



CO₂ INNOVATION IN THE LIME SECTOR 4.0

The European Lime Association | Edition 2025



Innovation that delivers
on sustainability



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1. Executive summary

ADVANCING LIME INNOVATION AT THE HEART OF EUROPE'S CLEAN INDUSTRIAL DEAL

Europe is at a pivotal moment. As we transition toward a climate-neutral, competitive, and resilient economy, the European Union's Clean Industrial Deal should offer a robust policy and investment framework to decarbonise energy-intensive industries while strengthening Europe's technological leadership and industrial sovereignty.

Within this evolving context, the European Lime industry is stepping up. Lime and limestone are fundamental materials and essential enablers of other critical value chains, from steel and chemicals to environmental services and agriculture. Though often overlooked by the public eye, their role is vital to achieving a net-zero industrial ecosystem.

Innovation is the engine of this transformation.

EuLA and its members are committed to making innovation a cornerstone of our sector's response to the climate challenge. We are not only working to reduce emissions from our own operations, but also to develop solutions that enable decarbonisation across downstream industries. This is our contribution to building a thriving, clean, and competitive industrial Europe.

The EuLA Innovation Report 4.0 showcases the sector's continued commitment and progress. With around 20 new or advanced innovation projects (14 new initiated between 2022–2025) reported in this cycle, highlights how our member companies are working on topics of direct importance such as:

- Advancing CO₂ capture, use, and permanent storage technologies.
- Improving energy and resource efficiency across the value chain.
- Participating in CO₂ infrastructure development in UK.
- Addressing critical knowledge gaps through joint R&D & Innovation efforts.
- Innovating product applications that support circularity and low-impact industrial practices.

Importantly, we are also demonstrating how the unique properties of lime can contribute to emissions reductions beyond the production site. A key example is recarbonation, the chemical reabsorption of CO₂ by lime products during their use phase. Our sector has shown that, on average, 33% of CO₂ process emissions are recaptured within approximately one year through this mechanism. While this contribution is not yet accounted for in current carbon footprint assessments, it is

gaining increasing scientific and policy recognition. In particular, the Intergovernmental Panel on Climate Change (IPCC) is actively working on methodologies to better quantify and integrate carbon uptake through mineral carbonation, including recarbonation, into formal greenhouse gas inventories. Lime recarbonation potential delivers on carbonation in air, water and solid media. This development signals an important shift toward more comprehensive and accurate lifecycle carbon accounting.

We also acknowledge the challenges ahead. Creating favourable market conditions, securing funding access, and establishing a coherent regulatory framework are all essential to enabling innovation at scale. The recent

termination of promising projects such as [ZERCal](#) and [Columbus](#) due to economic and policy constraints rather than technical barriers illustrates the urgency of aligning innovation policy with industrial realities.

This report is both a testimonial of our achievements and a call to accelerate collective action. The lime sector stands ready to partner with institutions, academia, and industrial peers to realise the vision of a Clean Industrial Deal that is just, competitive, and globally leading.

Let this be an invitation to shape the future together, with lime as a catalyst for Europe's clean, smart, and sovereign industrial transformation.



Tim Van den Bossche
EuLA president



Rodolphe Nicolle
EuLA Secretary General

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:

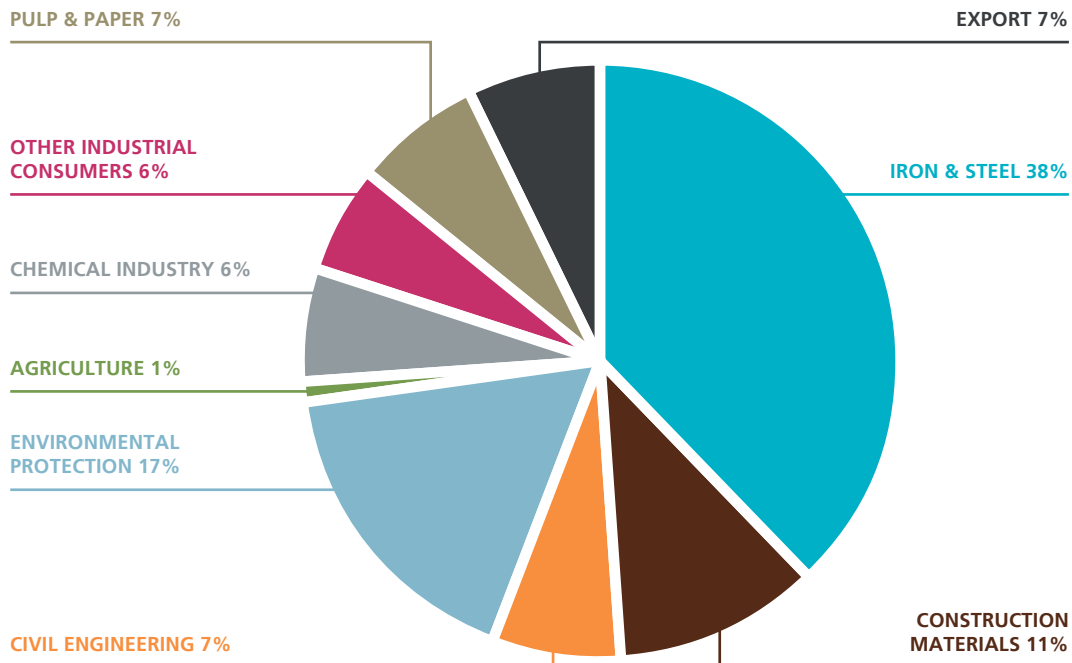
- Sustainable production.
- Responsible resources management.
- Delivering quality added valued products.
- Creating value and support local economies.
- Enabling the recycling of end of cycle materials in steel, glass and construction industry.
- Valorizing residues and turning them into raw materials 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 2023) [1]



REFERENCES:

[1] EuLA Database 2023. 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 cost effective 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 CO₂? [2]

Unique properties of lime contribute to emission reductions beyond the production site. A key example is recarbonation, the chemical reabsorption of CO₂ by lime products during their use phase. Lime sector has shown that, on average, 33% of CO₂ lime process emissions are recaptured within approximately one year through this mechanism.

...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.

...67% OF LIME IS RECYCLABLE? [3]

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 multiple by-products and waste streams. 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.

