CO_2 INNOVATION IN THE LIME SECTOR 3.0

The European Lime Association | Edition 2022

EuLA

Innovation that delivers on sustainability

1. Executive summary

The European Union is leading the vision and the global race for climate neutrality to 2050. The best tool to cope with climate change mitigation challenges and enhance European industry's competitiveness it is the innovation at sector or cross sectoral level.

Lime and limestone are basic enabling compounds which are necessary to many other industrial value chains, such as air pollution control, purifying drinking water, wastewater, support sustainable agriculture, enable the production of low-weight steel for lighter cars between others. Without these base materials, many involved applications would simply not function in the same way. When you first consider the simplicity of the chemistry involved, innovation might not be the most likely word you would associate with this sector. However, the intention of this report is to demonstrate how the sector manages to pursue innovation in many areas, from fuel consumption to process and resource optimization, application development, mining, and production technology, to really have a sustainable innovation pipeline.

The European Lime industry (EuLA) in its effort to demonstrate its contribution and achievements in innovation, has updated its innovation report with publicly available information on projects dedicated to innovation in energy efficiency and CO_2 mitigation for a long time. During the least years, several research and development initiatives were launched specifically focusing on circular CO_2 innovative solutions. This report, outlines some of the work that the member companies have already engage in the past to help our journey toward these policy /industry goals. These projects illustrate the company efforts to reduce CO_2 process related emissions through carbon capture and use, improve energy efficiency, lower environmental impact during the use phase and at the same time improve the performance of lime products during the use in multiple applications. This is in areas where the quickly increasing cost of CO_2 as part of the ETS scheme, is bringing more visibility to the importance of this topic. Despite ongoing innovation initiatives which are reflected in this report improving energy & resource efficiency in the production lime industry has started to pursue & develop opportunities to reduce the carbon footprint in the production. We have proven that over the life cycle of our products in the different applications already in average 33% of our CO_2 process emissions are captured in about one year time via the natural carbonation. This fact is not accounted in our carbon footprint, yet.

It is impressive how member companies have embraced this initiative, and looking at some projects where no single member company could undertake the work alone, and to work together for the benefit of the sector. EuLA has started to develop solutions to capture already released CO_2 from the atmosphere to address the fight against global warming by and acidification of oceans, rivers & lakes. EuLA has in the last years set out on a path towards looking at opportunities where the sector can work in a more collaborative way in terms of innovation.

If we go back to the objectives of the previous reports, we were very much looking to demonstrate that the lime industry does innovate not only in how the industry engages in production but also in how the products are used down the value chain. Today with this update we are showing that innovation is truly part of the day-to-day life of the industry, and that we are constantly looking at ways to improve lime operations and enable innovative solutions to industries that rely on lime. The European Lime industry is committed to reduce the carbon emissions and deliver climate solutions through the specific properties of our products. EuLA Innovation report, it is a sectoral response to Green Deal and illustrates the conviction that lime is an indispensable product that can contribute to EU and global climate challenges.

Dr **Burkhard Naffin**
EuLA president

Damien Grégoire
EuLA Technical Environment
Committee Chairman

2. Lime Industry Sector

What is lime and its uses

Lime is a mineral product derived from limestone by an industrial process. Naturally occurring limestone is composed almost exclusively of calcium carbonate.

The lime production process is based on a chemical reaction induced by heating calcium carbonate ($CaCO_3$) to produce quicklime (CaO). Inevitably, this reaction also produces CO_2. These emissions of CO_2, which are inherent to the lime production process, are called process emissions. These process emissions alone constitute 70% of the total CO_2 emissions from the lime production process, and they cannot be avoided.

Lime industry is committed to reducing combustion and indirect CO_2 emissions, however the only possibility lies with the deployment of reliable and competitive carbon capture technologies, knowing that modern lime kilns are already highly energy efficient (close to the efficiency limit).

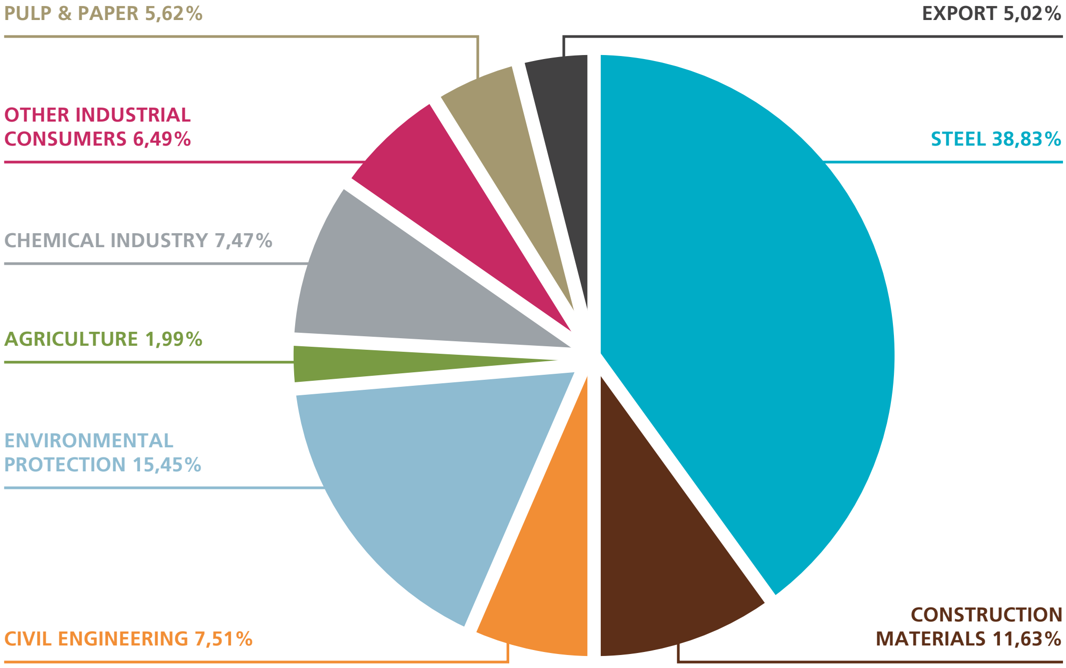
The Innovation in the lime sector is achieved through:

- Sustainable production.
- Responsible resources management.
- Delivering quality added valued products.
- Creating value and support local economies
- Enabling the recycling of end of cycle materials in steel, glass and construction industry.
- Valorizing residues and turning them into raw materials for new processes, such as turning sulfur into gypsum for the plaster board industry.

The lime industry has a long tradition in Europe. Lime is produced in industrial kilns all over Europe and is a fundamental, integral part of Europe's industrial base. As lime often goes unseen, its importance and versatility are largely unknown.

Due to its particular chemical characteristics, lime is a fundamental raw material used in a large number of industries and different economic activities, and is therefore essential to many aspects of many people's lives. As an essential and enabling material, the use of lime for multiple sectors for the year 2018 is shown on page 8.

OVERVIEW OF LIME CUSTOMER MARKETS (SALES BY SECTORS 2018) [1]



REFERENCES:
[1] EuLA Database 2019. Exports meaning the total quantity of burnt product sold to a market outside of the EU28 or EFTA countries.

Did you know that...

...EACH EU CITIZEN USES AROUND 150GR OF LIME PER DAY?

A key enabling material for many industries (in e.g. steel, aluminum, paper, glass) **no high- grade steel without lime!**

A key product for environmental applications (in e.g. Flue gas cleaning, waste water treatment) **lime is the most economic material able to absorb many pollutants!**

A corner stone for **agriculture** (calcium for soil and crop improvement) as well as for animal food.

A multifunctional binder for construction (plasters & mortars) and public works (asphalt pavement and soil stabilization) **Lime is an efficient component for the road constructions and building isolation of tomorrow.**

An **essential mineral product,** but often unseen (in e.g. toothpaste, sugar, ceramics).

...LIME IS A SPONGE FOR CO_2?

In applications such as mortars and soil stabilization, lime functions as a carbon sink and absorbs up to 80% of the carbon emitted during its production process. In Precipitated Calcium Carbonate (PCC) for paper production, 100% of process CO_2 is re-absorbed.

...LIME IS THE MATERIAL HELPING TO PROTECT OUR ENVIRONMENT?

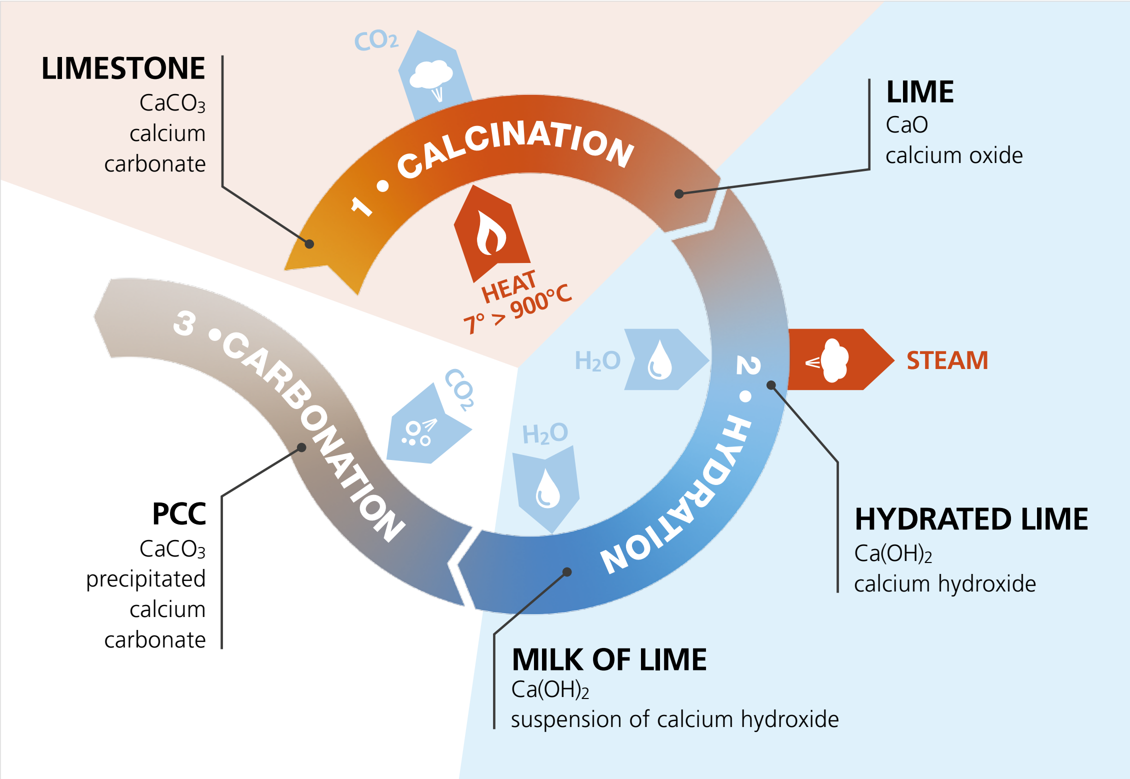
Environmental applications have been the main driver for new lime applications in recent. Acid rain causes lakes and streams to become acidic and can damage trees. Lime is used to treat industrial waste gases to remove acidic gases to reduce acid rain and so protect our forests.

...68% OF LIME IS RECYCLABLE?

Lime is used as an input in a wide range of applications and end-products. Most of those are recyclable. The recycling rate of lime in steel applications for instance, is estimated to be around 95%, in civil engineering works (concrete, bricks, lime mortars and soil stabilization) the recycling rate of lime is estimated to be around 65%. Lime can also help to add value to some by-product and wastes. For example, the use of lime in flue gas treatment allows to create gypsum, which is reused in construction markets such as plasterboards. The treatment of sludge with lime allows to recycle some wastes into bio-solids which are re-used in agriculture.

is the only mineral product that can be used to produce steel and sugar in the same day

CYCLE OF LIME



Innovation in lime sector

The lime sector is innovative and this can also be seen in the number of applications submitted by lime companies at the **European Patent Office (EPO)** and **World Intellectual Property Organisation (WIPO)** for the use of lime in multiple markets. Notably product innovation is taking place, as the sector provides highly standardized products to mature markets. Patents emerging from the industry itself target own manufacturing processes, product innovation and/or customization as well as innovation in lime use.

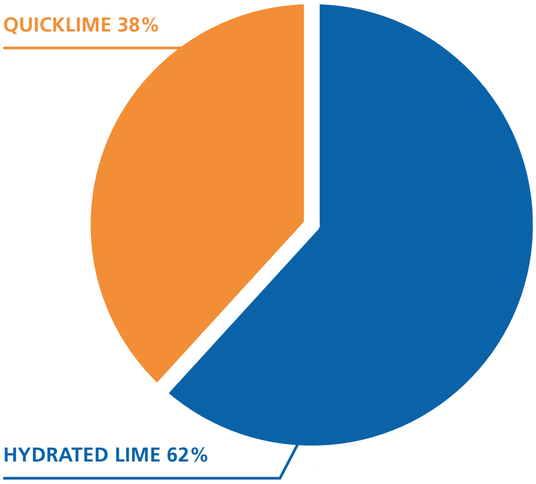
A comprehensive list of patents requested or granted inside and outside our industry is by far larger A query launched at WIPO searching for "**Hydrated lime**" while excluding "**Quicklime**" returns some **1300 patents** from WIPO and EPO over **the last 20 years**. Similarly, a query searching for "Quicklime" while excluding "Hydrated lime" returns an additional **800 patents**. Important to stress is the fact that fundamental and applied Research & Development (R&D) is clearly developed at large scale by the large companies accounting for 67% of the total patents. The SMEs, use the patent or innovate on small scale.

Concerning products, the most significant innovation are "High Surface Hydrates" which feature an active reaction face of > 35 m^2/g. Adding activated carbon and/or other ingredients can further customize these hydrates. They are applied to various flue gas streams in industry to effectively capture pollutants like HCl; Dioxins; Furans; Heavy Metals. Customized hydrates are considered BAT in several BREFs.

Other than in the EU, Lime is increasingly added to asphalt mixtures in the USA where Lime is known to enhance the durability of asphalt pavements. The field experience from North American State agencies estimate that hydrated lime – at the usual rate of 1-1,5% in the mixture (based on dry aggregate) – gives rise to the durability of asphalt pavements by 2 to 10 years. Neither US Life Cycle Cost Assessments in Hot Mixed Asphalt nor research published "Improvement of Quality of Asphalt by Addition of hydrated Lime – Experiments on a practical Scale" (Germany, AiF-Nr. 12542) are sufficiently acknowledged by public responsible officers across Europe.

REFERENCES:
[2] Hicks R.G., Scholz T.V., 2003. Life Cycle Costs For Lime In Hot Mix Asphalt. Volume I – Summary Report. lime.org/documents/publications/free_downloads/lcca_vol1.pdf.
[3] Schneider M., Schellenberg K., Ritter H.-J., Schiffner H.-M., 2002. Verbesserung von Asphalteigenschaften durch Zugabe von Kalkhydrat – Praxisversuch / Mischtechnik. In German. fg-kalk-moertel.de/files/2_2002_AiF_Projekt_12542.pdf.

PATENT APPLICATION FOR LIME PRODUCTS



Definitions

Anaerobic Digester (AD): is a process where micro-organisms break down some organic biomass in anaerobic conditions to produce biogas, $CH_4 + CO_2$.

Best Available Techniques (BAT): are drawn up for defined activities and describe, in particular, applied techniques, present emissions and consumption levels, considered for the determination of best available techniques as well as BAT conclusions and any emerging techniques, giving special consideration to the criteria listed in Annex III of 2010/75/EU Directive [4].

Biomass: refers to any source of organic carbon that is renewed rapidly as part of the carbon cycle.is derived from plant materials but can also include animal materials. **1st generation biomass/biofuels**: first generation biofuels are made from the sugars and vegetable oils found in arable crops, which can be easily extracted using conventional technology. **2nd generation biomass/biofuels**: known as advanced biofuels, are fuels that can be manufactured from various types of biomass. Second generation biofuels are made from lignocellulosic biomass or woody crops, agricultural residues or waste, which makes it harder to extract the required fuel.

Carbon Dioxide Storage Mineralisation (CSM): an alternative to conventional geologic storage is carbon mineralization, where CO_2 is reacted with metal cations to form carbonate minerals. **Ex situ CSM**: the carbonation reaction occurs above ground, within a separate reactor or industrial process. **In-situ CSM**: in situ mineralization, or mineral trapping, is a component of underground geologic sequestration, in which a portion of the injected CO_2 reacts with alkaline rock present in the target formation to form solid carbonate species.

Definitions

Carbonate looping: in the Carbonate Looping Process lime (CaO) reacts with CO_2 from the flue gas in a fluidized bed reactor (Carbonator) producing limestone ($CaCO_3$). CO_2-free flue gas is released into the environment. In the second reactor (Calciner) the limestone is calcined and thereby CO_2 is released. The newly formed lime is lead back into the first reactor and consequently the loop is closed. In a third reactor (Combustor) coal is burnt with air and the heat is indirectly transferred to the Calciner to satisfy heat requirements for the calcination process.

Carbonation: is the natural process in which calcium hydroxide reacts with carbon dioxide and is transformed into calcium carbonate. The carbonation reaction in mortars and other alkaline materials consist of diffusion of the CO_2 through the pore structure and its dissolution in the capillary pore water where its reaction with calcium hydroxide occurs with the precipitation of calcium carbonate crystals ($CaCO_3$) known as hardening mechanism. Quicklime reaction: $CaCO_3$ + heat => CaO + CO_2; Hydrated lime (slaked lime) reaction: CaO + H_2O => $Ca(OH)_2$; Carbonation reaction: $Ca(OH)_2$ + CO_2 + H_2O => $CaCO_3$ + $2H_2O$.

Circular economy: is a policy definition used for a regenerative system in which resource input, waste, emission, energy leakage are minimized by closing, narrowing material and energy loops.

Combined heat and power (CHP): cogeneration or combined heat and power is the use of a heat engine or power station to generate electricity and useful heat at the same time.

Direct Separation Reactor (DSR): refers to re-engineering the existing process flows of a traditional calciner by indirectly heating the limestone via a special steel vessel. This system enables pure CO_2 to be captured as it is released from the limestone, as the furnace exhaust gases are kept separate.

Emerging technologies: are those technical innovations which represent the potential for progressive developments within a field for competitive advantage.

