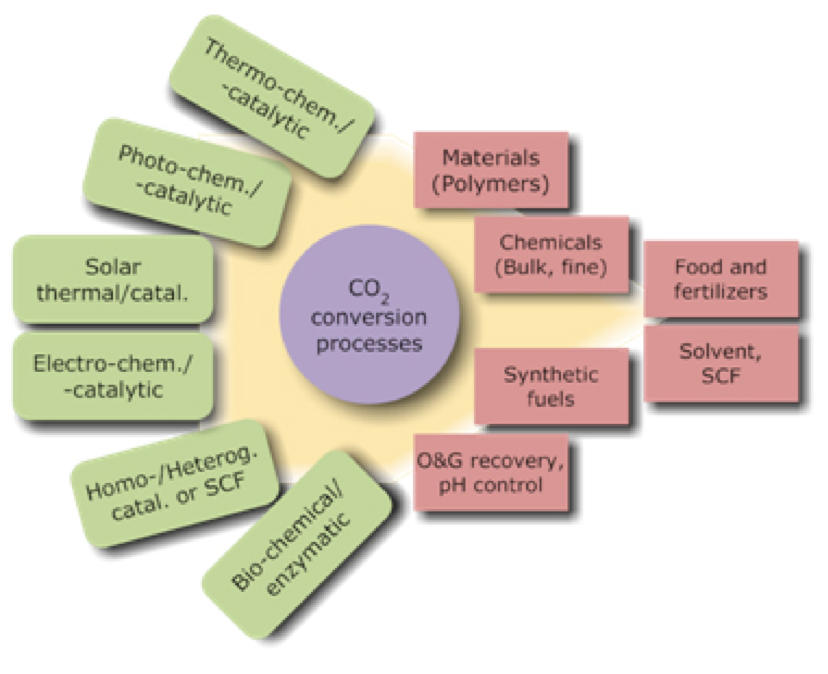
Outlook

There are many challenges to consider when it comes to the possible technology changes in the Allied Industries:

- ✓ In some ways (formulations, application of CCS), the industry is conservative, but in others (waste fuel burning, digitalization, heat recovery), the industry is quite rapidly developing. To reduce the emissions to near zero, it will be necessary to use CCS, likely in combination with the combustion of biomass; this will necessitate a significant increase in cost for cement.
- ✓ Cost is also very important in a commodity product that can be traded globally, and a key issue is in common for low-carbon cement and low-carbon steel is to ensure that any competitors in a market facing penalties for CO_2 emission are protected from competition from materials with high embedded CO_2 emissions.
- ✓ Proposals to end free allocations to **cement** companies and to establish "border tax adjustments" which would mean that European importers of clinker and cement would have had to purchase carbon allowances were ultimately rejected by the European Parliament.
- ✓ Although an important milestone for **the iron and steel sector**, the financial costs of mature capture technologies (i.e. amine scrubbing) are currently very high. Further development is required to improve the technoeconomic performance of capture processes and thereby the economic viability of CCS. Likewise, utilisation of off gases produced within the steel industry toward valuable chemical products is similarly economically challenged.
- ✓ There is strong motivation to decarbonise the **steel industry** with a wide variety of emergent technologies currently in development. However, none of these technologies currently offers a definitive solution for complete decarbonisation of the steel industry.
- ✓ Decarbonisation of the **mining sector** would trickle down to other industrial sectors since mining is the supply foundation of the entirety of industrial production. The mining sector stands at the start of most value chains, making the sector a critical supplier of essential products and raw materials
- ✓ The pace and scale of renewable energy deployment in **the mining sector** is slower than the business case requires. Causes include: (1) Lack of clear strategic plans to integrate renewable energy, (2) third parties not used to develop, fund and deliver renewable energy assets, (3) Renewables seen as "non-core," with significant opportunity cost

The allied industries including cement, iron and steel production, as well as mining are high profile greenhouse gas (GHG) emitters and are under increasing pressure to decarbonise their operations

Carbon Dioxide Capture and Conversion (CO_2CC) Program



The **Carbon Dioxide Capture and Conversion (CO_2CC) Program** is a membership-directed consortium, launched in January 2010, whose members are involved in developing, monitoring and utilizing the "state-of-the-art" in technological progress and commercial implementation of carbon dioxide capture and conversion.

The program's objective is to document and assess technically and commercially viable options for the capture/clean-up/utilization of CO_2 and its mitigation via energy efficiency gains which meaningfully address the challenges posed by CO_2 life-cycle and overall sustainability issues. Included in the program's scope are:

- Global decarbonization efforts towards net zero or negative carbon emissions
- Industrial process technology shifts towards renewable, circular and sustainable practices
- CO_2 capture and/or separation
- CO_2 concentration, purification and/or other post-treatment
- CO_2 utilization/conversion (e.g., CO_2 as a feedstock) for use as a fuel or intermediate, including enhanced oil recovery (EOR)
- Energy requirements (and other costs), including energy efficiency
- Industrial process improvements and energy saving initiatives which mitigate CO_2 production
- Bottom-line financial (income) impacts resulting from CO_2 reduction programs
- Life-cycle considerations and sustainability of CO_2 applications
- GHG/CO_2 regulation and "cap and trade" developments

By the direction of the member companies (through balloting and other interactive means) and operated by TCGR, the program delivers weekly monitoring communications via email (**CO_2CC Communiqués**), three techno-economic reports (highly referenced and peer reviewed) and scheduled meetings of members (either in-person or via webinar). **Access to deliverables is exclusive to members.**

In addition to the program deliverables, TCGR works with members to identify and foster competitive advantage and opportunity. This value-added relationship, along with active participation by the membership, leads to improved (or unique) external R&D and commercial investment possibilities.

Contact & More Information

More information about this and other services of the **CO_2CC Program** can be seen at http://www.catalystgrp.com/php/tcgr_co2cc.php.

Call +1-215-628-4447 or e-mail John Murphy, President jmurphy@catalystgrp.com, and we'll be happy to discuss these and other interesting membership benefits.

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The Catalyst Group Resources (TCGR), a member of The Catalyst Group Inc., is dedicated to monitoring and analyzing technical and commercial developments in catalysis as they apply to the global refining, petrochemical, fine/specialty chemical, pharmaceutical, polymer/elastomer and environmental industries.

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