REFERENCES:

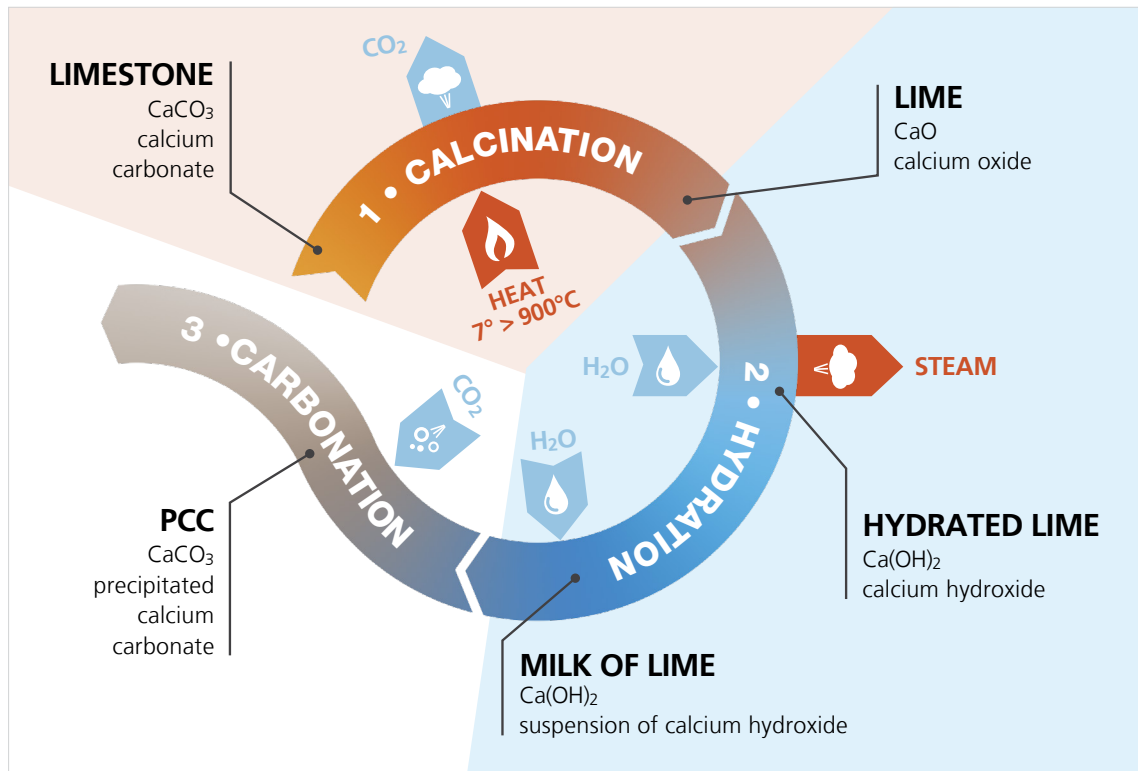
[2] EuLA, Carbonation, eula.eu/resources/carbonation.

[3] IMA-Europe, Recycling of industrial mineral applications. Contribution to circular economy, ima-europe.eu/wp-content/uploads/2023/08/IMA-Europe-Recycling-IM-2023-08-30-a-FINAL.pdf.



**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 $> 35 \text{ m}^2/\text{g}$. 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.

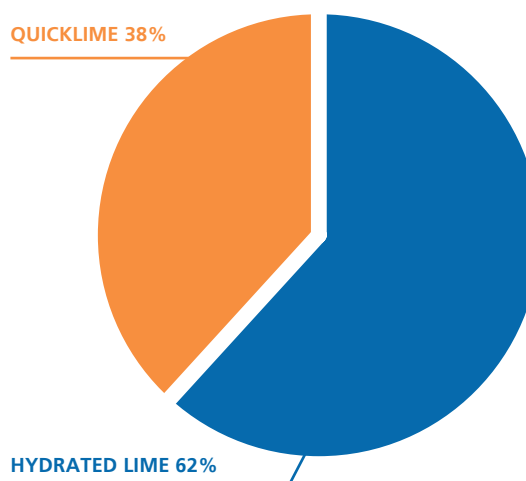
Other than in the EU, Lime is increasingly added to asphalt mixtures in the USA where Lime is known to enhance the durability of asphalt pavements. The field experience from North American State agencies estimate that

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:

- [4] 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.
- [5] 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, $\text{CH}_4 + \text{CO}_2$.

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 part of BAT Reference Documents (BREF) and any emerging techniques, giving special consideration to the criteria listed in Annex III of 2010/75/EU Directive [6].

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 veg-

etable 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 CO₂ from the flue gas in a fluidized bed reactor (Carbonator) producing limestone (CaCO₃). CO₂-free flue gas is released into the environment. In the second reactor (Calciner) the limestone is calcined and thereby CO₂ 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/Recarbonation: its the process by which lime reacts spontaneously with carbon dioxide (CO₂) to produce Calcium Carbonate (CaCO₃) to store it permanently. The reaction is exothermal and therefore thermodynamically favorable. Depending on the reaction matrix solid, water or gaseous, the CO₂ can come from the atmosphere, from water or from any other source. Quicklime reaction: $\text{CaCO}_3 + \text{heat} \Rightarrow \text{CaO} + \text{CO}_2$; Hydrated lime (slaked lime) reaction: $\text{CaO} + \text{H}_2\text{O} \Rightarrow \text{Ca(OH)}_2$; Recarbonation reaction: $\text{Ca(OH)}_2 + \text{CO}_2 + \text{H}_2\text{O} \Rightarrow \text{CaCO}_3 + 2\text{H}_2\text{O}$.

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 CO₂ 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.

Enhanced carbonation: the process by which the carbonation is fostered under enhanced carbonation dioxide concentration, and/or by optimised 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.

Flue gas treatment (FGT): industrial processes generate flue gases. These often contain pollutants such as sulfur oxides (SO₂ + SO₃), 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:

- [6] Best Available Techniques (BAT) Annex III of 2010/75/EU Directive.
- [7] 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.
- [8] EC. 2013. European Commission. HORIZON 2020-WORK PROGRAMME 2014-2015. 19. General Annexes Revised. Pp. 36.
- [9] EC. 2015. European Commission Decision C (2015) 8621 of 4 December 2015.
- [10] MinGuide. 2016. The MIN-GUIDE common approach. Deliverable 1.1. Version 1. Pp. 49.
- [11] OECD & Eurostat. 2005. Oslo Manual: Guidelines for collecting and interpreting innovation data. Pp. 166.