Flue gas treatment (FGT): industrial processes generate flue gases. These often contain pollutants such as sulfur oxides (SO_2 + SO_3), hydrochloric acid (HCl), hydrofluoric acid (HF) as well as heavy metals, dioxins and furans. Lime, hydrated lime and limestone-based products are highly efficient reagents for capturing contaminants and are used in flue gas treatment (FGT). When mixed with other components, they also remove so-called micro-pollutants.

Innovation: refers to the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations (OECD & Eurostat. 2005, p. 146). The innovation can be grouped into: 1. Product Innovation; 2. New innovative methods of production; 3. Market innovation; 4. Organisation innovation; 5. System Innovation (MinGuide. 2016, p. 10-14).

Organic Rankine Cycle (ORC): is a well-known and widely spread form of energy production from heat, mostly in biomass and geothermal applications, but great rises in solar and heat recovery applications are also expected.

Public Private Partnership (PPP): is a broad term is used for a funding model involving partners from private and public entities that includes funding, planning, building, operation, maintenance and divestiture of projects of interest. PPP arrangements are useful for large projects that require highly-skilled workers and a significant cash outlay to get started.

Return on Investment (ROI): is a profitability ratio that calculates the profits of an investment as a percentage of the original cost over time.

Technology assessment (TA): is a scientific, interactive, and communicative process that aims to contribute to the formation of public and political opinion on societal aspects of science and technology.

Technology life-cycle (TLC): describes the commercial gain of a product through the expense of research and development phase, and the financial return during its "vital life". Some technologies, such as steel, paper or cement manufacturing, have a long lifespan (with minor variations in technology incorporated with time) while in other cases, such as electronic or pharmaceutical products, the lifespan may be quite short.

Technology Readiness Level (TRL): are determined during a Technology Readiness Assessment (TRA) that examines program concepts, technology requirements, and demonstrated technology capabilities. TRL are based on a scale from 1 to 9 with 9 being the most mature technology. The use of TRLs enables consistent, uniform discussions of technical maturity across different types of technology (EARTO, 2014).

Technology transfer, known also as transfer of technology (TOT): is the process of transferring (disseminating) technology from the places and ingroups of its origination to wider distribution among more people and places. It occurs along various axes: among universities, from universities to businesses, from large businesses to smaller ones, from governments to businesses, across borders, both formally and informally, and both openly and surreptitiously.

REFERENCES:
[4] Best Available Techniques (BAT) Annex III of 2010/75 /EU Directive.
[5] EARTO. 2014. The TRL scale as a Research & Innovation Policy Tool: EARTO Recommendations. Pp. 17. earto.eu/fileadmin/content/03_Publications/TRL_EARTO_Recommendations_-_Final.pdf.
[6] EC. 2013. European Commission. HORIZON 2020- WORK PROGRAMME 2014-2015. 19. General Annexes Revised. Pp. 36.
[7] EC. 2015. European Commission Decision C (2015) 8621 of 4 December 2015.
[8] MinGuide. 2016. The MIN-GUIDE common approach. Deliverable 1.1. Version 1. Pp. 49.
[9] OECD & Eurostat. 2005. Oslo Manual: Guidelines for collecting and interpreting innovation data. Pp. 166.

3. Process Emissions Mitigation

- BiOxySorb
- CaO_2
- CARINA
- CaLEnergy
- ECO
- ECO_2
- LEILAC1
- LEILAC2
- CSM
- C4U
- Columbus
- $LOWCO_2$
- ZerCaL
- DinamX

BIOXYSORB • Biomass co-combustion under both air- and oxy-fuel conditions

bioxysorb.eu-projects.de

Scope of work

The main objective of BiOxySorb is two-fold:

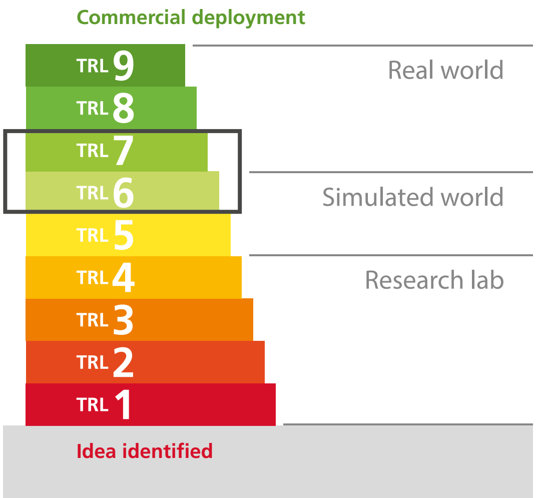
- Assess experimentally and techno-economically of 1st and 2nd generation biomass co-combustion under both air- and oxy-fuel conditions at various co-combustion ratios in combination with flexible, low cost SO_x, HCl and Hg emission control by sorbent injection.
- Economic low carbon power production and emissions control for future and flexible biomass co-fired power stations.

Status of the project

Project finalized in 2016. The following achievements can be reported:

- Assessment behaviour of emission (PM, HCl, CO, NO_x, SO_x and Hg) of various first and second generation biomasses and co-combustion shares under air and oxy-fuel conditions.
- Choice and evaluation of sorbents (e.g. alkalines, earth-alkalines, and activated carbon or lignite/coal coke) and investigation of their application for control of HCl, SO_2, SO_3 and Hg emissions under air and oxy-fuel firing conditions.
- Investigation of necessary plant modifications for high thermal share biomass co--milling and co-combustion and for injection of sorbents.
- Techno-economical study of different degrees of biomass co-combustion and emission control by sorbent injection under air and oxy-fuel conditions. Utility and technology and supplies manufacturer (E.ON, LHOIST, GBS) will use the data generated in the experimental small, technical and large scale tests to assess the impact of the co-combustion and sorbents on full-cycle, full-scale power plants and to determine their impact on cycle optimization, ash valorisation and emissions control [10].
- Development of generic guidelines covering important considerations to be made in an overall economic optimisation of co-fired coal/biomass systems and the application of sorbents for emission control both with and without oxy-fuel combustion.

Type	Innovation action (pilot)
Partners	Leader: IFK (DE) Lime: Lhoist
Funding	EU / FP7 / RFCS Total project: 2.1 Mill EUR EU contribution: 1.3 Mill EUR
Duration	07.2013 – 06.2016
TRL	Technology Readiness Level: TRL 6-7



Contribution to

Energy efficiency – Emission control – Co-fired technology – Multiple policy objectives – Economic assessment.

REFERENCES:

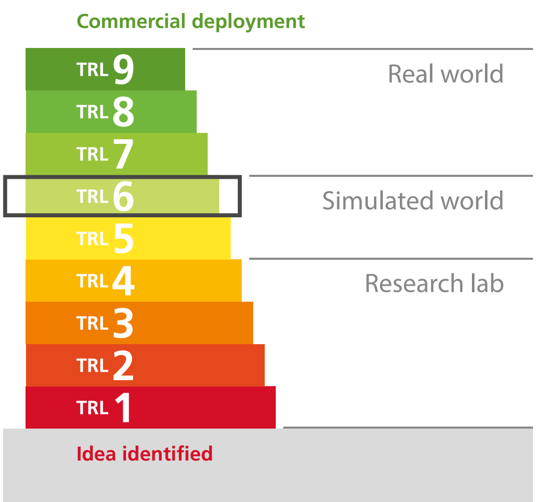
[10] Spörl R., Pek S., Qin S., Maier J., Scheffknecht G. 2015. Acid Gas Control by Dry Sorbent Injection in Air and Oxy-Fuel Combustion. 5th Oxyfuel Combustion Research Network Meeting in Hongyi Hotel, Wuhan, China from 27-30th October 2015. Platform presentation.

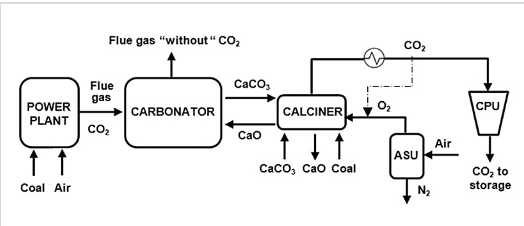
CaO_2

Calcium carbonate looping for coal power plants

cao2.eu

Type	Innovation action (pilot)
Partners	Leader: Endesa Generation (ES) Lime: Carmeuse
Funding	EU / FP7 / RFCR Total project: 3.2 Mill EUR EU contribution: 1.6 Mill EUR
Duration	06.2014 – 05.2017
TRL	Technology Readiness Level: TRL 6





Simplified scheme of the proposed CaL process developed in this project.

REFERENCES:

[11] Abanades C. 2015. Progress on the calcium looping postconditions process. 6th High Temperature Solid Looping Cycles network meeting. 1-2 September 2015 at Politechnico di Milano in Milan Italy.

Scope of work

The objectives of this project were two:

- The CaO_2 project intends to demonstrate in a large pilot (2-3 MW_{th}) a process optimisation of the CO_2 capture post combustion calcium looping system for coal based power plants. This process scheme is intended to minimize or even avoid the need of a CO_2 recycle to the oxyfired circulating fluidized bed calciner, by exploiting the endothermic nature of the calcination reaction and the large solid flow circulating from the carbonator.
- The practical realization requires a profound redesign of this novel reactor configuration, investigating the implications of the new conditions in the key reactions at particle level in the system (combustion, calcination, carbonation, sulfation), using and adapting reactor and process models to the new operating conditions and deriving experimental data which are relevant at pilot scale.

Status of the project

Project was terminated in 2017. Key deliverables of the project consist of:

- Reduce the heat requirements in the calciner and therefore the consumption of coal and O_2.
- Reduce the calciner size for the same heat input (to keep similar gas velocities in the CFB calciner) and the size of the ASU, which implies a decrease of investment costs.
- The validation of the concept will be done in La Pereda CaL pilot plant in Asturias (Spain), the biggest CaL facility in the world. Basic mass and heat balance calculations reveal that the standard CaL system can reduce about 20-30% the energy requirements in the calciner by switching to a configuration as proposed in the CaO_2 project [11].

Contribution to

Carbon sequestration – Emission reduction – Efficient industrial process – Carbon looping technology – Energy efficiency.

CARINA • Carbon Capture by Indirectly Heated Carbonate Looping Process

publications.europa.eu/en/publication-detail/-/publication/27bb757a-fc83-11e5-b713-01aa75ed71a1/language-en

Scope of work

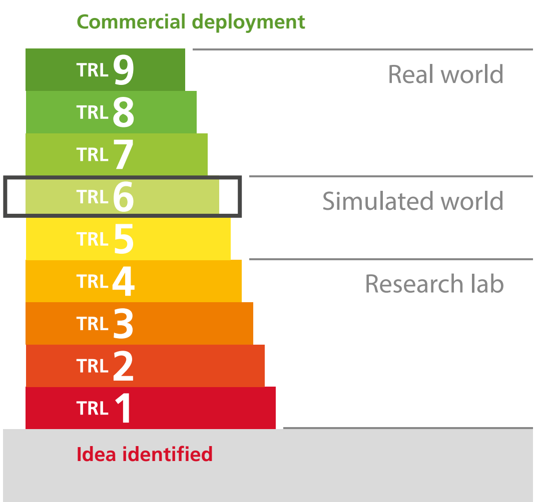
To achieve a technological proof-of-concept and a detailed economical evaluation for the retrofit of an existing coal fired power plant. The process should yield higher plant efficiency and lower CO_2 avoidance costs than other CO_2 capture technologies which are currently under investigation. Screening of different sorbents (i.e. lime), to investigate the impact of the heat pipe surface on the attrition of the sorbents. Additionally, the fluidization behavior of sorbents with extremely low fluidization velocities and the selection of sorbents at reduced calcination temperatures will be examined. Investigating and testing a new concept with an indirectly heated calciner using heat pipes, offering even higher plant efficiency and lower CO_2 avoidance costs than the oxy-fired standard carbonate looping process.

Status of the project

Project finalized in 2016. The following achievements can be reported:

- The proposed concept is based on a fluidized bed heat exchanger system transferring heat from a combustor to the calciner by means of heat pipes. The main advantage of an externally fired calciner is the avoidance of oxygen production by an air separation unit. The estimated gain in electrical net efficiency is around 2-3% points, compared to a directly fired calciner [12].
- The heat input into the calciner is no longer effected directly, but indirectly by means of heaters. This results in a multitude of process engineering advantages.
- The standard carbonate looping promises low energy penalties for post-combustion CO_2-capture and is particularly suited for retrofitting existing power plants [13].
- The concept was tested at a 1 MW_{th} test plant at TU Darmstadt. The process optimization for reactor temperatures, fluidization velocity of the calciner and sorbent materials as well as a feasibility study for a full-scale plant was evaluated [14].

Type	Innovation action (pilot)
Partners	Leader: TU Darmstadt (DE) Lime: Lhoist
Funding	EU / FP7 / RFCS Total project: 2.5 Mill EUR EU contribution: 1.6 Mill EUR
Duration	07.2010 – 09.2014
TRL	Technology Readiness Level: TRL 6



Contribution to

Energy efficiency – Retrofitting – Best available techniques – Carbon looping – Lime technology – Coal fired power plant.

REFERENCES:

[12] Höftberger D., Karl J. 2013. Self-Fluidization in an Indirectly Heated Calciner, Chemical Engineering & Technology, Volume 36: 9. Pp. 1533-1538.

[13] Junk M., Reitz M., Ströhle J., Epple B., 2013. Thermodynamic evaluation and cold flow model testing of an indirectly heated carbonate looping process, Chemical Engineering & Technology, Volume 36: 9. Pp. 1479-1487.

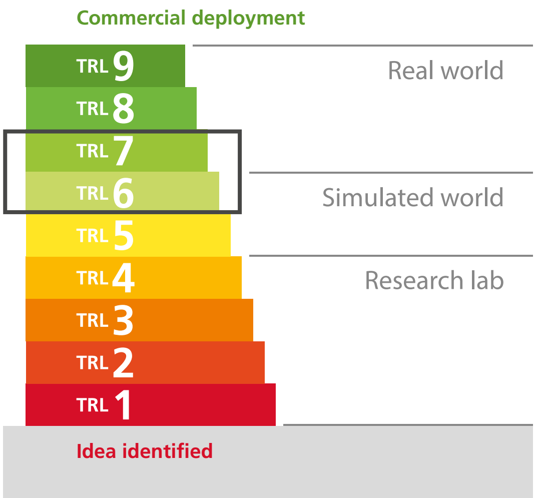
[14] Kremer J., Galloy A. Ströhle J., Epple B., 2013. Continuous CO_2 Capture in a 1-MW_{th} Carbonate Looping Pilot Plant. Chemical Engineering & Technology. Volume 36: 9. Pp. 1518-1524.

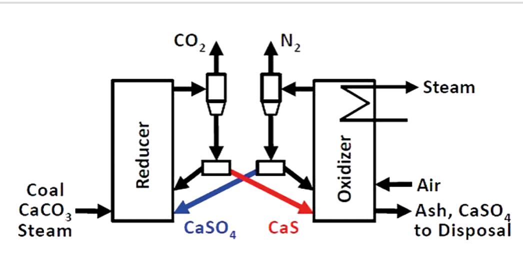
CALENERGY

Chemical Looping 4 Combustion Technology

netl.doe.gov/research/coal/energy-systems/advanced-combustion/project-information/proj?k=FE0009484

Type	Innovation action (pilot)
Partners	Leader: ALSTOM (USA) Lime: Carmeuse
Funding	USA (DoE) Programme Total project: 11.1 Mill EUR DoE contribution: 8.9 Mill EUR
Duration	10.2012 – 09.2017
TRL	Technology Readiness Level: TRL 6-7





Alstom's LCL-C process implementation.

Scope of work

Alstom Power, through prior U.S. DOE funding, has been developing a limestone-based chemical looping combustion technology. The objectives of this project were to:

- Demonstrate in a large pilot (2-3 MW_{th}) a Alstom's Chemical Looping Combustion Technology with CO_2 Capture for New and Retrofit Coal-Fired Power.
- Enabling a full analysis of the process through an engineering system and economic study along with the development of a screening tool for process improvements.
- Analyses to include an evaluation of pressurizing the limestone chemical looping combustion process.

Status of the project

Project was terminated in 2017. Key deliverables of the project consist of:

- This project focuses on development of the limestone chemical looping combustion system [15].
- The low-cost limestone oxygen carrier along with less-expensive more-efficient reactors drives down capital and operating costs relative to conventional systems.
- This project addressed technology gaps and generating data to support scale-up via continuous, stable operation of a 1 MWe prototype system [16].

Contribution to

Carbon looping – Cost efficient solution – Lime technology – Energy efficiency.

REFERENCES:

[15] Chamberland R. 2015. Alstom's Chemical Looping Combustion Technology with CO_2 Capture for New and Existing Coal-Fired Power Plants. Alstom Power, Inc., 2015 NETL CO_2 Capture Technology Meeting June 2015, Pittsburgh, PA.

[16] Marion J. 2016. Alstom's Chemical Looping Combustion Technology with CO_2 Capture for New and Existing Coal-Fired Power Plants, GE Power, 2016 NETL CO_2 Capture Technology Project Review Meeting Aug 2016, Pittsburgh, PA.

ECO

Ecological CO_2 scrubbing (ECO)

fg-kalk-moertel.de/forschungsberichte.html

Scope of work

The aim of this research project was to investigate the recycling of anthropogenic CO_2 into the natural carbon cycle using lime products. In practice, the capture of CO_2 from flue gases with the help of a limestone-CO_2-washing process similar to the naturally occurring carbonate weathering process. Subsequently after the CO_2 cleaning process the "produced" calcium bicarbonate-rich solution (mineralized water) should be returned to limnic and marine environments as natural buffer [17].

Status of the project

The project was finished in 2012. The CO_2 scrubbing process with limestone powder in solution was successfully demonstrated at the waste water facility in Bad Orb. During performance tests a reduction of CO_2 within the flue gas by up to 13% was achieved [32]. A four-five stage cleaning system could lead to a CO_2 reduction of up to 80%, as modelling and calculations revealed [18].

Contribution to

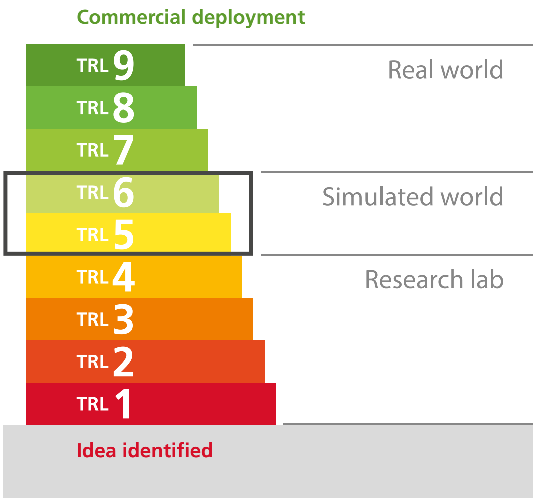
Carbon capture & use (CCU) – Natural carbon cycle – Lime technology – CO_2 reduction.