3. CO₂ process emission mitigation

- BiOxySorb
- CaO₂
- CARINA
- CaLEnergy
- ECO
- ECO₂
- LEILAC1
- LEILAC2
- SCARLET
- CSM
- C4U
- LOWCO₂
- DinamX
- CaLby2030
- Butterfly
- HECO2 Axe 5: SATURN
- IS2H4C
- Co₂ncreat
- CalCC



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, SO₂, SO₃ 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 [1].
- 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

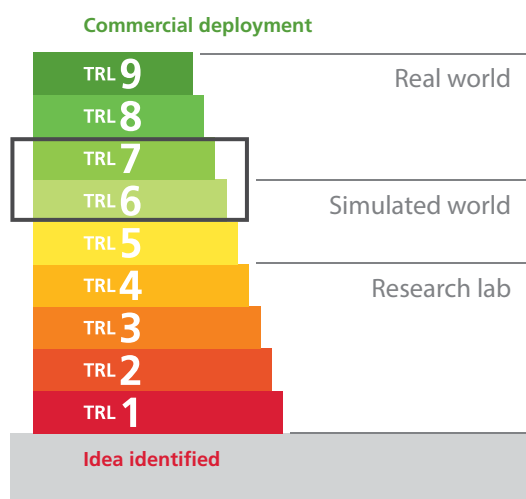


Funding EU / FP7 / RFCS
Total project: 2.1 Mill EUR
EU contribution: 1.3 Mill EUR



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:

- [1] 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.

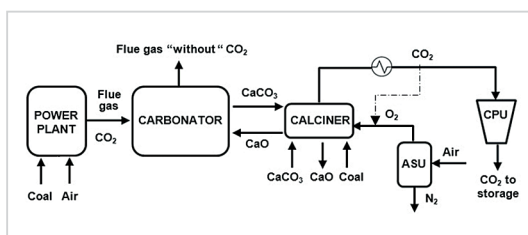
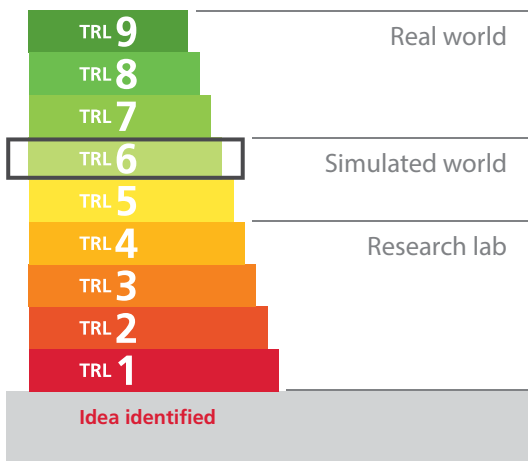
CaO₂

Calcium carbonate looping for coal power plants

carmeuse.com

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

Commercial deployment



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

REFERENCES:

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

Scope of work

The objectives of this project were two:

- The CaO₂ project intends to demonstrate in a large pilot (2-3 MW_{th}) a process optimisation of the CO₂ 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 CO₂ 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, recarbonation, 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 O₂.
- 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 CaO₂ project [1].

Contribution to

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

CARINA • Carbon Capture by Indirectly Heated Carbonate Looping Process

op.europa.eu/en/publication-detail/-/publication/27b-b757a-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 CO₂ avoidance costs than other CO₂ 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 CO₂ avoidance costs than the oxy-fired standard carbonate looping process.

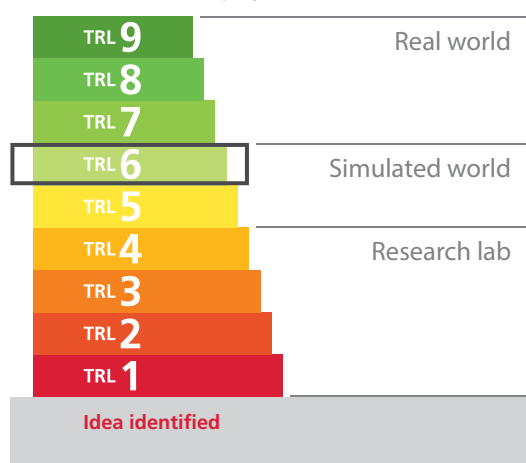
Status of the project

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 [1].
- 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 CO₂-capture and is particularly suited for retrofitting existing power plants [2].
- 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 [3].

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

Commercial deployment



Contribution to

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

REFERENCES:

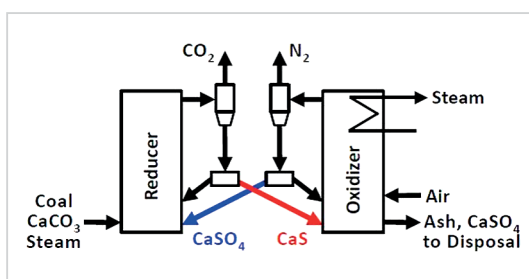
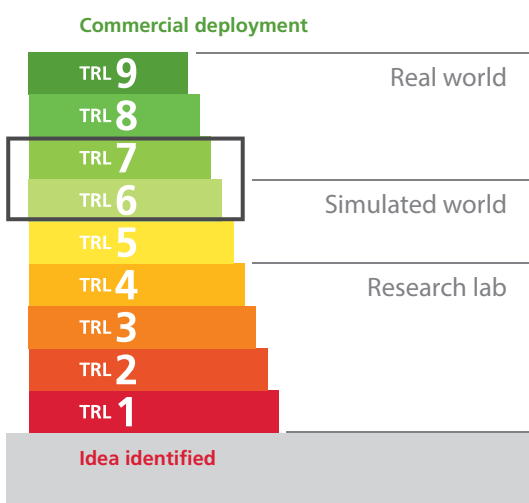
- [1] Höftberger D., Karl J. 2013. Self-Fluidization in an Indirectly Heated Calciner, Chemical Engineering & Technology, Volume 36: 9. Pp. 1533-1538.
- [2] Junk M., Reitz M., Ströhle J., Eppe B., 2013. Thermodynamic evaluation and cold flow model testing of an indirectly heated carbonate looping process, Chemical Engineering & Technology, Volume 36: 9. Pp. 1479-1487.
- [3] Kremer J., Galloy A. Ströhle J., Eppe B., 2013. Continuous CO₂ 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

carmeuse.com

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 CO₂ 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 [1].
- 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 [2].

Contribution to

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

REFERENCES:

- [1] Chamberland R. 2015. Alstom's Chemical Looping Combustion Technology with CO₂ Capture for New and Existing Coal-Fired Power Plants. Alstom Power, Inc., 2015 NETL CO₂ Capture Technology Meeting June 2015, Pittsburgh, PA.
- [2] Marion J. 2016. Alstom's Chemical Looping Combustion Technology with CO₂ Capture for New and Existing Coal-Fired Power Plants, GE Power, 2016 NETL CO₂ Capture Technology Project Review Meeting Aug 2016, Pittsburgh, PA.

ECO ● Ecological CO₂ scrubbing (ECO)

fgkalk.de//forschungsberichte

Scope of work

The aim of this research project was to investigate the recycling of anthropogenic CO₂ into the natural carbon cycle using lime products. In practice, the capture of CO₂ from flue gases with the help of a limestone-CO₂-washing process similar to the naturally occurring carbonate weathering process. Subsequently after the CO₂ cleaning process the "produced" calcium bicarbonate-rich solution (mineralized water) should be returned to limnic and marine environments as natural buffer [1].