REFERENCES:

[17] Haas S., Weber N., Berry A., Erich E., 2014. Limestone powder CO_2 scrubber: artificial limestone weathering for reduction of flue gas CO_2 emissions. ZKG (Zement Kalk Gips) International: 1-2. Pp. 64-72.

[18] Haas S., Weber N., Berry A., Erich E. 2014. Limestone powder carbon dioxide scrubber as the technology for carbon capture and usage. Cement International: 12-3. Pp. 34-45.

Type	Innovation action (pilot)
Partners	Leader/Lime: BVK (DE)
Funding	National: 0.5 Mill EUR
Duration	05.2010 – 09.2012
TRL	Technology Readiness Level: TRL 5-6



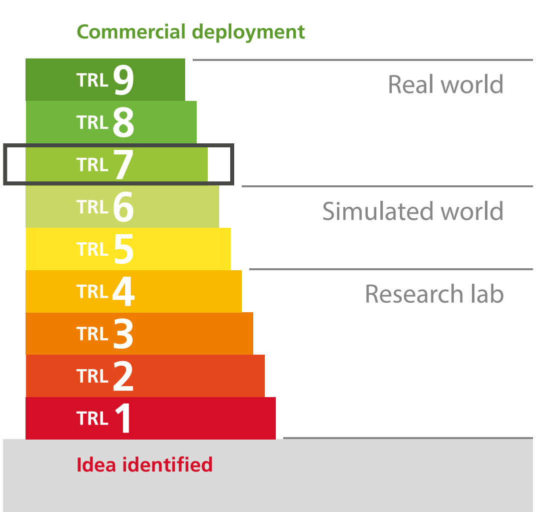
CO_2 scrubber used at the waste water facility at Bad Orb, Germany.

ECO_2

Economical CO_2 scrubbing

fg-kalk-moertel.de/eco2.html

Type	Innovation action (pilot)
Partners	Leader/Lime: BVK (DE)
Funding	National: 0.7 Mill EUR
Duration	01.2015 – 05.2018
TRL	Technology Readiness Level: TRL 7



Pilot CO_2 scrubber of ECO_2 project, Wilhelmshaven coal-fired power plant, where pilot testing is carried out.

Scope of work

German economy relies heavily on an economically optimal solution for CO_2 reduction due to the withdrawal from nuclear power generation, almost 100% import of natural gas and the particularly high quotas for CO_2 reduction. This study assesses the following points by constructing a pilot plant CO_2 scrubber, chemical analysis and modeling:

- Optimization of CO_2 reduction performance,
- Verification of the ecological safety of process water (bicarbonate rich solution) discharge into limnic or marine waters.
- Modeling of the expected positive biochemical and ecological effects.

Status of the project

Project to be finalized in 12.2017. The following achievements can be reported:

- Cascaded scrubber system to remove CO_2 with limestone powder and produce ready to use buffered water.
- Pre-trial finished. Pilot plant build. Tests at IUTA (Duisburg)
- Bio- and ecological modelling to test the harmlessness of process water discharge and biochemical effects are ongoing.
- Location for pilot plant: coal-fired plant Wilhelmshaven (Uniper). Test campaign from March to June 2017 [19].

Contribution to

CO_2 reduction – Carbon capture and utilization (CCU) – Buffering of aquatic systems – Freshwater restauration – Multiple policy objectives.

REFERENCES:

[19] ECO_2 reports in German are available upon request. info@eula.eu.

LEILAC1

Low Emissions Intensity Lime And Cement

project-leilac.eu

Scope of work

The aim of the project is to develop in situ CO_2 capture process for lime/dolime and cement manufacturing:

- LEILAC1 will pilot the Direct Separation Reactor (DSR) advanced technology that has the potential to capture unavoidable process emissions and enable both Europe's cement and lime industries to reduce emissions by around 60% to 70%.
- Direct Separation provides a common platform for CCS in both the lime and cement industries. Calix's DSR technology has been used successfully to produce niche "caustic MgO" since 2012, while trapping the plant's process CO_2 emissions. The DSR is an in-situ CO_2 capture technique that requires no additional chemicals or equipment.
- LEILAC1 project innovation consists in the temperature scale up the DSR.

Status of the project

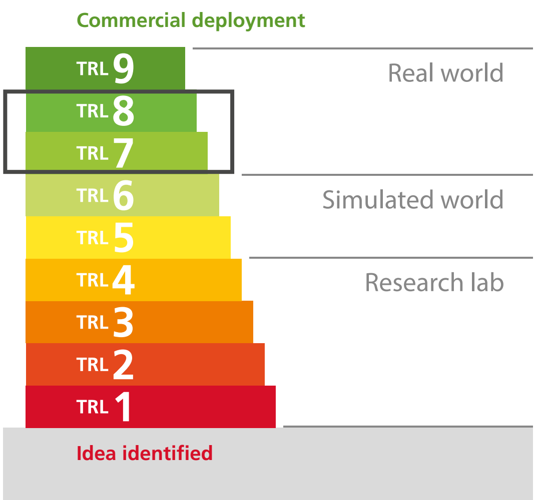
Project ongoing until 2020. The following progress can be reported:

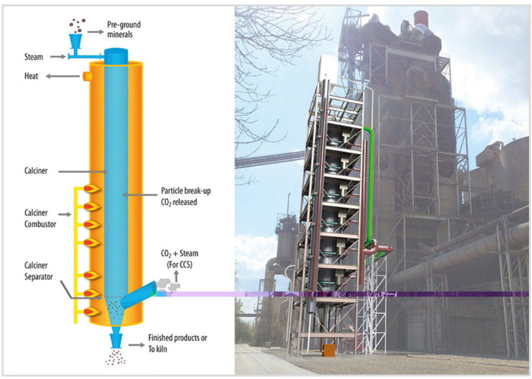
- LEILAC1 will develop, build, operate and test at 8 tons per hour limestone feed rate (~100 tons per day lime) pilot plant at Heidelberg Cement's plant in Lixhe (BE), demonstrating that over 95% of the process CO_2 emissions could be captured [35].
- This technology can be proven at a suitable scale (approximately within 5 years for the lime industry, and likely more than 10 years for larger cement plant).
- In a lime plant, the unit will just replace the kiln. This design could also work with alternative fuels.
- Techno-economic analysis, and Life Cycle Analysis will be conducted at pilot scale to assess opportunity for technology's scale and deployment via a Roadmap [20, 21].

Contribution to

CCU/CCS – Process emissions reduction – CO_2 mitigation.

Type	Innovation action (pilot)
Partners	Leader: Calix (Australia) Lime: Lhoist & Tarmac/CRH calix, Lhoist, TARMAC A CRH COMPANY, PSE, CARBON TRUST, Quantis, HEIDELBERGCEMENT, TNO innovation for life, Imperial College London, CEMEX
Funding	EU / H2020 Total project: 20.8 Mill EUR EU contribution: 11.9 Mill EUR Horizon 2020
Duration	01.2016 – 06.2021
TRL	Technology Readiness Level: TRL 7-8





Original DSR and DSR superimposed in the Lixhe plant.

REFERENCES:

[20] Rennie, D. 2017. Trapping process CO_2 emissions with the LEILAC project. GLOBAL CEMENT: CO_2 CAPTURE. Pp. 16-21.

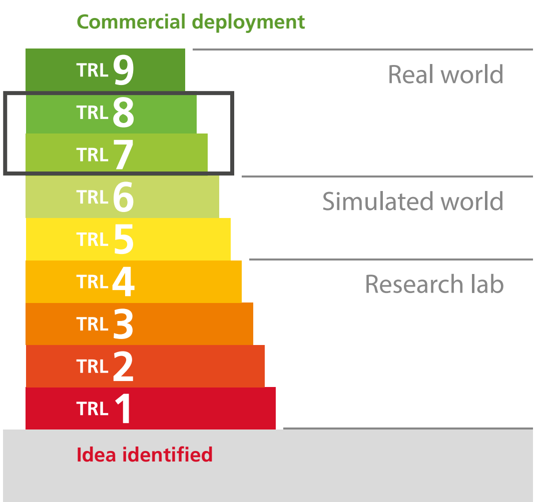
[21] Edwards, P. 2017. Trapping process CO_2 emissions with the LEILAC project. Global Cement Magazine. globalcement.com/magazine/articles/1004-trapping-process-co2-emissions-with-the-leilac-project.

LEILAC2

Low Emissions Intensity Lime And Cement

project-leilac.eu
cordis.europa.eu/project/id/884170

Type	Innovation action (project)
Partners	Leader: Calix (France) Lime: Lhoist
Funding	EU RIA – Research and Innovation Action Total project: 33.7 Mill EUR EU contribution: 16 Mill EUR
Duration	04.2020 – 03.2025
TRL	Technology Readiness Level: TRL 7-8



HeidelbergCement hosts the LEILAC2 Demonstration plant.

Scope of work

LEILAC2 first objective is to build a Demonstration Plant that will capture 20% of a full-scale cement plant, using Calix's Direct Separation Reactors. A x4 scale up of LEILAC1 will be built in Germany in a Heidelberg cement plant and integrated to the clinker production process. It is intended to capture 100 ktpa CO_2 process emissions. This scale up corresponds to a 400 tpd lime kiln. The second objective of LEILAC2 is to upgrade LEILAC1 DSR into dual mode electricity / Natural gas so reducing fuel CO_2 emissions, and potentially capable of load balancing services to the grid.
LEILAC2 has additional objectives related to assessment of various CCUS application options.

Status of the project

The project was launched in April 2020 and will run until March 2025.
It successfully passed the pre-FEED phase (process design) in April 2021. It is presently in the FEED stage (Front End Engineering & Design) [22].

Contribution to

CCU/CCS – Process emissions reduction – CO_2 mitigation.

REFERENCES:

[22] Rennie, D. 2020. the LEILAC Projects - Capturing Cement's CO2. WorldCement. Pp. 22-27. www.world-cement.com/magazine

CSM

Carbon Storage by Mineralisation

ccspfinalreport.fi/print

Scope of work

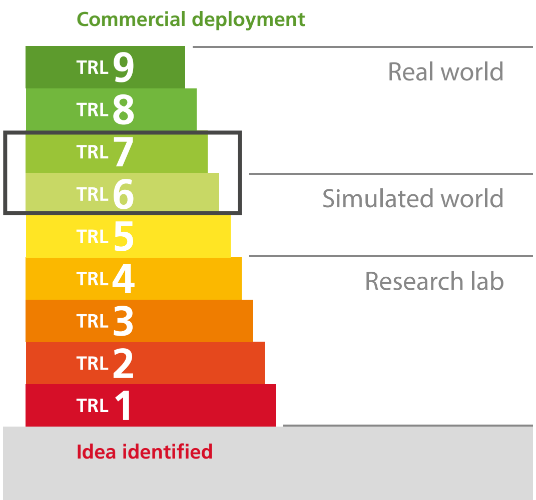
The stepwise carbonation of serpentinite, a rock composed mainly of magnesium silicate mineral serpentine reacts with the CO_2 to form a stable compound, thus fixing the CO_2 permanently. The reaction kinetics have received attention but the work done in Carbon Capture Storage Program (CCSP) is unique in having the minimization of energy input and chemicals use as starting point. The purpose of Carbon Storage by Mineralisation (CSM) is to promote CO_2 fixation by metal oxides into thermodynamically stable carbonates while benefiting of the exothermicity of the carbonation reaction Application of the mineral carbonation process at an industrial lime kiln was investigated in a pilot plant as part of the CCSP in Finland.

Status of the project

Project finalized in 2016. The following achievements can be reported:

- The recent study shows that operating at 80 bar carbonation pressure with ~22%-vol CO_2 flue gas without capture, mineral sequestration may be accomplished at an energy penalty of 0.9 GJ/t CO_2 electricity besides 2.6 GJ/tCO_2 heat which can be extracted from the kiln gas [23].
- Direct mineralisation of flue gas instead of separated and compressed CO_2, eliminates the need of ex-pensive and energy intensive processes to isolate and compress CO_2, thus significantly lowering the materials and energy requirements for the overall CCS process chain [23, 24].
- An exergy analysis is used to optimise process layout and energy efficiency, and at the same time max-imise the amount of CO_2 that can be bound to $MgCO_3$ given the amount of waste heat available from the lime kiln.
- Also, experimental results are reported for producing $Mg(OH)_2$ (and Fe,$Ca(OH)_2$) from local rock material.
- Operating without CO_2 separation makes CSM an attractive and cost-competitive option when compared to conventional CCS involving underground storage of CO_2 [24].

Type	Innovation action (demonstration)
Partners	Leader: Cluster for Energy & Environment CLEEN (FI) + 18 industry, 9 research (FI) Lime: Nordkalk
Funding	National Finnish Funding Agency for Technology & Innovation (TEKES) Total project: 15 Mill EUR
Duration	2011 – 2016
TRL	Technology Readiness Level: TRL 6-7



- Use of serpentinite as a CO_2 capturing mineral looked promising, but replicating to limestone minerals technical difficulties and the results were quite poor [24, 25].

Contribution to

Carbon dioxide storage by mineralisation (CSM) – Lime kiln – Process emissions – Multiple policy objectives.

REFERENCES:

[23] Romao I., Eriksson M., Nduagu E., Fagerlund J., Gando-Ferreira L.M., Zevenhoven R., 2012. Carbon Dioxide storage by mineralisation applied to a lime kiln. 25th International Conference on Efficiency, Cost, Optimisation, Simulation and Environmental impactr on Energy Systems. 26-29 June in Perugia.Italy. Pp. 13.

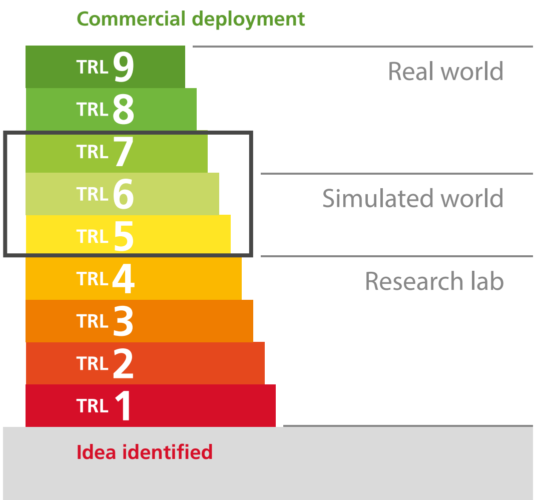
[24] CCSP Carbon Capture and Storage Program 1.1.2011 – 31.10.2016. Final report. Pp. 1-248. ccsp-finalreport.fi/reports/CCSP_Final_report.pdf.

[25] Teri S. Et al. 2013. CCSP Carbon Capture and Storage Program. Mid-term report. Pp. 82.

C4U
Carbon for You

cordis.europa.eu/project/id/884418

Type	Innovation action (demostration)
Partners	Leader: University College London (UK) Lime: Carmeuse
Funding	H2020 IA – Low Cost Low Carbon Energy Supply Total project: 13.8 Mill EUR EU contribution: 12.5 Mill EUR
Duration	04.2020 – 03.2024
TRL	Technology Readiness Level: TRL 5-7



Scope of work

The Paris Agreement sets out a global framework to mitigate global warming to well below 2 °C and pursuing efforts to limit it to 1.5 °C. Without carbon capture, utilisation and storage (CCUS), it is difficult to realise the temperature levels indicated in the Paris Agreement.

C4U as a holistic interdisciplinary project involves the collaboration of 20 partners from 8 European countries and Mission Innovation Countries (Canada, China and USA). The scope of the project covers:

- Address all the essential elements required for the optimal integration of CO_2 capture in the iron and steel industry as part of the CCUS chain.
- Using a whole system approach, the project accounts the impacts of the quality of the captured CO_2 on the safety and operation of the CO_2 pipeline transportation and storage infrastructure whilst exploring utilisation opportunities based on integration into the North Sea Port CCUS industrial cluster.
- The elevation from TRL5 to TRL7 of two highly energy-efficient high-temperature solid-sorbent CO_2 capture technologies for decarbonising blast furnace gas and other carbon containing gases. In addition, the C4U project assesses the societal readiness and analyses the optimal design for full-scale integration of such technologies in industrial plants operated by the world's largest iron and steel manufacturer, ArcelorMittal. For the first time, in combination, these two technologies will target up to 90% of the total emissions from the steel plant that come from a variety of sources.
- Successful incorporation into the North Sea Port CCUS cluster, makes this a top candidate for the fourth Union list of Projects of Common Interest2, CO_2TransPorts aims to establish the necessary infrastructure to facilitate the large-scale capture, transport and storage of CO_2 from three of the most important ports in Europe; North Sea, Rotterdam and Antwerp and to transport and store up to 10 Mt/yr of CO_2 per year.

Status of the project

The project started in 2020.

Contribution to

CCU/CCS – Process emissions reduction – CO_2 mitigation – CO_2 infrastructure – Carbon capture engineering.

COLUMBUS
Power to Methane

innovation.engie.com/en/news/medias/green-mobility/engie-s-columbus-power-to-methane-project-wins-the-febeliec-energy-award-2020/24706
johncockerill.com/en/press-and-news/news/john-cockerill-carmeuse-and-engie-join-forces-to-reduce-industrial-co2-emissions-in-wallonia/
youtube.com/watch?v=e-WijzdP26w

Scope of work

The scope of the project covers:

- The project, based on carbon capture and methanation technologies, aims to reduce carbon emissions by transforming CO_2 generated during the lime production process into e-methane, a renewable gas that can be injected into the gas network or used to power vehicles and industry.
- The process up-scales and combines existing and emerging technologies, such as the fabrication of hydrogen, using some of the world's largest electrolysers and a new type of lime kiln to generate purer CO_2.
- The green hydrogen will be produced by a 75 MW electrolyser plant powered by green electricity. This project is the largest of its kind in the world. It opens new routes for significant carbon emission reductions in Europe and the world.
- The projet Columbus "Power to Methane" is the winner of the Febeliec Energy Award 2020.

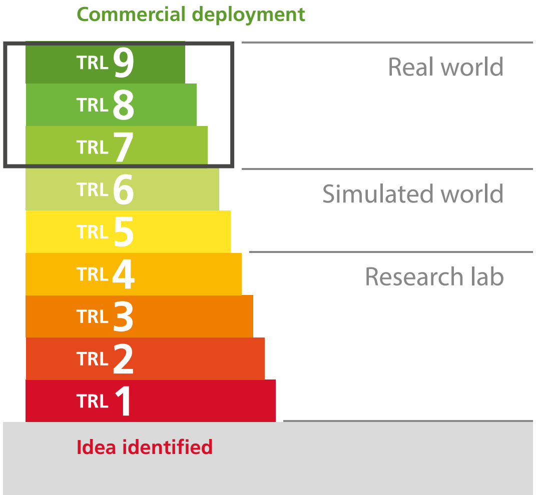
Status of the project

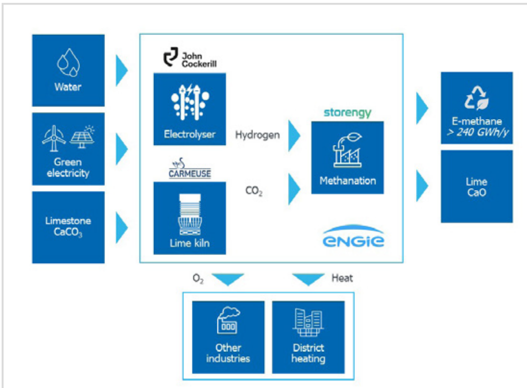
The project will start in 2022.

Contribution to

CCU/CCS – Process emissions reduction – CO_2 mitigation – Hydrogen.

Type	Innovation action (pilot)
Partners	Leader: Engie Lime: Carmeuse
Funding	Strategic Forum for Important Projects of Common European Interest (IPCEI) – via EU Innovation Fund Total project: 150 Mill EUR (TBC) EU contribution: (TBC)
Duration	2022 – 2025
TRL	Technology Readiness Level: TRL 7-9

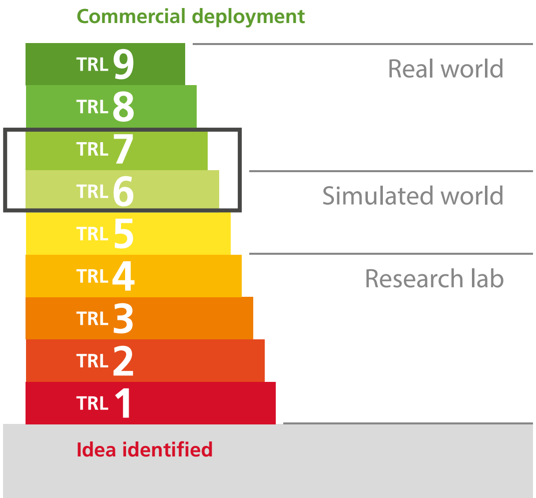




LOWCO₂

aclima.eus/proyecto-lowco2-alternativa-para-mitigar-el-cambio--climatico-y-mejorar-la-competitividad-de-la-industria-vasca/

Type	Ongoing pilot plant tests
Partners	Leader: Lointek Lime: Calcinor
Funding	Total project: 4.6 Mill EUR EU & National contribution: 2 Mill EUR
Duration	2019 – 2022
TRL	Technology Readiness Level: TRL 6-7



Scope of work

The LOWCO₂ project objective is to innovate towards competitive technologies of capture and valorization of industrial CO_2. With a duration of 4 years, some technologies of capture and valorisation of industrial CO_2 will be developed and validated. Several strategic innovations are piloted: new materials and processes for the capture of CO_2; technologies for the carbonation of residues (incorporation of the CO_2 in the residual materials) that allow the improvement of its performances as a raw material for construction; the production of methane and methanol obtained from CO_2 transformation.
The processes of CO_2 capture that are being studied are focused on the use of new materials to the end of reducing the current operating costs.

Status of the project

To meet the climate objectives of the Paris agreement, approximately 12 Giga-tons of CO_2 ($GtCO_2$) should be captured and stored between 2015 and 2030, and more than 100 $GtCO_2$ at a global level during the 2030-2050 period whereas. Now only 1% of the released CO_2 is reused. In this context, the LOWCO₂ project will contribute to give an answer to this global challenge, delivering a competitive position in the market, creating new opportunities of sustainable business trimming them economically.
The LOWCO₂ project contributes to reduce the carbon footprint, improves European competitiveness and it gives an answer to the challenges set forth by the global heating from a point of view of sustainability and of business development. This project is focused in three main CO_2 uses:

- CO_2 valorization processes incorporating it to alkaline residues (slags of energy plants, slags of steel mills, residues of RCDs construction and demolition). By means of carbonation its properties are improved and its recovery as a secondary raw material for the construction sector is facilitated, generating products of lower carbon footprints, with a more competitive position in the market reducing the current operating costs.
- Methane production, the technologies that are going to be developed will allow the generation of an energetically recoverable gas at the same site of the CO_2 emissions, thus improving the energy efficiency of the industries, and even enabling the possibility of selling this synthetic natural gas taking advantage of the current gas infrastructure.
- Methanol is a raw material used in the manufacturing of many consumption products, synthetic textiles, plastics, paints, adhesives, foams, and it relies on a growing market; its generation from CO2 will allow the decrease of the carbon footprint both in emissions and in processes of industrial manufacturing.

The solutions that will be developed will improve competitiveness for the consortium companies by the minimization of the CO_2 emissions, and creation of new value chains thanks to CO_2 capture and use.

Contribution to

CCU/CCS – Process emission reduction – CO_2 mitigation – Carbon Capture Engineering – Carbonation.

ZERCAL
Zero-Carbon Lime pilot plant

origencarbonsolutions.com

Scope of work

Singleton Birch and Origen have partnered to develop a new design of lime kiln which is able to capture all the CO_2 generated during the lime production process – both the CO_2 generated by the calcination of calcium carbonate and the CO_2 generated by the combustion of natural gas. They have completed construction of a pilot plant at Singleton Birch's Melton Ross site which will have the capacity to produce 3000 tonnes of lime per year. The oxy-fuel flash calcination process results in the production of a highly reactive lime and a flue gas that is > 95% CO_2. This flue gas can be cleaned up and pressurized to CO_2 pipeline standards and geologically sequestered. This will allow for the production of 'zero-carbon lime' – lime produced without emission of CO_2. Lime, in use, carbonates with CO_2 from ambient air (the proportion that carbonates depends on the particular application of the lime, but varies from 23% for lime used in steel production and 100% for lime used in the softening of water) [26]. As the lime has been produced without emissions, the overall use of zero-carbon lime results in net negative emissions.

Status of the project

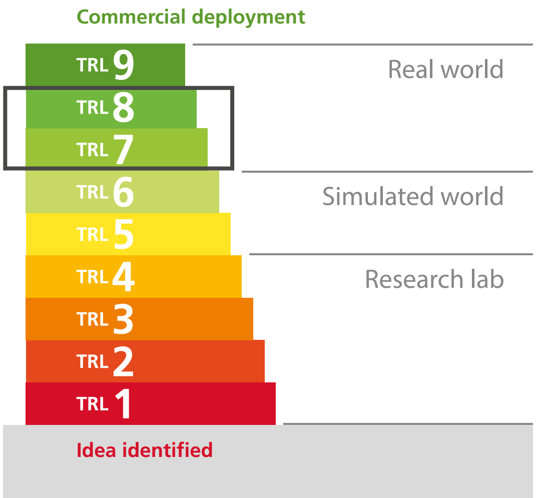
At the time of writing (April 2022), the construction of the pilot plant is close to completion, with commissioning planned for Q2 and Q3 2022.

Contribution to

Negative Emissions Technologies (NETs) – Greenhouse Gas Removal (GGR), Net Zero Emissions, Paris Agreement.

REFERENCES:
[26] Campo, F. P., Tua, C., Biganzoli, L., Pantini, S., & Grosso, M. (2021). Natural and enhanced carbonation of lime in its different applications: a review. Environmental Technology Reviews, 10(1), 224-237.

Type	Pilot plant
Partners	Leader: Origen (UK) Lime: Singleton Birch (UK)
Funding	3.8 Mill £
Duration	09.2021 – 09.2024
TRL	Technology Readiness Level: TRL 7-8



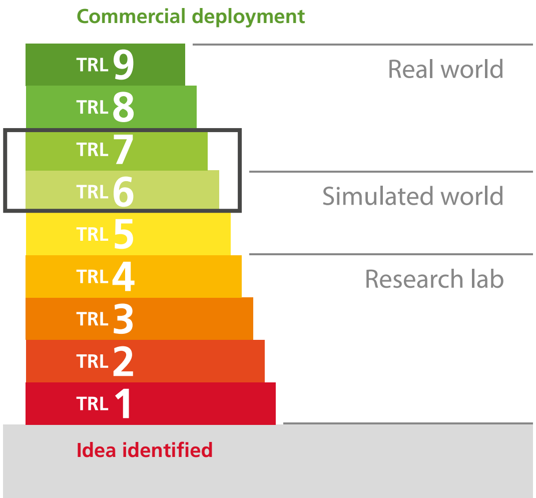
Zero-Carbon Lime pilot plant in final stages of construction (April 2022).

DINAMX

Demonstration and DMX Innovative Application

usinenouvelle.com/article/captage-de-co2-lhoist-rejoint-le-projet-dinamx.N1222832

Type	Innovative application
Partners	Leader: Axens Lime: Lhoist
Funding	National: Ademe Total budget: 3 514 646 EUR Funding: 1 405 858 EUR
Duration	01.2020 – 12.2024
TRL	Technology Readiness Level: TRL 6-7



Photograph illustrating the pilot plant Demixing (DMX) for 3D projects.

REFERENCES:

[27] info-chimie.fr/captage-de-co2-lhoist-rejoint-le-projet-dinamx,114399

[28] carboncapturejournal.com/news/launch-of-dinamx--industrial-co2-capture-pilot-in-france/4440.aspx?Category=all

Scope of work

Feasibility study of an advanced amine-based carbon capture technology coupled with a large integrated capture, storage and transportation project. Carbon capture technology based on Amine absorption is one of the most developed process applicable to various CO_2 initial concentration. To reduce the energy required to regenerate the amine, IFPEN developed a specific de-mixing amine blend. Only the phase containing the high concentration of carbonated amine will be separate from the lean phase and will be regenerated, significantly reducing the total energy demand of the process.

The demixing (DMX) process is currently being demonstrated on a demonstration pilot installed in a French steel mill plant, as part of an EU H2020 funder project.

The DMX process is applicable to decarbonize a large variety of gas streams, including flue gases from various sources, as confirmed by laboratory pilot tests performed by IFPEN. As part of the ADEME funded DinamX project the potential application of DMX technology at the Rety site have been evaluated [27, 28].

Status of the project

Project started in 2020. The following achievements can be reported:

- Validation on the lab pilot scale of the DMX process in the case of a lime flue gas typical composition.
- Elaboration of a specific DMX blend according to the specificities of the gas.
- First evaluation of the Capex and Opex including associated pre-treatment and utilities in the case of a full-size plant of about 600 ktpa of lime.

Contribution to

Carbon Capture – Amines scrubber – Advanced amines absorption – Demixing technology.

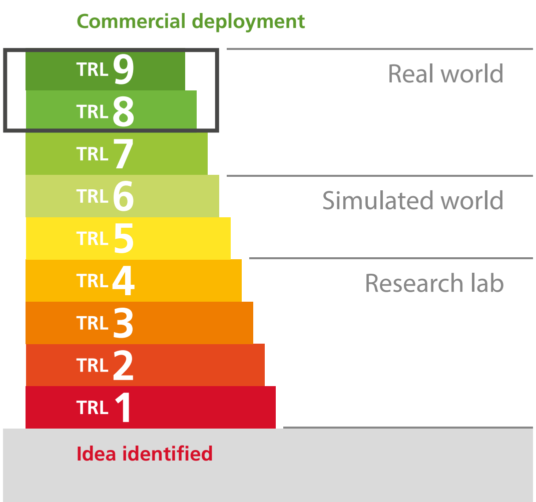
4. Innovation in Energy

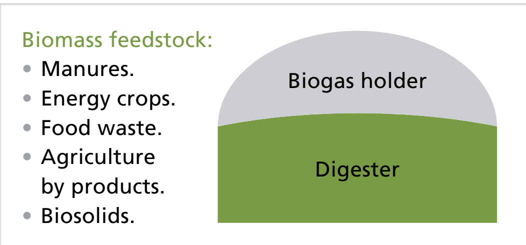
- ADiREN4Lime
- WHeatRec4PG
- Energy optimisation
- Energy generation
- CHP Generation
- Hydrogen Fuel Energy Innovation
- FFL
- NKL

ADIREN4LIME • Anaerobic Digestion as a Renewable Energy for the Lime Industry

birchenergy.co.uk

Type	Innovation action (pilot: renewable energy generation)
Partners	Leader: Birch Energy (UK) Partner: Singleton Birch (UK)
Funding	Own initiative + UK Total project: 8.5 Mill £ UK contribution: yes
Duration	11.2014 – 04.2015
TRL	Technology Readiness Level: TRL 8-9





Biomass feedstock and stirred tank.

AD installation.

Scope of work

Lime processing needs large amount of energy (kiln, hydrator, crushers, mill). Objective:

• Reduce energy costs and reliance on grid electricity and gas.

• Invest in gas or electricity generating projects.

• 2013 decision made to build an Anaerobic Digester (AD) to meet these objectives.

• AD is a process where micro-organisms break down some organic biomass in anaerobic conditions to produce biogas, CH_4 + CO_2.

• The methane can be used to produce electricity or upgraded to Biomethane for injection into the gas grid and can be used as a fuel for lime kilns.

Status of the project

Project finalized in 2015. Birch Energy financed, managed, operates the AD installation in a restored area of the former quarry operations. The following achievements can be reported:

• Built in 2 phases: 1: 1.25MW Combined Heat and Power (CHP); Phase 2: 2 MW CHP plus 1.5 MW drier.

• Uses 45,000 tonnes of feedstock annually.

• Combined output of the 3 AD plants is 110% of Singleton Birch's electricity demand.

• Grid connection with capacity to export 100% of electricity to grid and generates 15,000 GWhrs of elec-tricity per annum.

• Dryer using waste heat from the CHP engines to dry digestate as a high value fertiliser [29].

• Employs 5 people.

Contribution to

Energy efficiency – Renewable energy into the grid – Agriculture – Fertilizer – Waste management – Management – Employment.

REFERENCES:

[29] Haworth M. 2016. Anaerobic Digestion as a renewable power source for the Global Lime Industry. ILA October 2016 annual meeting in Washington (USA).

WHEATREC4PG

Waste Heat Recovery for Power Generation

theenergyst.com/wp-content/uploads/2016/05/theenergyst_0516-web.pdf

Scope of work

Lime processing needs large amount of energy for the different multiple processing stages. The objective of energy intensive industry operators is to improve the overall energy efficiency, resulting in reducing the energy costs and the reliance on grid electricity. This are the drivers for the feasibility study of a Heat recovery system installation in lime operations:

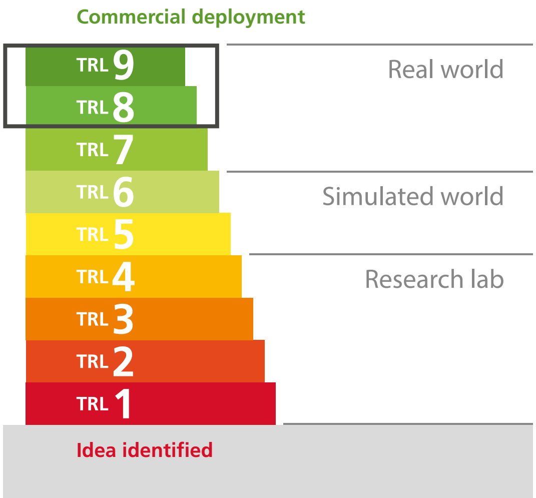
- Waste heat recovery systems integrate organic rankine cycle (ORC) technology into renewable heat sources, industrial kilns and furnaces.
- The ERC generator can convert waste heat temperatures as low as 85°C into electricity.
- Waste heat from heat intensive industrial processes can be recovered by: 1. High temperature hot water above 85°C. 2. Saturated steam above 6 bar. 3. Exhaust gas above 130°C.
- These sources of waste heat are fitted with a heat exchanger designed for the application.

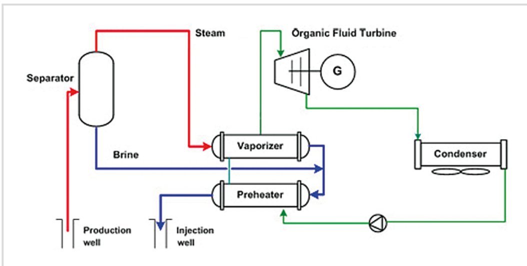
Status of the project

Project is already operational. The following can be reported:

- A waste heat to power system was commissioned in September 2013 at Lhoist-Steetley Dolomite facility in Thrislinton-UK.
- The WHRPG system recovers 4 MW of thermal power from a rotary kiln exhaust gas, and converts it to 0.5 MWe of low carbon electrical power.
- The new system delivered 25% improvement in electrical efficiency of the plant.
- it can generate net power of around 3,000 MWh annually, equivalent to 7,500 hours of carbon-free electricity.
- In total, kiln CO_2 emissions will be reduced by 1,600 tonnes per year.
- The project offers an attractive return on investment, when considering £1.3m investment against purchasing 3,000 MWh per year of electricity from the grid over the next 10 years [30, 31].

Type	Innovation action (pilot: heat recovery)
Partners	Leader/Lime: Lhoist/Steetley (UK)
Funding	Funding: Own initiative + UK support Total project: 1.3 Mill £ UK support: 0.2 Mill £
Duration	06.2012 – 09.2013
TRL	Technology Readiness Level: TRL 8-9





Organic rankine cycle (ORC).

Contribution to

Energy efficiency – Waste heat recovery – CO_2 mitigation – Power generation.

REFERENCES:

[30] Bryant D. 2016. Waste not, Want Not. ENERGYST. Pp. 48-49.