Status of the project

The project was finished in 2012. The CO₂ scrubbing process with limestone powder in solution was successfully demonstrated at the waste water facility in Bad Orb. During performance tests a reduction of CO₂ within the flue gas by up to 13% was achieved [1]. A four-five stage cleaning system could lead to a CO₂ reduction of up to 80%, as modeling and calculations revealed [2].

Contribution to

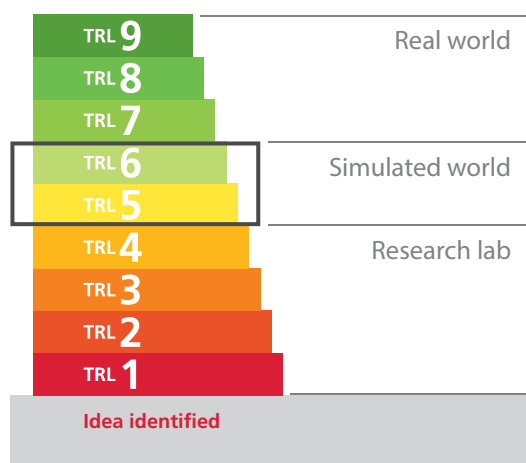
Carbon capture & use (CCU) – Natural carbon cycle – Lime technology – CO₂ reduction.

REFERENCES:

- [1] Haas S., Weber N., Berry A., Erich E., 2014. Limestone powder CO₂ scrubber: artificial limestone weathering for reduction of flue gas CO₂ emissions. ZKG (Zement Kalk Gips) International: 1-2. Pp. 64-72.
[2] 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

Commercial deployment

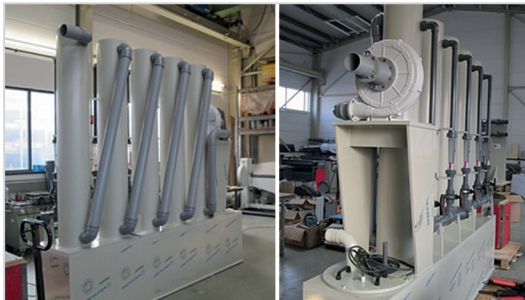
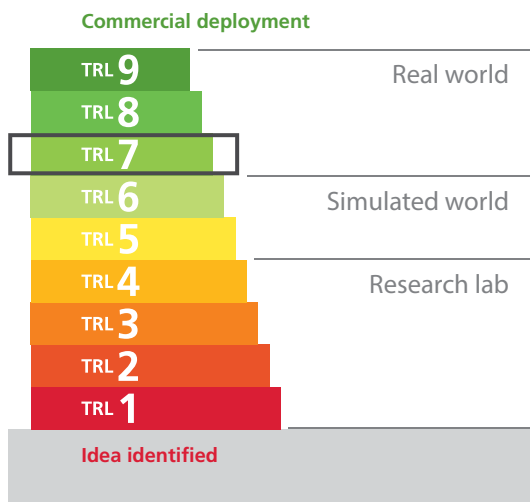


CO₂ scrubber used at the waste water facility at Bad Orb, Germany.

ECO₂ Economical CO₂ scrubbing

fgkalk.de

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 CO₂ scrubber of ECO₂ 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 CO₂ reduction due to the withdrawal from nuclear power generation, almost 100% import of natural gas and the particularly high quotas for CO₂ reduction. This study assesses the following points by constructing a pilot plant CO₂ scrubber, chemical analysis and modeling:

- Optimization of CO₂ 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 CO₂ 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 [1].

Contribution to

CO₂ reduction – Carbon capture and utilization (CCU) – Buffering of aquatic systems – Freshwater restoration – Multiple policy objectives.

REFERENCES:

[1] ECO₂ reports in German are available upon request. info@eula.eu.

LEILAC1

Low Emissions Intensity Lime And Cement

leilac.com

Scope of work

The aim of the project is to develop in situ CO₂ 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 CO₂ emissions. The DSR is an in-situ CO₂ 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 CO₂ emissions could be captured [1].
- 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 [1, 2].

Contribution to

CCU/CCS – Process emissions reduction – CO₂ mitigation.

REFERENCES:

[1] Rennie, D. 2017. Trapping process CO₂ emissions with the LEILAC project. GLOBAL CEMENT: CO₂ CAPTURE. Pp. 16-21.

Type Innovation action (pilot)

Partners Leader: Calix (Australia)
Lime: Lhoist & Tarmac/CRH



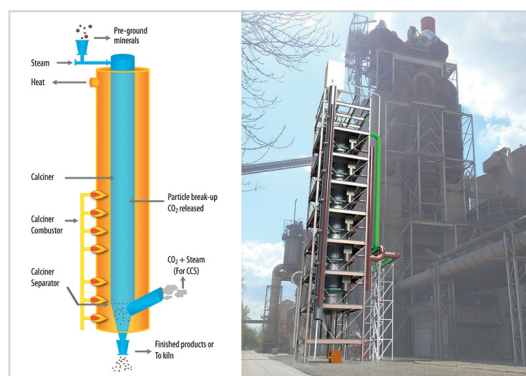
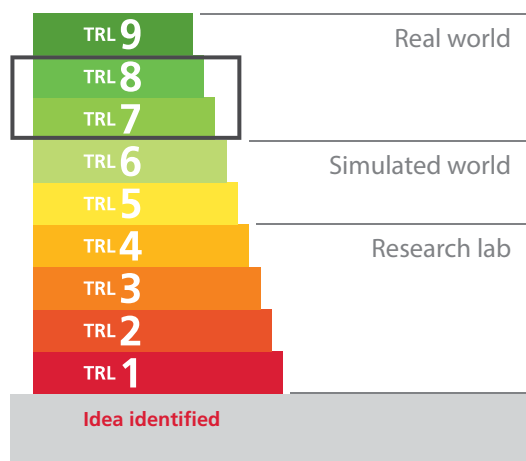
Funding EU / H2020
Total project: 20.8 Mill EUR
EU contribution: 11.9 Mill EUR



Duration 01.2016 – 06.2021

TRL Technology Readiness Level:
TRL 7-8

Commercial deployment



Original DSR and DSR superimposed in the Lixhe plant.

[2] Edwards, P. 2017. Trapping process CO₂ emissions with the LEILAC project. Global Cement Magazine. globalcement.com/magazine/articles/1004-trapping-process-co2-emissions-with-the-leilac-project.