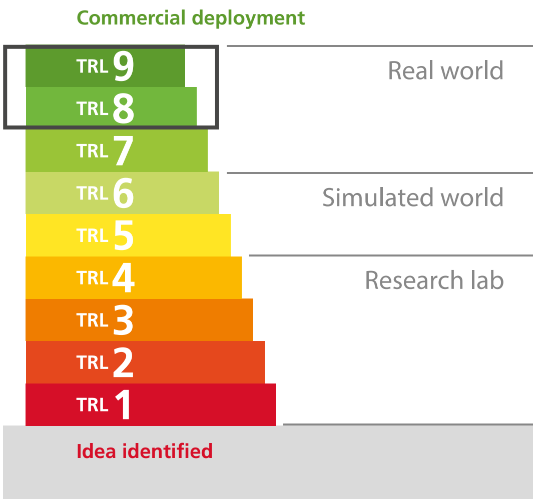
[31] 2013. Heatcatcher secures waste heat recovery project with Steetley Dolomite. Global Cement: Pp. 20.

ENERGY OPTIMISATION

Reduced energy consumption through optimized processes and capacity use

www.spin-project.eu/downloads/2_SPIN_Project_biogas_barrierefrei_reduziert.pdf

Type	Innovation action (energy efficiency)
Partners	Leader/Lime: Nordkalk (FI, SE) Nordkalk
Funding	Own initiative + Swedish Swedish contribution: yes
Duration	2011 – 2016
TRL	Technology Readiness Level: TRL 8-9



Biofuel tested at Ignaberga in Sweden.

Contribution to

Energy efficiency – Renewable fuels.

REFERENCES:

[32] 2011. Nordkalk. Environmental report. Pp. 12.

[33] Reinson K. & Roioiose Antti.2012. BioGas. Report prepared by University of Taru. Pp. 11.

Scope of work

Lime processing needs large amount of energy (kiln, hydrator, crushers, mill). Objective:

- Improve energy efficiency and introduce renewable fuels.
- Reducing energy consumption, a priority in new investments and repairs in the lime processing facilities.

Status of the project

Few projects were implemented, and the following can be reported:

- The automation system of the lime kiln in Pargas was renewed in 2016; the new automatic optimization system adjusts the kiln's operation parameters for obtaining uniform lime quality and low energy consumption. The system monitors constantly the measurements of the process and product quality to level out changes in the process. It also decreases the possibility for production interruptions. The automatic process optimization has been calculated to save annually up to 4000 MWh heat energy [47].
- The grinding plant in Vampula uses biogas supplied through a 1.5 km pipeline by the local biogas producer Vambio. The gas is produced from by-products of the food industry, slaughterhouses and livestock-breeding as well as wastewater sludge [47].
- In 2015, Nordkalk tested the use of biofuel in Ignaberga (Sweden) facility. The fuel is a surplus product from ecological feed production. The tests have given good results, and so in 2016, Nordkalk invested in equipment to adjust the production and equipment for the switch from fossil fuels to biofuels. The stone drying in Ignaberga runs now 100% on biofuel. Nordkalk was granted climate investment support for the Ignaberga project by the Swedish Environmental Protection Agency in December 2015. Nordkalk is one of twelve companies receiving support for "measures that demonstrate the greatest sustained reduction of greenhouse gas emissions per crown invested" [32, 33].

ENERGY GENERATION

Largest Solar panel farm in Wallonia by a mining company

Scope of work

Limestone processing to make, quicklime & hydrated lime needs large amount of energy (crushers, kiln, hydrator, mill). Objective of this project is multifold:

- Invest in renewable energy generating project.
- Generate renewable energy to be used for the lime operating facilities.
- Improve the energy mix of the lime manufacturing.
- Reducing the overall energy consumption, a priority in new investments and repairs in the lime processing facilities.

Status of the project

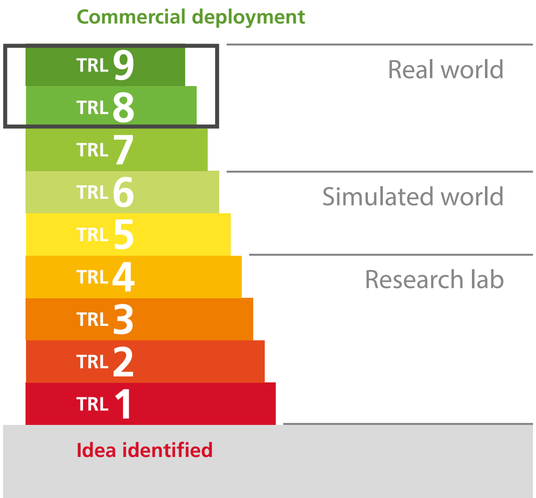
These objectives were addressed by building a photovoltaic farm near the lime facilities. The following can be reported:

- The largest Photovoltaic farm in Wallonia to date. 13.200 solar panels will supply annually over 3,6 GWh of electricity to the Carmeuse quarry located at Moha (province of Liège).
- On an annual basis, the solar plant will cover 9% of the quarry's and process facility total electricity consumption. PV coverage will average over 14% during the months of April till September.
- The ground-mounted panel arrays are installed on 4,5 ha of industrial wasteland right next to the quarry and they are operational since 2017.

Contribution to

Renewable energy production – Lower CO_2 emissions.

Type	Innovative action (pilot: renewable energy generation)
Partners	Leader/Lime: Carmeuse (BE)
Funding	Own initiative + Wallonia Total project: not reported Wallonia contribution: yes
Duration	2014 – 2017
TRL	Technology Readiness Level: TRL 8-9

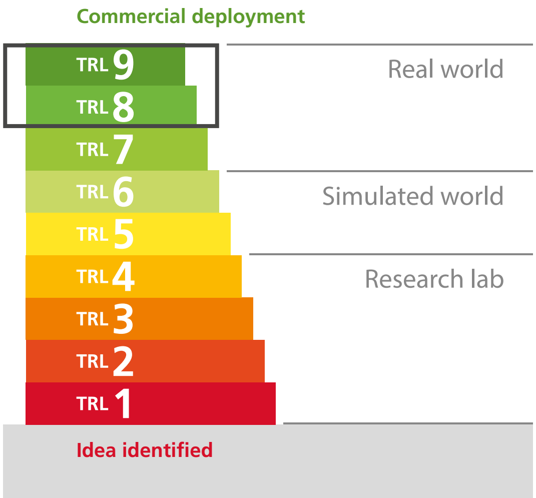


Solar panel farm at Moha (Wallonia).

CHP GENERATION

Combined Heat and Power (CHP) for Limestone Milling

Type	Innovation action (demonstration)
Partners	Leader/Lime: Lhoist (DE)
Funding	Own initiative Total project: not reported
Duration	2012 – 2013
TRL	Technology Readiness Level: TRL 8-9



Scope of work

Installation of a combined heat and power plant (CHP).

Producing electrical power with two micro gas turbines and usage of waste gas from gas turbines for drying purposes in limestone milling:

- Energy recovery from drying / heating off gases: Instead using 40% of natural gas' thermal energy for producing electrical power, in the CHP more than 70% of thermal energy is utilized.
- Contribution to electrical power supply.
- Backup electrical power supply for community.
- Reduce energy costs and reliance on grid electricity and gas.

Status of the project

Project realized in 2012 with commissioning in 2013.

Few projects were implemented, and the following can be reported:

- The micro gas turbines had been implemented in 2013 in plant Middel [D] and were in operation since that time.
- The waste gas of the turbines contains of 790 kW thermal power. A small increase of approx 30 kW is required by an additional gas burner is required to lift the energy content of the waste gas to the required level. The connected vertical roller mill dries the product on full production rate.
- The limestone feed material has a humidity of 7-8% and is dried to < 1% in the finished product.
- Installation costs ~0.6 Mill EUR.

Contribution to

Energy efficiency – Off heat utilisation.

HYDROGEN FUEL ENERGY INNOVATION

Alternatives to natural gas for high calcium lime manufacturing

Scope of work

This project aims to use of hydrogen as an alternative fuel for high calcium lime manufacturing. Natural gas systems are well established in the lime sector, both in terms of supply and process design and management. Alternative gas feeds will need to be considered not only for the possible impact on product quality, but also on operational processes, process engineering, health and safety, environmental management and workforce skills and competencies.

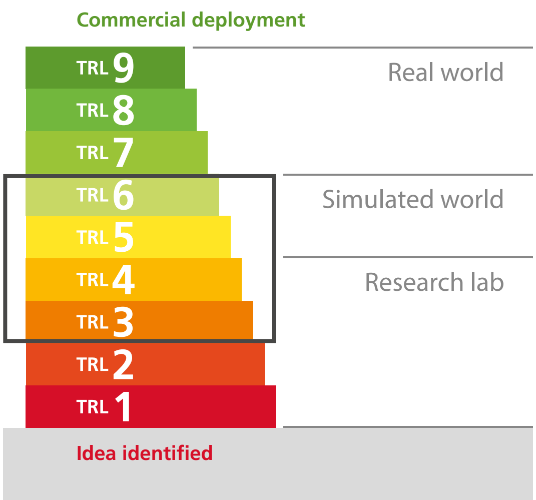
In the UK, lime is manufactured using two types of gas-fired kiln; vertical shaft kilns and parallel flow regenerating (PFR) kilns. PFR kilns are widely considered to be the most energy efficient. Vertical shaft kilns use similar technology and processes but are less efficient. However, by their nature, vertical shaft kilns are more challenged by hydrogen fuel than PFR kilns, given counter-current nature of the heating and the limited fuel and air mixing in vertical shaft kilns and the importance of this mixing to product quality. Key challenges to be addressed to convert vertical shaft and PFR kilns to hydrogen include:

- Gas density, flame speed and flame temperature and the impact on kiln performance and product quality.
- The long-term embrittlement and degradation of materials in kiln systems, including potential damage to refractories.

As lime manufacturing is permitted under the Environmental Permitting Regulations, demonstration of hydrogen fuel in lime manufacturing offers an environmentally robust means to assess technology feasibility within the sector.

This project is funded by the UK Department for Business, Energy and Industrial Strategy (BEIS) Energy Innovation Programme. The project is managed by the Mineral Products Association (MPA) and the British Lime Association (BLA).

Type	Innovation action (pilot: hydrogen as fuel)
Partners	Leader/Lime: Mineral Products Association / British Lime Association
Funding	UK Department for Business, Energy and Industrial Strategy (BEIS) Energy Innovation Programme Total Project: 2.82 Mill £
Duration	11.2019 – 03.2022
TRL	Technology Readiness Level: TRL 3-6



Status of the project

Kiln modelling, safety assessments and equipment installation are largely complete. Full scale demonstrations are expected to be completed during 2022.

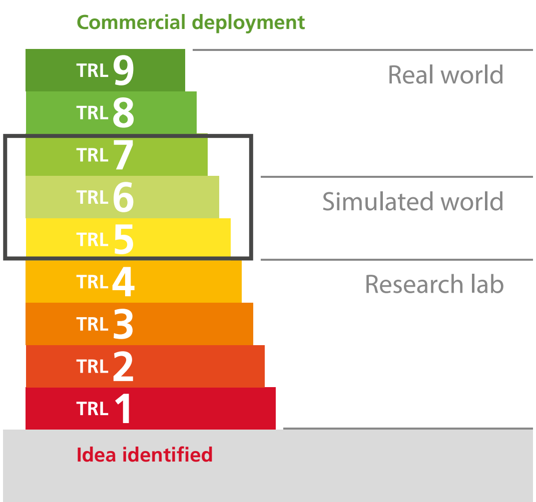
Contribution to

Climate change – Low carbon fuels – Hydrogen.

FFL • Fossil Free Lime (FFL) for the Fossil Free Steel (FFS) making

businessfinland.fi/en/whats-new/news/cision-releases/2021/research-is-fostering-the-sustainable-reform-of-the-metal-and--steel-industry

Type	Innovation action (CO_2 free fuels)
Partners	Leader: SSAB Lime: Nordkalk
Funding	Total project: 10.7 Mill EUR National contribution: 5.6 Mill EUR
Duration	02.2021 – 01.2024
TRL	Technology Readiness Level: TRL 5-7



Scope of work

The Fossil Free Steel (FFS) project will build the new expertise needed and support billion-euro investment decisions that will correspondingly contribute to reaching goal of carbon neutrality for the steel companies. The FFS project highlights building research cooperation with major domestic companies in the energy sector in, for example, the area of green hydrogen. One of the challenges in the project will be to combine a new production technology, new forms of energy and the manufacture of high strength performing steels in economically viable manner considering sustainability. The project is part of the Association of Finnish Steel and Metal Producers' strategic agenda, which is based on Finland's goal to be carbon neutral by 2035. Lime has a very crucial role in steel manufacturing and therefore it is important to develop Fossil-fuel Free Lime (FFL) as part of the roadmap towards FFS.

Status of the project

Lime is a common slag former, used by steel industry since a very long time. The properties of lime, contributing with CaO-molecules, enable the steel plant to have the right basicity in the steel slag during the first metallurgical steps of the steel production process. This property of the slag is important during removal of impurities from the steel, as the right slag property enhances the transfer of the impurities from melt into the slag.
Different steel plants have different demands for slag chemistry: e.g. amount and type of impurity to be removed, refractory chemistry, type of melting process etc. This means that different steel plants have different demands and a challenge for a lime supplier is to meet all these demands at once. However, a common demand is low sulphur and phosphorus content in lime, as these are some the most common elements to be removed from steel melt when generating steel slag.
But, as lime producers are looking into different CO_2 mitigation options, so does the steel industry. One clear example of this is the Hybrit project, where steel is to be produced with the help of hydrogen instead of carbon. This will not only be the end of the blast furnaces in the Nordics, but it will also change the demands for lime size fraction and chemistry. All in all, things will change, new lime products will be introduced, alternative fuels will be used. But all this has the clear target of lowering the total CO_2 emissions when producing steel [34].

Contribution to

Low carbon steel – Low carbon intensity lime.

REFERENCES:

[34] nordkalk.com/news/news/2022/02/lime-in-steel

NKL
Neutral Kero Lime

Scope of work

Study of an innovative e-Kerosene process using CO_2 from a lime kiln and hydrogen produced from green electricity. The capture of CO_2 at the lime plant would leverage some energy recovery from the synthetic kerosene via the Fischer-Tropsch process that converts a mixture of carbon monoxide and hydrogen or water gas into liquid hydrocarbons.

The challenge to be addressed (regulatory / societal / national / global):

- Defossilize aviation by 2050.
- Sustainable Aviation Fuels (SAF) / E-Fuel is the most credible solution.

Policy & Market drivers:

- EU Climate Low: Fit for 55 imposes a min. of 0,7% (~0.5Mt) of e-Fuel in 2030 to 28% (~0.5 Mt) in 2050.
- International Air Transport Association (IATA): 65% SAF for Net Zero by 2050 (23 bn liters in 2030).

Generate and optimize a set of data / methodologies / technologies that will:

- Capture of lime plant CO_2.
- Produce e-kerosene from this CO_2 and green H_2.

Construction and operation of a pilot unit combining the technological bricks:

- Optimization of technology depending on its local environment and available networks (renewable, H_2, CO_2, heat…).
- Dynamic model for the capture of the fatal CO_2 in the lime industry.
- Fischer-Tropsch: CO_2 supply instead of CO (RWGS optimization).

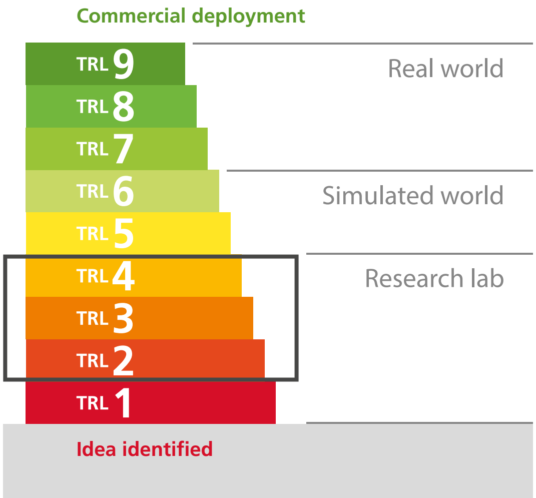
Status of the project

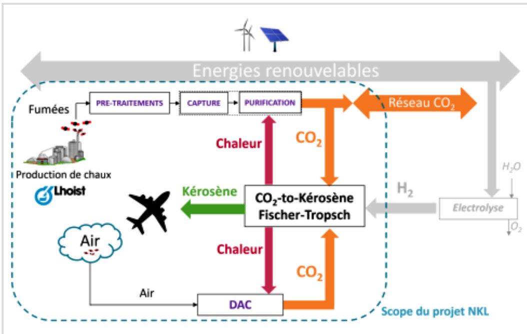
Funding awarded and project has started.

Contribution to

Carbon Capture – Amines scrubber – Energy integration – eFuel / eKerosen – CCU.

Type	Innovation action (CCU)
Partners	Leader: RESA Lime: Lhoist
Funding	Funding: National (BE) GreenWin Total budget: < 10 Mill EUR
Duration	02.2022 – 01.2026
TRL	Technology Readiness Level: TRL 2-4





5. Innovation in Carbonation

- Carbonation
- Steel
- Construction: Pure airlime mortars
- Construction: Mixed airlime mortars
- Construction: Hemp lime
- Environment: Drinking water
- Environment: Flue gas cleaning
- Pulp and paper: PCC
- Non-Ferrous: Aluminum
- Civil Engineering: Soil Stabilization

CARBONATION

Carbonation of lime (summary)

eula.eu/politecnico-di-milano-literature-review-on-the--assessment-of-the-carbonation-potential-of-lime-in-different-markets-and-beyond/

Scope of work

The production of lime involves heating limestone ($CaCO_3$) to transform it into high purity quicklime (CaO), releasing carbon dioxide (CO_2) as part of the chemical reaction called "process CO_2". This means lime production is inherently a carbon intensive process. The European lime sector (EuLA) acknowledges has an important role to play in the European Union's ambition to become carbon neutral by 2050 and is fully committed to the Green Deal objectives. This is why EuLA Commissioned the Politechnico di Milano (PoliMI) to carry out an extensive literature review and assess the potential of carbonation (natural and enhanced carbonation) from various lime applications.

Carbonation rate it is the percentage ratio between the amount of CO_2 absorbed during carbonation and the amount of process CO_2 emitted during calcination.

Enhanced carbonation, it is the process by which the carbonation is fostered under enhanced carbon dioxide concentration, and/or by optimized process parameters such as the temperature, the relative humidity, the surface reactivity area, the pH and others, depending on the reaction matrix in the solid, water or gaseous phase. Thus, the time of carbonation is reduced.