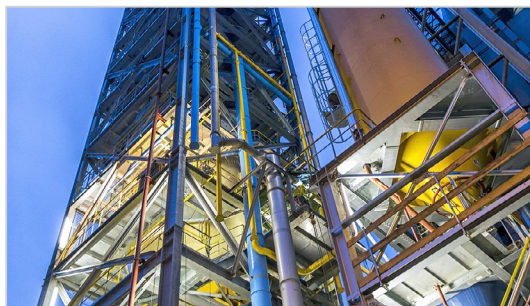
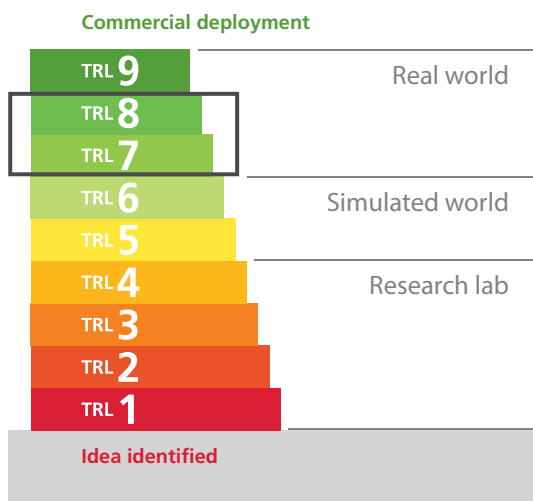
LEILAC2

Low Emissions Intensity Lime And Cement

leilac.com

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 CO₂ 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 CO₂ 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) [1].

Contribution to

CCU/CCS – Process emissions reduction – CO₂ mitigation.

REFERENCES:

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

SCARLET

Scale-up of Calcium Carbonate Looping Technology for Efficient CO₂ Capture from Power & Industrial Plants

cordis.europa.eu/project/id/608578/reporting

Scope of work

Calcium Carbonate Looping (CCL) is a technology tested for low-cost post combustion CO₂ capture for fossil fuels using limestone based solid sorbents. It combines the advantages of a small efficiency penalty of 5% to 7% points and a low CO₂ capture cost compared to competing technologies currently under development. First tests performed on the 1 MW_{th} scale have confirmed the feasibility of the technology.

- Long-term pilot testing of the CCL process at 1 MW_{th} scale at TU Darmstadt.
- Development and validation of scale-up tools and guidelines.
- Design, cost estimation, risk assessment study for a 20 MW_{th} CCL pilot plant.
- Techno-economic and environmental impact of commercial full scale CCL application.

Status of the project

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

- Long-term pilot testing with hard coal and lignite. Four long-term CCL test campaigns, were successfully performed. In more than 1,200 hours, CO₂ was captured under a wide range of parameters achieving capture rates up of to 94% in the carbonator with a corresponding total capture efficiency of 97%. Sorbent analysis showed that steady-state conditions reached chemical sorbent.
- Scale-up and engineering of 20 MW_{th} pilot plant. The CCL process is being scaled up to a 20 MW_{th} pilot plant hard coal power plant as the host site in France. The process configuration was defined as well as heat and mass balances for design case and various load cases were created. The design of reactors as well as auxiliary systems and measurement equipment is ongoing.
- The SCARLET project has identified the technical and economic integration of CCL into a commercial power plant, a steel plant, or a cement plant to optimize performance and minimise technical risks, targeting efficiency, reliability, and operability [1, 2].

Type Innovation action (pilot)

Partners Leader: TU Darmstadt (DE)
Lime: Lhoist



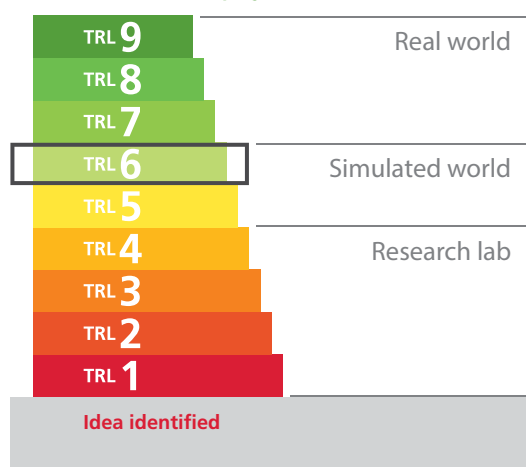
Funding EU / FP7
Total project: 7.3 Mill EUR
EU contribution: 4.7 Mill EUR



Duration 04.2014 – 03.2017

TRL Technology Readiness Level:
TRL 6

Commercial deployment



Contribution to

Carbon looping – Lime technology – CCU.

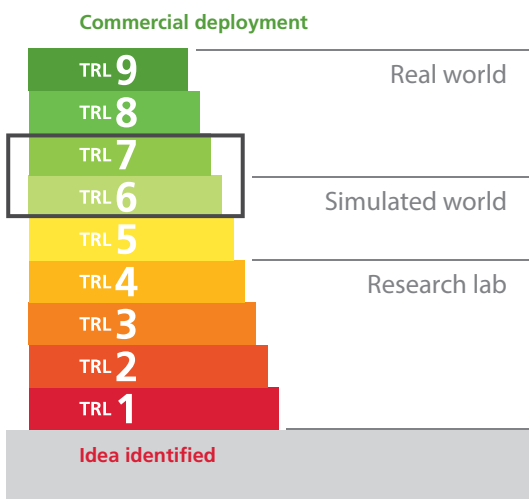
REFERENCES:

- [1] Stroh A., Alobaid F., Ströhle J., Hasenzahl M.T., Hilz J., Eppe B., 2015. Comparison of three different CFD methods for dense fluidized beds and validation by a cold-flow experiment. Particulate 2015, Article in Press.
- [2] Zeneli M., Nikolopoulos A., Nikolopoulos N., Grammelis P., Kakaras E., 2015. Application of an advanced coupled EMM5-TFM model to a pilot scale CFB carbonator, Chemical Engineering Science: 138, Pp. 482-498.

CSM ● Carbon Storage by Mineralisation

nordkalk.com

Type	Innovation action (demonstration)
Partners	Leader: Cluster for Energy & Environment CLEEN (FI) + 18 industry, 9 research (FI) Lime: Nordkalk ◆ 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 CO₂ capturing mineral looked promising, but replicating to limestone minerals technical difficulties and the results were quite poor [2, 3].

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

REFERENCES:

- [1] 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 impact on Energy Systems. 26-29 June in Perugia, Italy. Pp. 13.
- [2] CCSP Carbon Capture and Storage Program 1.1.2011 –31.10.2016. Final report. Pp. 1-248. finalreports.fi/wp-content/uploads/2023/12/CCSP-Final-report.pdf.
- [3] Teri S. Et al. 2013. CCSP Carbon Capture and Storage Program. Mid-term report. Pp. 82.