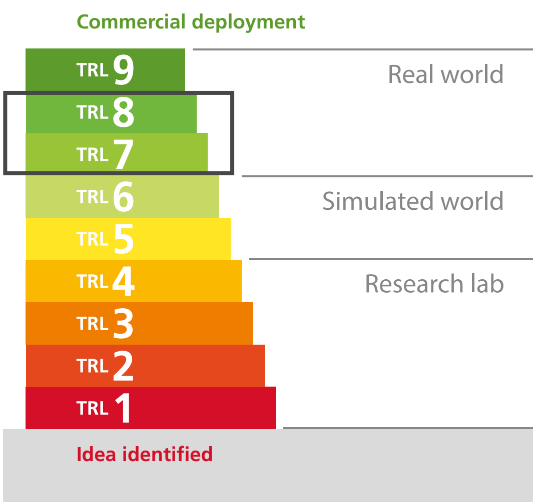
The findings from PoliMI study show that:

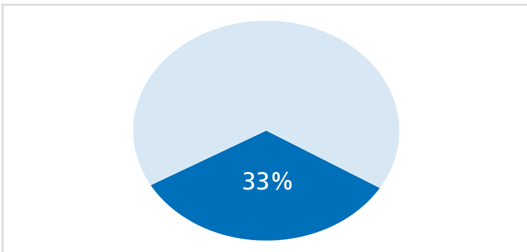
- On average 33% of unavoidable process emissions emitted during production are captured by using lime in various applications.
- This is a first step to better understand the total carbon balance of the lime cycle and to identify how to improve the removal of carbon from the atmosphere, using lime-based products.
- EuLA is working to investigate further the potential of natural and enhanced carbonation potential from lime.

Status of the project

Finalized [35].

Type	Innovation action (demonstration)
Partners	Leader: Politecnico di Milano (PoliMI-IT) Lime: EuLA (EU)
Funding	EuLA EU contribution: not applicable
Duration	12.2018 – 03.2021
TRL	Technology Readiness Level: TRL 7-8





Total CO_2 captured by natural carbonation.

Contribution to

Carbon removal – Carbon sink – Carbonation – CCU.

REFERENCES:

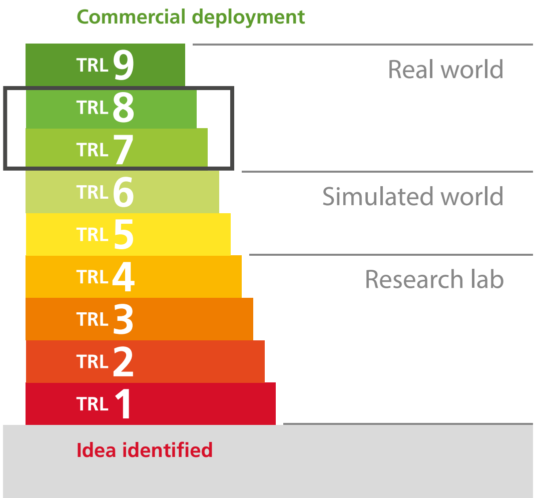
[35] Grosso M., Biganzoli L., Campo F. P., Pantini S., Tua C. 2020. Literature review on the assessment of the carbonation potential of lime in different markets and beyond. Report prepared by Assessment on Waste and Resources (AWARE) Research Group at Politecnico di Milano (PoliMI), for the European Lime Association (EuLA). Pp. 333.

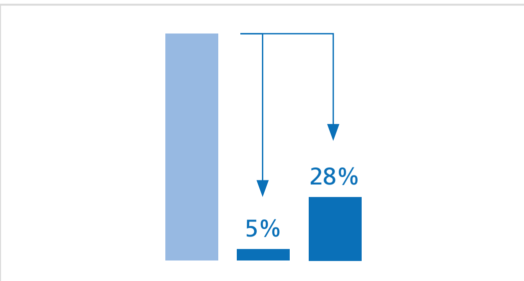
STEEL

Carbonation in steel (study)

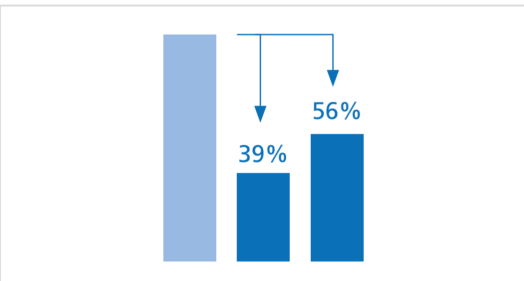
eula.eu/politecnico-di-milano-literature-review-on-the-assessment-of-the-carbonation-potential-of-lime-in-different-markets-and-beyond/

Type	Innovation action (demonstration)
Partners	Leader: Politecnico di Milano (PoliMI-IT) Lime: EuLA (EU)
Funding	EuLA EU contribution: not applicable
Duration	12.2018 – 03.2021
TRL	Technology Readiness Level: TRL 7-8





Natural carbonation rate (gradual increase over time).



Enhanced carbonation rate (gradual increase over time).

Scope of work

Use: lime is used in steel to neutralise acid-forming elements, to remove impurities, and enables the foamy slag in Electrical Arch Furnace (EAF's), and protects the steel refractories.

PoliMI assessed 72 publications in total to assess the carbonation rate in the steel application. Out of 72 publications, 55 contained relevant information on the carbonation process and carbonation rate values for this application.

The following findings can be reported for the carbonation in steel:

- Natural carbonation: occurs during open air storage of steel slag over 3-6 months periods.
- The natural carbonation rate in steel is: 5 to 28%.
- Enhanced carbonation rate in steel application is: 39 to 56%.

Status of the project

Finalized [36].

Contribution to

Carbon removal in steel – Carbon sink – Carbonation – CCU.

REFERENCES:

[36] Campo F. P., Tua C., Biganzoli L., Pantini S., & Grosso M. 2021. Natural and enhanced carbonation of lime in its different applications: a review. Environmental Technology Reviewss. 10:1. Pp. 224-237. https://doi.org/10.1080/21622515.2021.1982023

CONSTRUCTION: PURE AIRLIME MORTARS • Carbonation pure airlime mortars (study)

eula.eu/politecnico-di-milano-literature-review-on-the--assessment-of-the-carbonation-potential-of-lime-in-different-markets-and-beyond/

Scope of work

The main objectives of this project were:

- Assess the literature on the carbonation of lime in mortar applications based on relevance, reliability and adequacy.
- Comparative assessment to highlight the differences in the environmental impact between various mortars/renders/lasters, and assess sensitivity of some parameters (e.g. lime content) on the results.

Status of the project

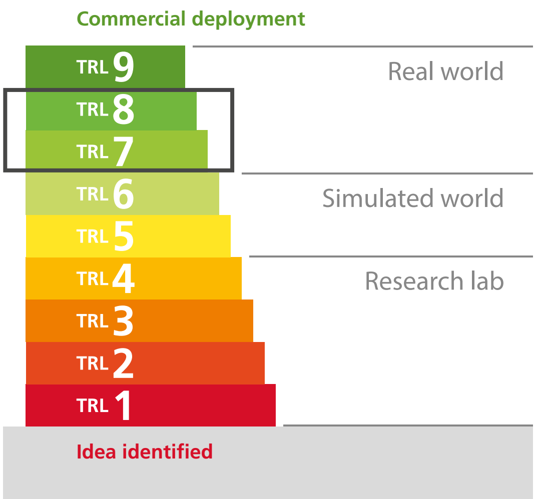
Project finalized in 2012. The following can be reported:

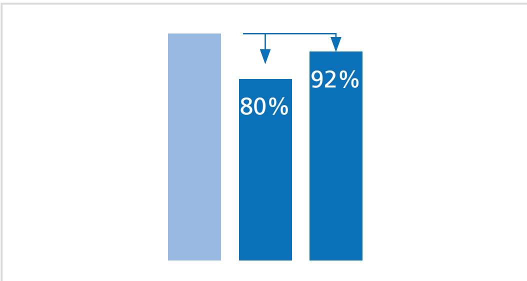
- A carbonation front moves progressively from mortar surface exposed to the atmosphere to depth of the mortar.
- Carbonation levels in ancient and new air lime mortars is: 80 to 92% generally [37, 38, 39].
- The carbonation front progresses around 190 mm for 100 years. Fastest carbonation rate is within the first years (i.e. 20 mm end of first 400d).
- The LCA results show that, the impact of the carbonation is the highest for the mortars or renders with the highest lime content. CO_2 footprint is reduced by 3% (cement based mortars) to 17% (lime based mortars).
- Considering carbonation, will change the overall carbon footprint for the lifetime of mortars/plasters [38, 39].

Contribution to

Lime carbonation – Lower carbon footprint – Intelligent building skins.

Type	Innovation action (demonstration)
Partners	Leader: EESAC (FR), Politecnico di Milano (PoliMI-IT) Lime: EuLA (EU)
Funding	EuLA EU contribution: not applicable
Duration	09.2011 – 09.2012 12.2018 – 03.2021
TRL	Technology Readiness Level: TRL 7-8





Air lime mortar (gradual increase over time).

REFERENCES:

[37] Schlegel T., Shtiza A., 2015. Environmental footprint study of mortars, renders and plasters formulations with no, low or high hydrated lime content. Mauerwerk 19: 5. Pp. 370-382. In English & German.

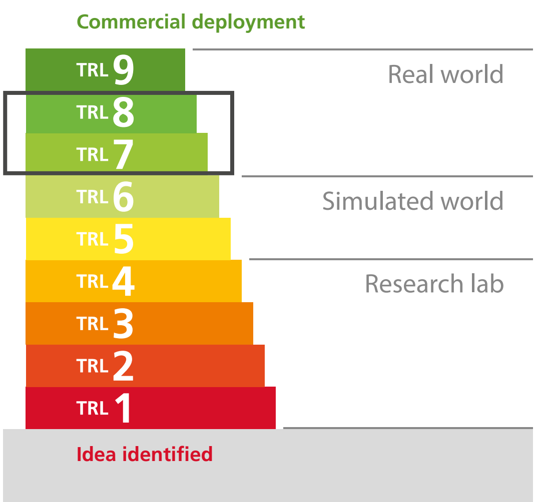
[38] Despotou E., Schlegel T. Shtiza A., Verhelst F., 2016. Literature study on the rate and mechanism of carbonation of lime in mortars. Mauerwerk 20: 2. Pp. 124-137. In English & German.

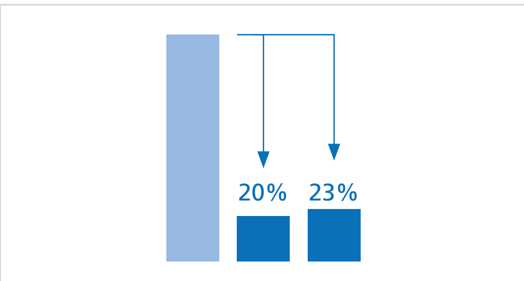
[39] Campo F. P., Grosso M. 2021. Lime based construction materials as carbon sink. Proceedings of MSSM2021, 4-6 August 2021, Brunel University London.

CONSTRUCTION: MIXED AIRLIME MORTARS • Carbonation mixed mortars (study)

eula.eu/politecnico-di-milano-literature-review-on-the--assessment-of-the-carbonation-potential-of-lime-in-different-markets-and-beyond/

Type	Innovation action (demonstration)
Partners	Leader: Politecnico di Milano (PoliMI-IT) Lime: EuLA (EU)
Funding	EuLA EU contribution: not applicable
Duration	12.2018 – 03.2021
TRL	Technology Readiness Level: TRL 7-8





Mixed air lime mortar (gradual increase over time).

Scope of work

Use of lime in mortar: lime mortars have been used since ancient times. Air lime mortars are made of hydrated lime ($Ca(OH)_2$) and Mixed air lime mortars are a mix of lime and other compounds to accelerate binding, e.g. Portland cement.
Air lime mortars harden as a result of their exposure to atmospheric CO_2, forming calcium carbonate ($CaCO_3$).
Thus, carbonation is part of the hardening and self healing process of air lime mortars. In mixed air lime mortars the hydrated lime will set by carbonation to limestone, while the co-binder sets in another reaction, often by hydration.
The information in literature indicated that for mixed air-lime mortars, the carbonation rate is: 20 to 23%.

Status of the project

Finalized [35, 36, 39].

Contribution to

Carbon removal in mortars – Carbon sink – Carbonation – CCU.

REFERENCES:
[35] Grosso M., Biganzoli L., Campo F. P., Pantini S., Tua C. 2020. Literature review on the assessment of the carbonation potential of lime in different markets and beyond. Report prepared by Assessment on Waste and Resources (AWARE) Research Group at Politecnico di Milano (PoliMI), for the European Lime Association (EuLA). Pp. 333.
[36] Campo F. P., Tua C., Biganzoli L., Pantini S., & Grosso M. 2021. Natural and enhanced carbonation of lime in its different applications: a review. Environmental Technology Reviewss. 10:1. Pp. 224-237. https://doi.org/10.1080/21622515.2021.1982023
[39] Campo F. P., Grosso M. 2021. Lime based construction materials as carbon sink. Proceedings of MSSM2021, 4-6 August 2021, Brunel University London.

HEMP LIME

Carbonation in hemp lime (study)

eula.eu/politecnico-di-milano-literature-review-on-the--assessment-of-the-carbonation-potential-of-lime-in-different-markets-and-beyond/

Scope of work

Use of lime for hemp lime: hemp lime construction materials are mainly used in France and the United Kingdom, where most publications originate from. Hemp lime material is made with hemp shiv, the chopped woody core of the stalks of the hemp plant. This is mixed with an air lime binder with pozzolanic cementitious or hydraulic lime additives and in some cases surfac-tants.

The air lime binder is hydrated lime ($Ca(OH)_2$). During the use phase of the hemp lime construction material, the hydrated lime carbonates by reacting with atmospheric CO_2 forming calcium carbonate ($CaCO_3$).

The literature review shows that for hemp lime:

- The natural carbonation rate is: 55%
- The enhanced carbonation rate is: 65%.

Status of the project

Finalized [35, 36, 39].

Contribution to

Carbon removal in hemp lime – Carbon sink – Carbonation – CCU.

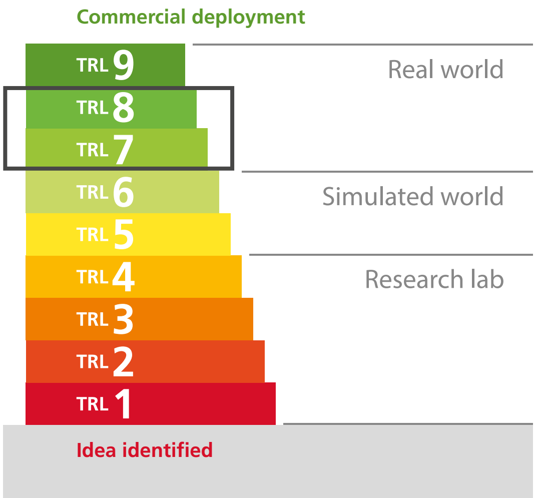
REFERENCES:

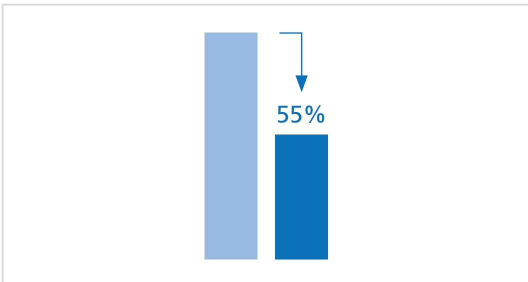
[35] Grosso M., Biganzoli L., Campo F. P., Pantini S., Tua C. 2020. Literature review on the assessment of the carbonation potential of lime in different markets and beyond. Report prepared by Assessment on Waste and Resources (AWARE) Research Group at Politecnico di Milano (PoliMI), for the European Lime Association (EuLA). Pp. 333.

[36] Campo F. P., Tua C., Biganzoli L., Pantini S., & Grosso M. 2021. Natural and enhanced carbonation of lime in its different applications: a review. Environmental Technology Reviewss. 10:1. Pp. 224-237. https://doi.org/10.1080/21622515.2021.1982023

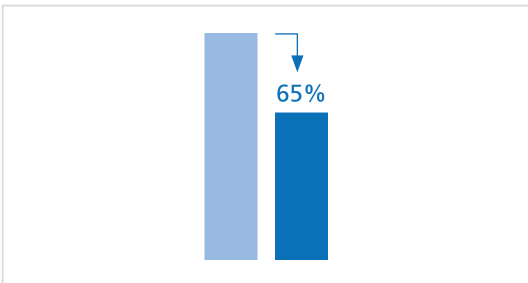
[39] Campo F. P., Grosso M. 2021. Lime based construction materials as carbon sink. Proceedings of MSSM2021, 4-6 August 2021, Brunel University London.

Type	Innovation action (demonstration)
Partners	Leader: Politecnico di Milano (PoliMI-IT) Lime: EuLA (EU)
Funding	EuLA EU contribution: not applicable
Duration	12.2018 – 03.2021
TRL	Technology Readiness Level: TRL 7-8





Natural carbonation rate (gradual increase over time).



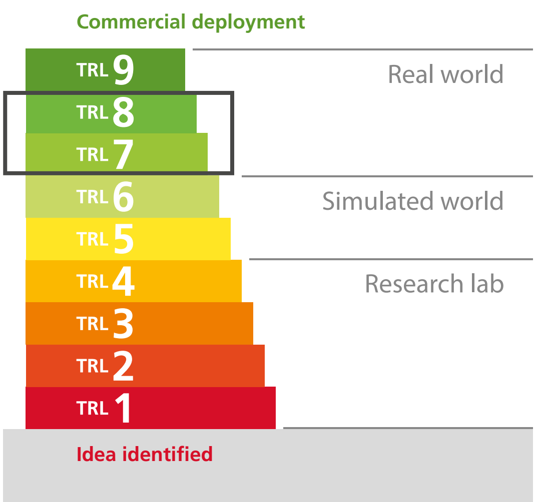
Enhanced carbonation rate (gradual increase over time).