Scope of work ●

The stepwise carbonation of serpentinite, a rock composed mainly of magnesium silicate mineral serpentine reacts with the CO₂ to form a stable compound, thus fixing the CO₂ 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 CO₂ 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 CO₂ flue gas without capture, mineral sequestration may be accomplished at an energy penalty of 0.9 GJ/t CO₂ electricity besides 2.6 GJ/tCO₂ heat which can be extracted from the kiln gas [1].
- Direct mineralisation of flue gas instead of separated and compressed CO₂, eliminates the need of expensive and energy intensive processes to isolate and compress CO₂, thus significantly lowering the materials and energy requirements for the overall CCS process chain [1, 2].
- An exergy analysis is used to optimise process layout and energy efficiency, and at the same time maximise the amount of CO₂ that can be bound to MgCO₃ 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 CO₂ separation makes CSM an attractive and cost-competitive option when compared to conventional CCS involving underground storage of CO₂ [2].

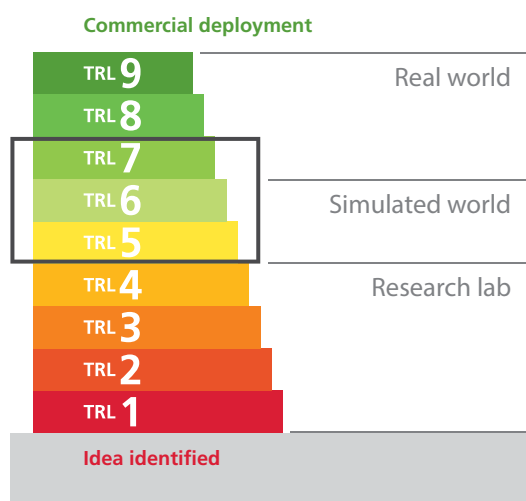
Scope of work

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 CO₂ 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 CO₂ on the safety and operation of the CO₂ 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 CO₂ 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, CO₂TransPorts aims to establish the necessary infrastructure to facilitate the large-scale capture, transport and storage of CO₂ 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 CO₂ per year.

Type	Innovation action (demonstration)
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 – 03.2025
TRL	Technology Readiness Level: TRL 5-7



Status of the project

The project started in 2020.

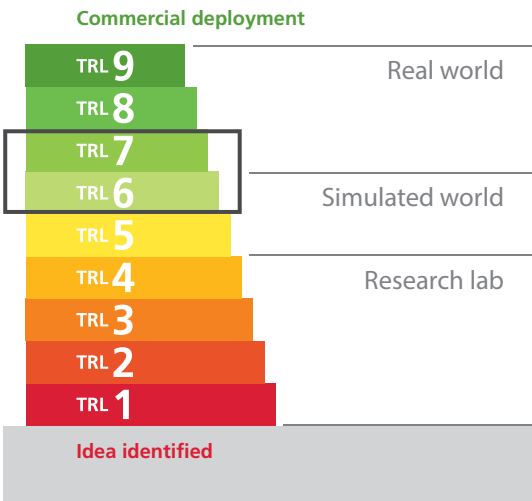
Contribution to

CCU/CCS – Process emissions reduction – CO₂ mitigation – CO₂ infrastructure – Carbon capture engineering.

LOWCO₂

aclima.eus/noticia/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



proving 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 CO₂ emissions, and creation of new value chains thanks to CO₂ capture and use.

Contribution to CCU/CCS – Process emission reduction – CO₂ mitigation – Carbon Capture Engineering – Carbonation/Recarbonation.

Scope of work

The LOWCO₂ project objective is to innovate towards competitive technologies of capture and valorization of industrial CO₂. With a duration of 4 years, some technologies of capture and valorisation of industrial CO₂ will be developed and validated. Several strategic innovations are piloted: new materials and processes for the capture of CO₂; technologies for the carbonation of residues (incorporation of the CO₂ 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 CO₂ transformation.

The processes of CO₂ 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 CO₂ (GtCO₂) should be captured and stored between 2015 and 2030, and more than 100 GtCO₂ at a global level during the 2030-2050 period whereas. Now only 1% of the released CO₂ 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 CO₂ uses:

- CO₂ 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 CO₂ emissions, thus im-

DINAMX

Demonstration and DMX Innovative Application

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

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 CO₂ 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 Retz site have been evaluated [1, 2].

Status of the project

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

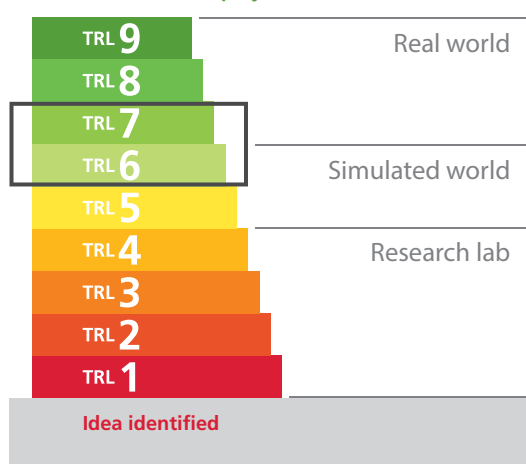
- Validation on the lab pilot scale of the DMX process in the case of a lime flue gas typical composition.
- Elaboration of a specific DMX blend according to the specificities of the gas.
- First evaluation of the Capex and Opex including associated pre-treatment and utilities in the case of a full-size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

Contribution to

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

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

Commercial deployment



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

REFERENCES:

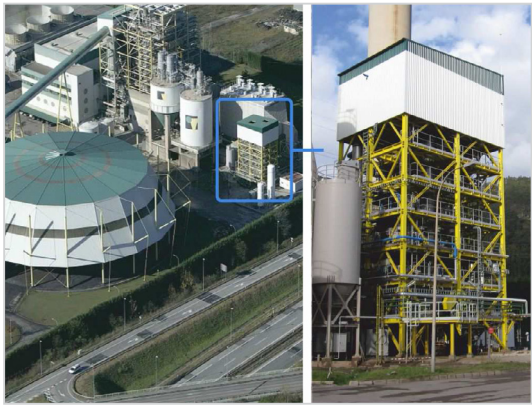
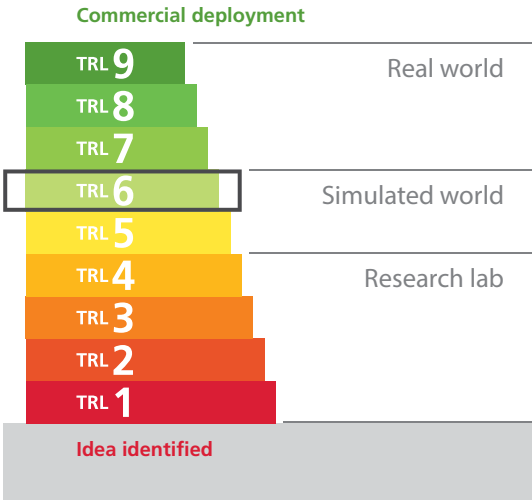
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- [2] carboncapturejournal.com/news/launch-of-dinamx-industrial-co2-capture-pilot-in-france/4440.aspx?Category=all.

CALBY2030 ●

Decarbonising industrial processes with Calcium Looping by 2030

calby2030.eu

Type	Carbonate looping
Partners	Leader: Agencia Estatal Consejo Superior de Investigaciones Cientificas (ES) Lime: Carmeuse (BE)
	
Funding	Total project: 15 Mill EUR EU contribution: 15 Mill EUR
Duration	10.2022 – 03.2026
TRL	Technology Readiness Level: TRL 6



One of the pilot plant located in CHP plant.

Scope of work ●

Calby2030 aims to facilitate the commercial deployment of Calcium Looping technology from 2030 in industries where a significant portion of their CO₂ emissions is currently unavoidable. Three TRL 6 pilot plants will be established across Europe – in Sweden, Germany, and Spain – to test this circulating fluidized bed-based technology under industrially relevant operating conditions [1, 2].

Status of the project ●

Over 4.5 years, Pilots will collectively create a database with thousands of operation hours. This data will be analyzed with advanced modeling tools to scale up CO₂ capture reactors to commercial levels. Techno-economic simulation, cluster optimization, and Life Cycle Analysis will aim to maximize renewable energy use and materials circularity. This information will support FEED studies for EU demonstration plants. Novel solutions are under development and testing to achieve >99% CO₂ capture rates while minimizing cost and energy intensities. Societal scientists and environmental economists are assessing the social acceptability and preferences for “zero” or “negative emissions” CaL demonstration projects using methodologies intended to identify and help overcome current societal barriers for the implementation of CCUS.

Contribution to ●

Calcium looping – Circulating fluidized bed – Recarbonation – Calcination – CO₂ capture – CO₂ concentration.

REFERENCES:
[1] calby2030.eu/resources/resources-34/publications.
[2] cordis.europa.eu/project/id/101075416.

BUTTERFLY ●

carmeuse.com/eu-en/newsroom/global/minister-willy-borsus-lays-first-foundation-stone-carmeuse-innovative

Scope of work ●

The 30th of June 2024 Carmeuse Butterfly project laid the foundation stone of the new demonstrator site. The project aims to revolutionize lime production and combat the pressing issue of CO₂ emissions. With financial backing from the Walloon Government and the European Union, this ambitious goal seeks to develop an industrial-scale demonstrator: a new type of kiln designed to effectively capture and concentrate CO₂ released during lime production. By achieving a highly concentrated CO₂ stream (more than 80%) at the end of the kiln stack, the project seeks to enable efficient capturing of CO₂ for subsequent utilization or sequestration (CCUS). This pioneering technology represents a significant leap forward in addressing the two primary sources of CO₂ emissions in lime production: approximately 30% from necessary combustion to generate high heat levels (around 1000 °C) and 70% from the inherent “process CO₂” which is unavoidable as this CO₂ is an inherent part of the decarbonization of the limestone. While combustion emissions could be mitigated by using low carbon fuels, tackling process-related CO₂ emissions remains imperative. Carmeuse’s efforts, demonstrated through the Butterfly project, offer a promising solution to produce carbon neutral lime.

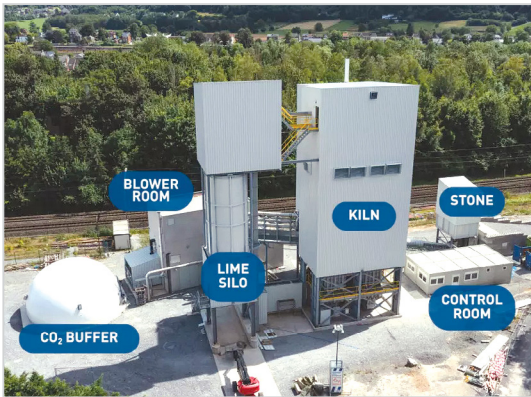
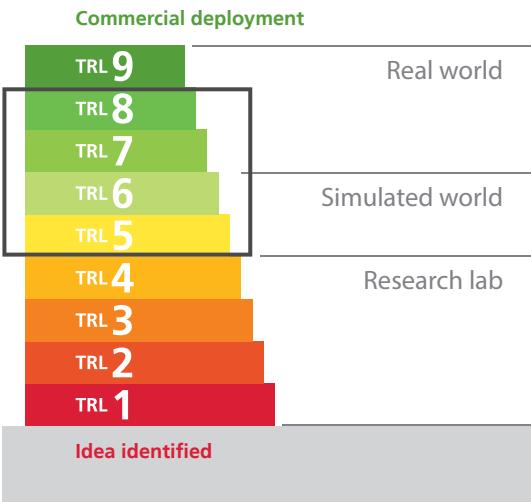
Status of the project ●

The industrial demonstrator entered in operation in October 2024, serving as a platform for technological testing. Several testing campaigns are foreseen in 2025 to validate the process. If successful, the technology could be implemented in Carmeuse lime production plants worldwide, enabling the production of carbon-neutral lime.

Contribution to ●

CCUS – Carbon neutral lime – Oxycombustion.

Type	CCU & CCS
Partners	Leader/Lime: Carmeuse 
Funding	Total project: not reported EU & national contribution: not reported
Duration	06.2024 – 06.2026
TRL	Technology Readiness Level: TRL 5-8

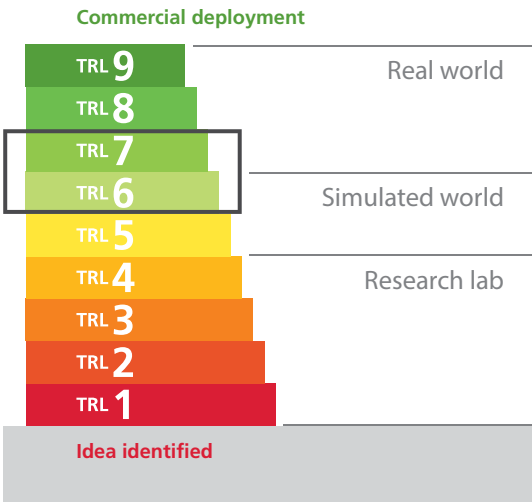


Oxyfuel demo kiln in Belgium.