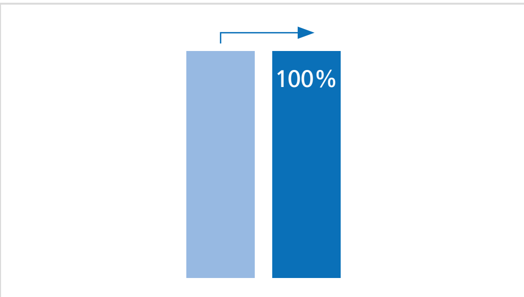
DRINKING WATER

Carbonation in treating drinking water (study)

eula.eu/politecnico-di-milano-literature-review-on-the--assessment-of-the-carbonation-potential-of-lime-in-different-markets-and-beyond/

Type	Innovation action (demonstration)
Partners	Leader: Politecnico di Milano (PoliMI-IT) Lime: EuLA (EU)
Funding	EuLA EU contribution: not applicable
Duration	12.2018 – 03.2021
TRL	Technology Readiness Level: TRL 7-8





Natural carbonation rate (instantaneous).

Scope of work

Use of lime in treating drinking water: lime is used in the drinking water sector for many applications such as softening, pH adjustment, acid neutralisation, metals removal, alkalinity adjustment or removal of fluoride, phosphate, sulphate and nitrogen. One of the main applications in water is softening, which aims to reduce the hardness of raw water (i.e. calcium and magnesium bicarbonates), reduce alkalinity and remove silica to avoid undesirable effects of scaling.

Carbonation process: the hard water is softened by using hydrated lime ($Ca(OH)_2$) to precipitate the dissolved calcium and magnesium as insoluble calcium carbonate and magnesium hydroxide, respectively. After sedimentation or settling these insoluble compounds are removed by filtration. Lime used in water softening is considered fully carbonated, because CaO and $Ca(OH)_2$ are absent in the obtained by-product containing calcium in the form of carbonate ($CaCO_3$).

Carbonation timeframe: the natural carbonation rate in time for drinking water is not reported in the assessed literature. It is presumably instantaneous, meaning that 100% of the amount of process emissions are absorbed during the use phase for the drinking water application.

Status of the project

Finalized [35, 36].

Contribution to

Carbon removal treating drinking water – Carbon sink – Carbonation – CCU.

REFERENCES:

[35] Grosso M., Biganzoli L., Campo F. P., Pantini S., Tua C. 2020. Literature review on the assessment of the carbonation potential of lime in different markets and beyond. Report prepared by Assessment on Waste and Resources (AWARE) Research Group at Politecnico di Milano (PoliMI), for the European Lime Association (EuLA). Pp. 333.

[36] Campo F. P., Tua C., Biganzoli L., Pantini S., & Grosso M. 2021. Natural and enhanced carbonation of lime in its different applications: a review. Environmental Technology Reviewss. 10:1. Pp. 224-237. https://doi.org/10.1080/21622515.2021.1982023

FLUE GAS CLEANING

Carbonation in flue gas cleaning (FGC) (study)

eula.eu/politecnico-di-milano-literature-review-on-the--assessment-of-the-carbonation-potential-of-lime-in-different-markets-and-beyond/

Scope of work

Use of lime in treating FGC: lime is used for removing the acid gases (HCl, SOx, HF) contained in flue gases generated from combustion plants: fossil fuel power plants, biomass combustion and waste in-cineration facilities. A flue gas treatment process can be semi-dry or dry, depending on the form of lime used. In (semi-)wet processes, lime is supplied as an aqueous solution or su-spension, i.e. as milk of lime or as lime slurry ($Ca(OH)_2$). During the reaction with the flue gas in wet processes, the reaction produces a slurry to be treated. While in semi-wet processes, the water evaporates and the reaction products are dry. In (semi)-dry pro-cesses, hydrated lime ($Ca(OH)_2$) powder is directly supplied as sorbent. For both pro-cesses the reaction products are separated in a conventional dedusting unit (typically a baghouse filter).

Carbonation process: during the flue gas treatment, lime reacts with HCl, HF and SOx but also with CO_2, forming calcium carbo-nate. The solid residues generated by the process, referred to as Air Pollution Control Residues (APCR), contain some amounts of free lime available for carbonation. Enhan-ced carbonation of APCR has been largely proposed as a technology to improve their chemical stability and their leaching beha-viour before their final disposal or recycling. Furthermore, enhanced carbonation of APCR allows for a contextual CO_2 sequestration directly at a CO_2 point source emission where these residues are generated.

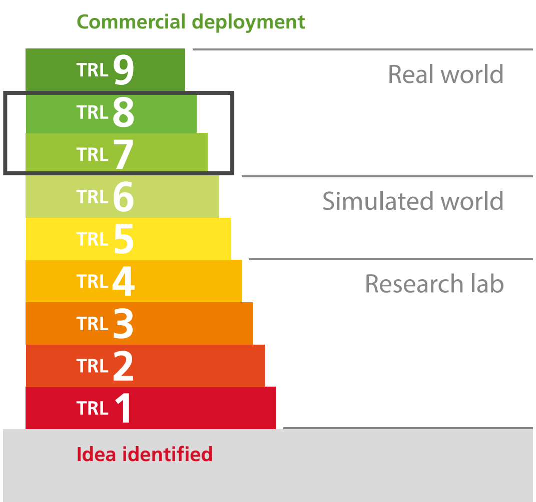
Status of the project

Finalized [35, 36].

Contribution to

Carbon removal in FGC – Carbon sink – Carbonation – CCU.

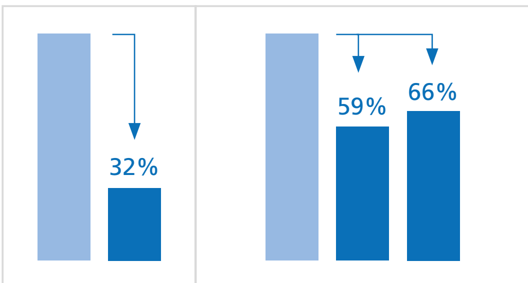
Type	Innovation action (demonstration)
Partners	Leader: Politecnico di Milano (PoliMI-IT) Lime: EuLA (EU)
Funding	EuLA EU contribution: not applicable
Duration	12.2018 – 03.2021
TRL	Technology Readiness Level: TRL 7-8



REFERENCES:

[35] Grosso M., Biganzoli L., Campo F. P., Pantini S., Tua C. 2020. Literature review on the assessment of the carbo-nation potential of lime in different markets and beyond. Report prepared by Assessment on Waste and Resources (AWARE) Research Group at Politecnico di Milano (PoliMI), for the European Lime Association (EuLA). Pp. 333.

[36] Campo F. P., Tua C., Biganzoli L., Pantini S., & Grosso M. 2021. Natural and enhanced carbonation of lime in its different applications: a review. Environmental Techno-logy Reviewss. 10:1. Pp. 224-237. https://doi.org/10.1080/21622515.2021.1982023



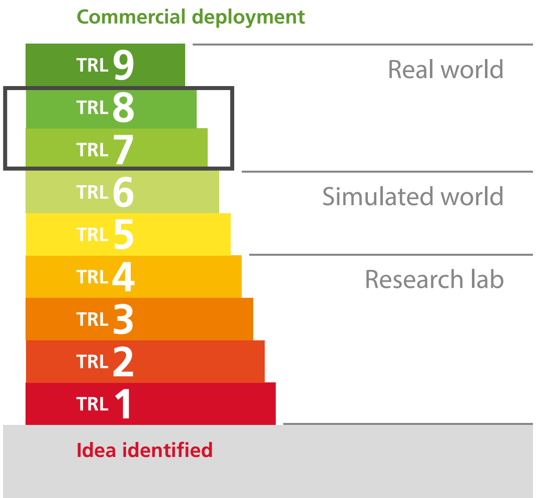
Natural carbonation rate (instantaneous).

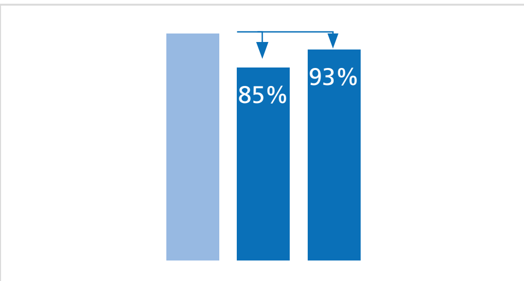
Enhanced carbonation rate (instantaneous).

PULP AND PAPER • Carbonation in precipitated calcium carbonate (PCC) (study)

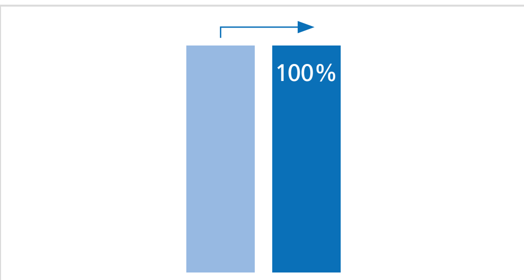
eula.eu/politecnico-di-milano-literature-review-on-the--assessment-of-the-carbonation-potential-of-lime-in-different-markets-and-beyond/

Type	Innovation action (demonstration)
Partners	Leader: Politecnico di Milano (PoliMI-IT) Lime: EuLA (EU)
Funding	EuLA EU contribution: not applicable
Duration	12.2018 – 03.2021
TRL	Technology Readiness Level: TRL 7-8





Natural carbonation rate (instantaneous).



Enhanced carbonation rate (instantaneous).

Scope of work

Use of lime in pulp and paper production: precipitated calcium carbonate (PCC) is largely used as a coating pigment or filler in pulp and paper but also in other industrial applications. PCC is produced chemically by combining carbon dioxide (CO_2) with lime (CaO) under controlled operating conditions. Hydrated lime slurry is put in contact with flue gases containing CO_2, leading to re-carbonation of the lime. Thus, calcium carbonate reforms, and being insoluble in water, it precipitates. Separation of impurities from the lime slurry is used to ensure high purity PCC.

The precipitation can produce each of the three crystalline forms (calcite, aragonite, and vaterite) depending on the reaction conditions. PCC characteristics can be tailored by regulating: the temperature, the CO_2 concentration and flow rate, the stirring rate, the particle size, the concentration of the hydrated lime slurry and the use of additives.

The literature review shows that for PCC:

- The natural carbonation rate is: 85 to 93%.
- The enhanced carbonation rate is: 100%.

Status of the project

Finalized [35, 36].

Contribution to

Carbon removal in PCC – Carbon sink – Carbonation – CCU.

REFERENCES:

[35] Grosso M., Biganzoli L., Campo F. P., Pantini S., Tua C. 2020. Literature review on the assessment of the carbonation potential of lime in different markets and beyond. Report prepared by Assessment on Waste and Resources (AWARE) Research Group at Politecnico di Milano (PoliMI), for the European Lime Association (EuLA). Pp. 333.

[36] Campo F. P., Tua C., Biganzoli L., Pantini S., & Grosso M. 2021. Natural and enhanced carbonation of lime in its different applications: a review. Environmental Technology Reviewss. 10:1. Pp. 224-237. https://doi.org/10.1080/21622515.2021.1982023

ALUMINUM

Carbonation in aluminum (study)

eula.eu/politecnico-di-milano-literature-review-on-the--assessment-of-the-carbonation-potential-of-lime-in-different-markets-and-beyond/

Scope of work

Use of lime in aluminium production: lime is used in the Bayer process, the principal means of refining bauxite ore for alumina extraction. During the Bayer process, bauxite is digested in a caustic liquor including lime. This process produces two output streams: a liquor rich with alumina that is used for sub-sequent aluminium production and a solid residue, called red mud, for disposal. This waste residue is an alkaline slurry with a water content of about 50-70% and a pH generally above 13. Current red mud disposal consists of dry stacking for thickening until it reaches a solid content of at least 48-55%. The thickened red mud is then stored in such a way that it consolidates and dries out.

Carbonation process: the natural carbonation of red mud involves both pore water carbonation and solid phase reactions of tri--calcium aluminate (TCA) dissolution and calcite precipitation. To neutralise the mud, reducing its pH, different neutralisation methods are proposed by means of seawater or tech-nologies that use artificial Ca and Mg rich brines. Another neutralisation is based on CO_2, i.e. a carbonation under enhanced conditions.

Carbonation timeframe: the timeframe for natural carbonation is not reported in the assessed literature. Carbonation occurring over a period of 100 years is considered as the worst case scenario.

The literature review shows that for aluminum:

- The natural and enhanced carbonation rate is: 11.5%.

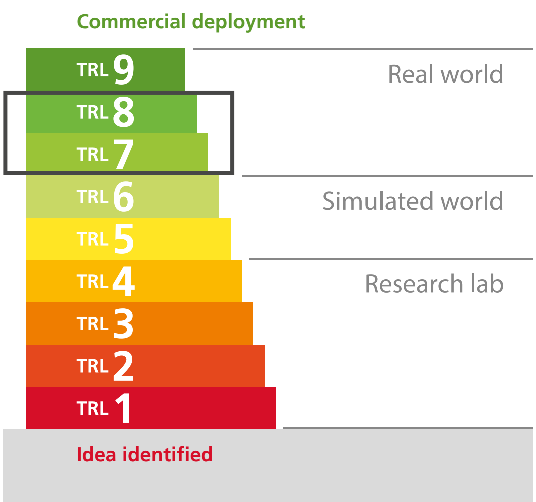
Status of the project

Finalized [35, 36].

Contribution to

Carbon removal in red mud – Carbon sink – Carbonation – CCU.

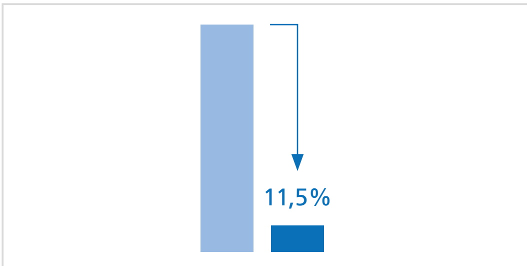
Type	Innovation action (demonstration)
Partners	Leader: Politecnico di Milano (PoliMI-IT) Lime: EuLA (EU)
Funding	EuLA EU contribution: not applicable
Duration	12.2018 – 03.2021
TRL	Technology Readiness Level: TRL 7-8



REFERENCES:

[35] Grosso M., Biganzoli L., Campo F. P., Pantini S., Tua C. 2020. Literature review on the assessment of the carbonation potential of lime in different markets and beyond. Report prepared by Assessment on Waste and Resources (AWARE) Research Group at Politecnico di Milano (PoliMI), for the European Lime Association (EuLA). Pp. 333.

[36] Campo F. P., Tua C., Biganzoli L., Pantini S., & Grosso M. 2021. Natural and enhanced carbonation of lime in its different applications: a review. Environmental Technology Reviewss. 10:1. Pp. 224-237. https://doi.org/10.1080/21622515.2021.1982023

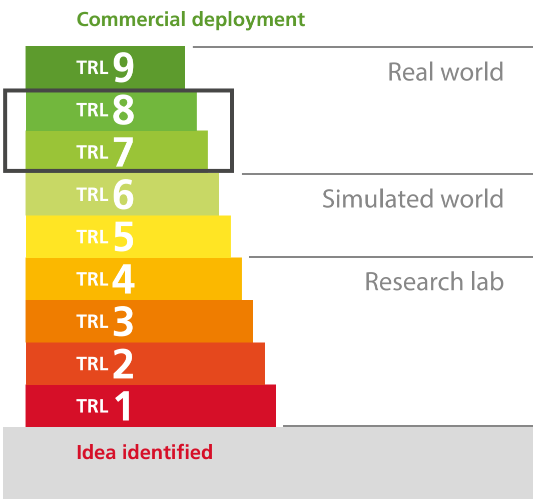


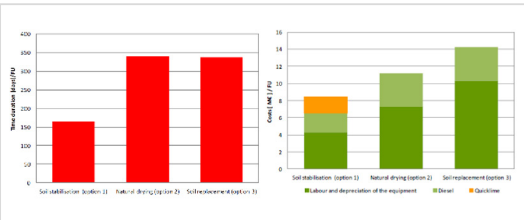
Natural carbonation rate (timeframe not reported in the assessed literature).

SOIL STABILIZATION
Carbonation in soil stabilization

eula.eu

Type	Innovation action (demonstration)
Partners	Leader/Lime: EuLA (EU)
Funding	Own initiative Total project: not reported
Duration	2014 – 2018, 2020 – 2023
TRL	Technology Readiness Level: TRL 7-8





Timeline to complete the works and cost savings.

REFERENCES:

[40] Haas S., Ritter H.-J. 2018. Soil improvement with quicklime – long-time behavior and carbonation. Journal Road Materials & Pavement Design by Francis & Taylor. Accepted. doi.org/10.1080/14680629.2018.1474793.

[41] Shtiza. 2016. La carbonatation de la chaux: Analyse du cycle de vie et analyse des couts du cycle de vie dans les applications au traitement des sols & mortiers. Mines & Carrières. Pp. 69-74. In English with French abstract.

[42] Denayer C., Verhelst F., Danvers J., Despotou E., Shtiza A., 2014. Linking environmental studies with natural carbonation: Case of two lime applications. 20th LCA Symposium Novi Sad (Serbia). 24 November 2014. Platform presentation.

Scope of work

The use of lime in soil treatment is widely known to improve the quality of soils for Civil engineering application. The effect is lime is widely documented for its benefits, and the carbonation reaction although known, has not been quantified. The main objectives of this project were:

- Perform tests to a German road build 34 years ago to measure qualitatively and quantitively the carbonation of lime in soil stabilization at a depth of 10 m. The selection of the site was relevant because similar study was performed 11 years after construction.
- The findings from the German study, were applied to a real soil stabilization project in France.

Status of the project

Project finalized in 2014. The following findings can be reported:

- The case study in a road in Germany, where the soil stabilization with lime was carried out 25 years ago indicated that carbonation rate is ranging between 35-40%. 10-15%: still available as free CaO and 50% is used for puzzolanic reactions. These results were obtained from the application of various techniques, such as X Ray Diffraction, Phenolphthalein as well as geochemistry modelling [40].
- When comparing: 1. Soil stabilisation with quicklime for the re-use of wet soils. 2. Natural drying of wet soils before re-use and 3. Replacement of wet soils by external suitable soils, the time to complete the works is shorter for option 1 and the cost savings by using lime soil treatment for the soil stabilization are in the range of 22% and 42% if compared to the natural drying (option 2) or Soil replacement (option 3) [41, 42].

Contribution to

Lime carbonation – Lower carbon footprint – Soil stabilization.

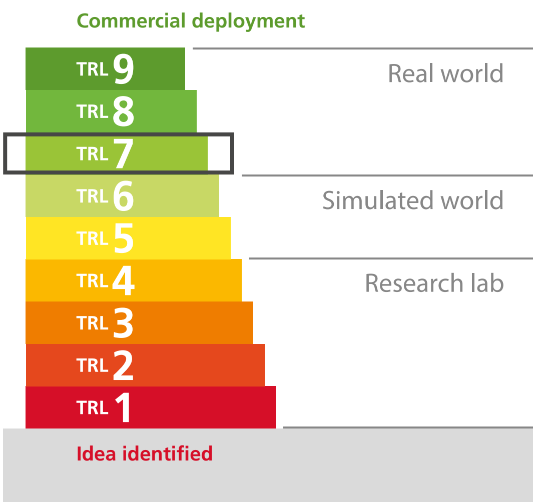
6. Projects in Pipeline

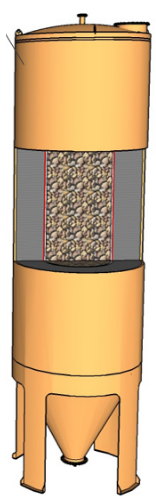
- CO_2 solid bed reactor
- CO_2ncrEAT
- Réty CCS

CO_2 SOLID BED REACTOR

Separation combined with a Bio-Methanation (CCU)

Type	Innovation action (pilot)
Partners	Leader: TBC Lime: manufacturing companies (10 from Germany, 4 from Austria) Electrochaea Pergande Group
Funding	Under negotiation Federal Ministry for Economic, Affairs and Climate Action (BMWK/KEI) Total project: 0.75 Mill EUR, ~60% funding rate if Phase II application is successful
Duration	12.2022 – 12.2025
TRL	Technology Readiness Level: TRL 7





Sketch of a CO_2 separation reactor.

Scope of work

The German lime industry has the vision of becoming carbon-negative through climate-neutral production until 2045. The project presented is of crucial relevance for this transformation, since this new CO_2 separation technology can be used as an end-of-pipe solution for separating unavoidable, process-related CO_2 of almost all kilns types and across industries. It is based on the principle of pressure swing absorption (PSA) and subsequent biological methanation (CCU). CO_2 with a purity of over 97% is to be separated from the flue gas of a lime kiln by means of a lime-based solid bed reactor and converted into methane in a bioreactor with the supply of hydrogen. The special feature of the separation reactor process is that the carbonization (CO_2 absorption) is carried out at overpressure and the calcination (CO_2 release) at negative pressure. Hence, the reaction enthalpy getting released during carbonization is stored within the solid bed and can be used for calcination subsequently. For that reason the reactor design and CO_2 separation is very energy- and cost-efficient compared to classic carbonate looping or MEA scrubbers. The CO_2 separation reactors (see figure) as well as the bio-methanation will be operated directly at a lime plant in the Harz Mountains. The pilot will have a 1:10 scale compared to a 200 t/d lime kiln. The methanation unit will be coupled in lab-scale within a mobile freight container.

Status of the project

Pilot plant project: Application Phase I was successful within the BMWK-program "Decarbonization of the industry"; Phase II application is submitted in 09.2022. Preceding project (running until 12.2022, Funding 0.75 Mill EUR): Tests at the technical center of the University of Magdeburg are finished, modelling is ongoing [43].

Contribution to

Carbon Capture – Carbon Dioxide Removal – Bio-Methanation (CCU).

REFERENCES:
[43] kalk.de/klimaschutz/co2-roadmap

CO_2ncrEAT • Industrialisation of the mineralization technology for building blocks using double circularity of lime process CO_2 emissions

Scope of work

Lhoist specializes in the production and sale of products based on minerals, calcium lime and dolomite, at its Dumont-Wautier site in BE-Hermalle-sous-Huy. Orbix develops and markets materials and sustainable technologies for the construction and steel industry. Prefer designs, produces, and sells precast concrete elements. Finally, Fluxys is the natural gas transporter in Belgium.
Their common point? These four companies combine their respective expertise around the innovative project CO_2ncrEAT, the block that eats CO_2. The project will support industry in Wallonia to decarbonize, by offering a sustainable solution for the construction sector. The production will deliver building blocks with a negative carbon footprint. "Lime is an essential product for various industries, such as steel recycling, Building, agriculture, water purification…". Lime production, generates unavoidable emissions given its process CO_2 part. With the CO_2ncrEAT project, the goal is to reuse approximately 20,000 tonnes of CO_2 annually from the lime operations and recovering it as a raw material to produce building blocks. This collaborative project proposal is first of a kind project, based on a strong and local circular economy and operators. The concrete result of the project is an eco-responsible block which will make an impact on the decarbonization of the building block and lime industry at the same time.

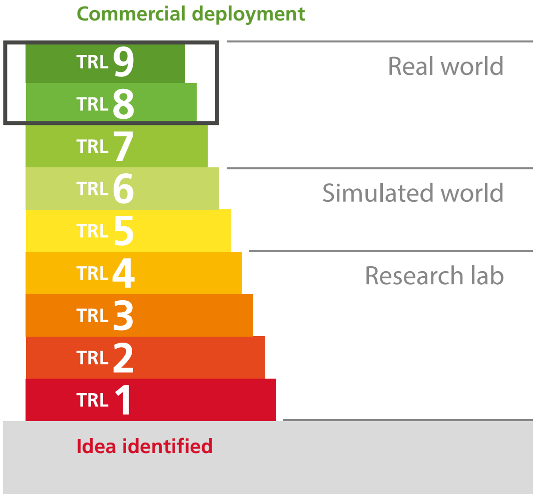
Status of the project

If funding is secured, the project will start in 2023.

Contribution to

CCU – Circular Emissions – Mineralization – Carbonation – First of a kind (FOAK).

Type	Innovation action (pilot)
Partners	Leader: Prefer Lime: Lhoist
Funding	Under negotiation Total project: 8 Mill EUR EU contribution: 4 Mill EUR
Duration	2023 – 2033
TRL	Technology Readiness Level: TRL 8-9



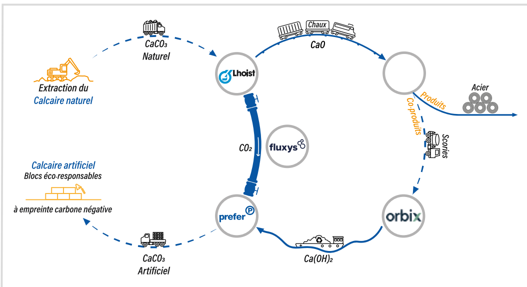


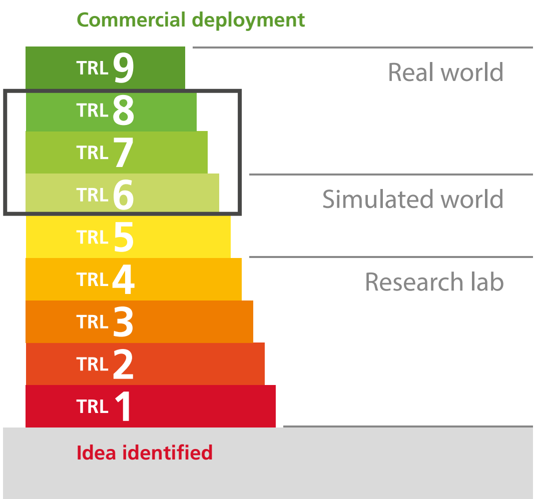
Illustration of the double circularity of the project.

RÉTY CCS

Decarbonizing lime manufacturing with Carbon Capture & Storage using cryogenic technology

lhoist.com/news/lhoist-and-air-liquide-join-forces-launch-first--its-kind-decarbonization-project-lime

Type	Innovation action (pilot)
Partners	Leader/Lime: Lhoist Partner: Air Liquide
Funding	Under negotiation Total project: confidential EU/national contribution: confidential
Duration	Construction: 2025 – 2027 Operation: 2028 – 2042
TRL	Technology Readiness Level: TRL 6-8



Scope of work

Lime manufacturing CO_2 emissions are from two sources:

- The unavoidable process emissions due to the calcining of limestone.
- CO_2 from the fuel combustion. The Lhoist site 'Chaux et Dolomies du Boulonnais' in Réty is the biggest lime production site in France.

Lhoist and Air Liquide have signed a memorandum of understanding with the aim of decarbonizing the Lhoist lime production plant located in Réty, in the Hauts-de-France region, using the Air Liquide cryogenic carbon capture technology. This technology aims to capture and purify 95% of the CO_2 emitted from Lhoist's existing lime production site in Réty, marking the first instance of its use to decarbonise lime production in France.

Once captured, the CO_2 gas will be transported to a multimodal CO_2 export hub currently under development in the area, before being permanently stored in the North Sea as part of the D'Artagnan EU project.

Thanks to this project proposal, Lhoist could reduce its CO_2 emissions from the Réty plant by more than 600,000 tonnes per year as from 2028. This is equivalent to the annual emissions of around 55,000 households in France.

Status of the project

Application submitted in 2022. Industrial operation targeted from 2028.

To kick off this project, Lhoist and Air Liquide have submitted a joint request for funding from the European Innovation Fund support program for large-scale projects. This partnership marks a new stage in the creation of a low-carbon industrial ecosystem in the wider area of Dunkirk.

Contribution to

Low carbon intensity lime – Carbon capture – CCS – CO_2 reduction.

7. Future Technological Innovation Priorities for the lime sector

The lime industry sector although small is an important sector due to its enabling nature and embedded in different value chains. Being an energy intensive sector, (70% of its CO_2 emissions are due to the decarbonation of the raw material), the lime industry's first priority is to find ways to mitigate those [44]. As you can see from this brochure extensive work has been done by the sector to address this challenge through multiple innovation actions/projects.

However, still a lot remains to be done. Finance to cover high risk investment from TRL 6 to TRL 9, is necessary to industrialize pilot findings. Technically and economically feasible CCU development could provide a sustainable solution for these emissions.

In a recent assessment, the lime industry agreed to focus on projects providing solution on **getting the CO_2 in some form of fuel and make it part of the fuel chain**, as for instance:

- Bioethanol.
- Biomass.
- Oxyfuel.

Few ideas for future innovation projects could be:

- Increase CO_2 concentration e.g. by looping.
- Indirect calcination.
- Methanisation.
- Low concentration CO_2 => Direct use for e.g. plant/algae/bacteria growth/feeding or flue gas cleaning.
- Combination with Oxyfuel process.
- Carbonation of mortars.
- Carbon dioxide Storage by Mineralisation (CSM).
- Storage of renewable energy by combination of Lime "Oxyfuel Process" with CO_2 – looping and methanization.
- Marine diesel desulphurization.

European Lime Industry is committed to provide sustainably produced products always caring about nature preservation, climate change mitigation technologies, energy efficient processes. Continuous improvements in technology innovation, health and safety at work place thus accompanying the current pathway towards an economically robust circular economy.

REFERENCES:

[44] EuLA. 2014. A Competitive and Efficient Lime Industry, Cornerstone for a Sustainable Europe (Lime Roadmap). Pp. 72.

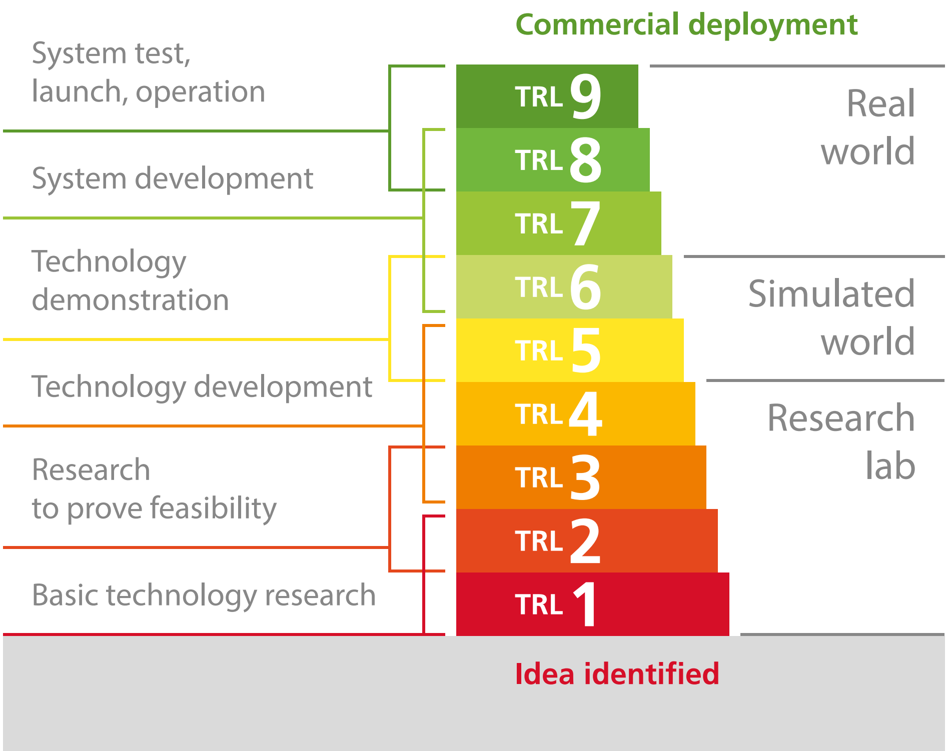
8. Annexes

Annex 1: Technology Readiness Levels (TRL scale)

Where a topic description refers to a TRL, the following definitions apply, unless otherwise specified [95]:

- TRL 1 – basic principles observed.
- TRL 2 – technology concept formulated.
- TRL 3 – experimental proof of concept.
- TRL 4 – technology validated in lab.
- TRL 5 – technology validated in relevant environment (industrially relevantenvironment in the case of key enabling technologies).
- TRL 6 – technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies).
- TRL 7 – system prototype demonstration in operational environment.
- TRL 8 – system complete and qualified.
- TRL 9 – actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies, or in space).

REFERENCES:
[95] ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf.



Annex 2: EuLA Innovation Task Force

This work was performed under the supervision of the European Lime Association (EuLA) Innovation Task Force and the coordination of Dr Aurela Shtiza. The support of experts contributing to the task force deliverables is greatly acknowledged.

To refer to this report please use the following reference: © EuLA. 2022. CO_2 Innovation in the lime sector 3.0. Pp. 1-60.

THE COMPOSITION OF THE EuLA INNOVATION TF AT THE TIME OF WRITING THIS REPORT WAS:

Active Members EuLA Innovation TF

Aladro Vico Jorge (Ancade)
Alan Ryan (Clogrennane)
Bernardi Lorenzo (Fassabortolo)
Choppin Thierry (Lhoist)
Connolly Joe (Clogrennane Lime)
Costea Bogdan (Carmeuse)
Cowling Tim (Tarmac/CRH)
Creveceour Stephane (Carmeuse)
Croft Christel (SingletonBirch)
Degerstedt Erik (Nordkalk)
Foster Steve (Singleton Birch)
Foucart Fabrice (Carmeuse)
Grégoire Damien (Carmeuse)
Habib Ziad (Lhoist)
Hopper Rebecca (BLA)
Makela Hanne (Nordkalk)
Marbehant Jean (Lhoist)
Markussen Eek (Franzefoss Minerals)
McCabe David (Tarmac/CRH)
Mehling Christine (Fels)
Mendizabal Gorka (Calcinor)
Mengede Martin (Franzefoss Minerals)
Moreschi Roberto (Unicalce)
Naffin Burkard (Fels)
Nuyken Philip (BVK)
O'Callaghan Denis (Clogrennane)
Ohnemüller Frank (BVK)
Patourel Laurence (UP Chaux)
Pelletier Marc (Lhoist)
Perrin Nicolas (Lhoist)
Peter Ulrike (Lhoist)
Pettiau Xavier (Lhoist)
Philipp Gerhard (Baumit)
Ponchon François (Carmeuse)
Pust Christopher (Lhoist)
Reilly Brendan (Cogrennane)
Roewert Bernd (Fels)
Roine Tiina (Nordkalk)
Ryan Jan Olav (Franzefoss Minerals)
Schmidt Sven-Olaf (BVK)
Shtiza Aurela (IMA-Europe)
Snare Mathias (Nordkalk)
Stumpf Thomas (Fels)
Tilquin Jean-Yves (Carmeuse)
Vaquette Cornelya (WKO)
Vels Thomas (Fels)
Verhelst Frederik (Lhoist)
Wangenborn Pernilla (Nordkalk)
Zocco Domenico (Lhoist)

Annex 3: List of projects and duration

Project	Company	Project type
PROCESS EMISSIONS MITIGATION		
BiOxySorb	Lhoist	Alternative fuel
CaO_2	Carmeuse	Carbonate looping
CARINA	Lhoist	Carbonate looping
CaLEnergy	Carmeuse	Carbonate looping
ECO	BVK	CO_2 capture
ECO_2	BVK	CO_2 capture
LEILAC1	Lhoist & Tarmac/CRH	CO_2 separation
LEILAC2	Lhoist	CO_2 separation
CSM	Nordkalk	Mineralization
C4U	Carmeuse	CCU
Columbus	Carmeuse	CCU
$LOWCO_2$	Calcinor	Ongoing pilot plant tests
ZerCaL	Singleton	Pilot plant
DinamX	Lhoist	Innovative application
INNOVATION IN ENERGY		
ADiREN4Lime	Singleton Birch	Anerobic digestion
WHeatRec4PG	Lhoist & Steetley	Heat recovery
Energy optimisation	Nordkalk	Heat recovery
Energy generation	Carmeuse	Energy generation
CHP Generation	Lhoist	Energy generation
Hydrogen Fuel Energy Innovation	BLA	Alernative fuels
FFL	Nordkalk	Innovation action (CO_2 free fuels)
NKL	Lhoist	Innovation action (CCU)
INNOVATION IN CARBONATION		
Carbonation	EuLA	(Re)Carbonation
Steel	EuLA	(Re)Carbonation
Construction: Pure airlime mortars	EuLA	(Re)Carbonation
Construction: Mixed airlime mortars	EuLA	(Re)Carbonation
Construction: Hemp lime	EuLA	(Re)Carbonation
Environment: Drinking water	EuLA	(Re)Carbonation
Environment: Flue gas cleaning	EuLA	(Re)Carbonation
Pulp and paper: PCC	EuLA	(Re)Carbonation
Non-Ferrous: Aluminum	EuLA	(Re)Carbonation
Civil Engineering: Soil Stabilization	EuLA	(Re)Carbonation
PROJECTS IN PIPELINE		
CO_2 solid bed reactor	BVK, Fels, Baumit	Innovation action (pilot)
CO_2ncrEAT	Lhoist	Innovation action (pilot)
Réty CCS	Lhoist	Innovation action (pilot)

2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
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