HECO₂ AXE 5: SATURN ●

greenwin.be/fr/page/au_sujet_de_heco2
youtube.com/watch?v=r9UmJG6Gmiw&t=82s

Type	Carbon capture
Partners	Leader: Aperam Lime: Carmeuse
	
Funding	Total project: not reported National contribution: not reported
Duration	06.2022 – 05.2026
TRL	Technology Readiness Level: TRL 6-7



Scope of work ●

The Saturn project aims at identifying the most suitable CO₂ capture technology applicable to 4 different industrial sectors: Stainless Steel, Lime, Glass and Phosphate production. After evaluation and comparison of the different technologies available and their applicability to the different industrial conditions, pilot testing of a carbon capture unit will be conducted in 4 representative industrial sites. Additionally, academic partners will provide expertise in the analysis of the different technologies and modeling capabilities to assess the technical and economical performance as well as their overall environmental impact [1].

Status of the project ●

Project started in 2022. The following achievements can be reported:

- Emissions profiles from the 4 different industries have been characterized.
- In depth screening and performance evaluation of the available carbon capture technologies have been conducted.
- LCAs of different technical solutions have been conducted for each industrial cases.
- Order of a pilot carbon capture plant.
- Preparation of the first trial campaign (planned for Q2 2025 in a Carmeuse plant).

Contribution to ●

CO₂ capture – CO₂ concentration – CCUS – Carbon neutral lime.

REFERENCES:

[1] 2024. Carmeuse-Sustainability Insights. Pp. 47. carmeuse.com/sites/default/files/2024-11/carmeuse_sustainability_report_2024_0.pdf.

IS2H4C

Sustainable Circular Economy Transition: from Industrial Symbiosis to Hubs for Circularity

is2h4c-project.eu/#projectobjectives

Scope of work

The IS2H4C project (Industrial Symbiosis Hubs for Circularity), funded under the EU Horizon Twin Transition programme, promotes systemic industrial symbiosis to drive the Circular Economy. It focuses on transforming industrial areas into interconnected ecosystems based on resource efficiency, CO₂ capture, renewable hydrogen production, and cross-sector collaboration.

To achieve this, IS2H4C is developing four demonstration hubs (Germany, Spain, Turkey, and the Netherlands), where industries, research organisations, and public entities co-create sustainable technologies. Key innovations include carbon capture and utilisation (CCU), green hydrogen via electrolysis, and circular valorisation of industrial by-products. The project also explores novel governance and business models to scale Hubs4Circularity across Europe.

Status of the project

Launched in 2024, IS2H4C includes Calcinor as a key player in the Basque Hub, one of Spain's most industrialised regions and part of the Basque Hydrogen Corridor. Calcinor works alongside the steel, oil refining, pulp and paper sectors, and the regional wastewater treatment facility.

Three main synergies are being developed:

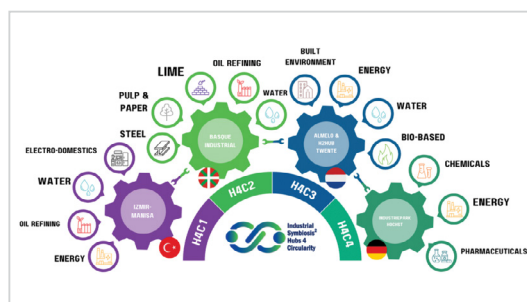
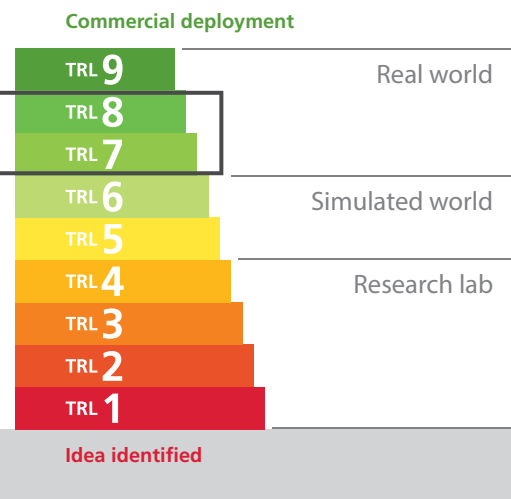
1. Oxy-combustion using O₂ and H₂ in steel manufacturing, with renewable hydrogen from refining electrolysis;
2. CO₂ capture in lime kilns, and CCU to produce methane and potentially e-fuels;
3. Carbonation of steel slags using captured CO₂ to develop low-carbon construction products.

Calcinor's participation, supported by EU funding, reflects the lime industry's strong commitment to climate-neutral innovation and scalable industrial decarbonisation.

Contribution to

Cross sectoral innovation – Industrial Symbiosis – Carbonation – Oxyfuels.

Type	Ocyfuel – CCU
Partners	Leader: Universiteit Twente (NL) Basque Industrial Hub partners* Lime: Calcinor (ES)
Funding	Total project: 23.3 Mill EUR EU contribution: 19.9 Mill EUR
Duration	01.2024 – 01.2028
TRL	Technology Readiness Level: TRL 7-8



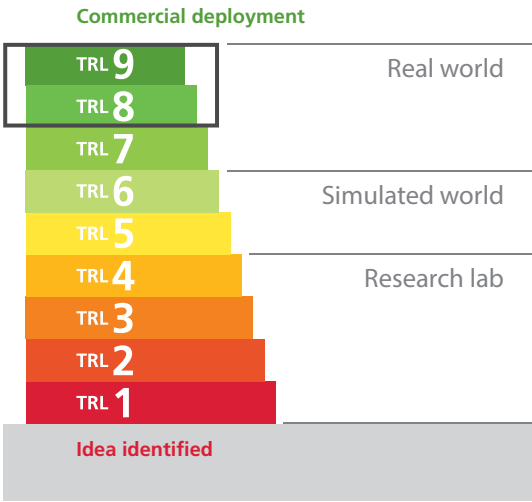
* The IS2H4C project is a collaborative multi-disciplinary effort involving a diverse group of experienced partners from across Europe (8 countries) and beyond. is2h4c-project.eu/partners-2/.

CO₂NCREAT ●

Industrialization of a mineralization technology for building blocks

lhoist.com/en/co2ncreat

Type	Carbon capture & use (CCU)
Partners	Leader: Prefer (BE) Lime: Lhoist
	   
Funding	Total project: not reported EU contribution:
Duration	expected 2027
TRL	Technology Readiness Level: TRL 8-9



* The information provided in this document is intended solely for general informational purposes and does not constitute a binding commitment. It is based on current assumptions and projections and is therefore subject to change. No warranties or guarantees are made regarding the accuracy, completeness, or future validity of the content presented.

Scope of work ●

CO₂ncreat is an innovative industrial project based in Hermalle-sous-Huy, Belgium, designed to manufacture eco-friendly masonry blocks with a negative carbon footprint. The process replaces traditional cement and natural aggregates with recycled steel slags (from Orbix) and CO₂ captured from dolime kiln exhaust gases (from Lhoist), transported via pipeline by Fluxys.

Status of the project ●

Under development.

Contribution to ●

CCU – Circular emissions – Mineralization – Recarbonation – First of a kind (FOAK).

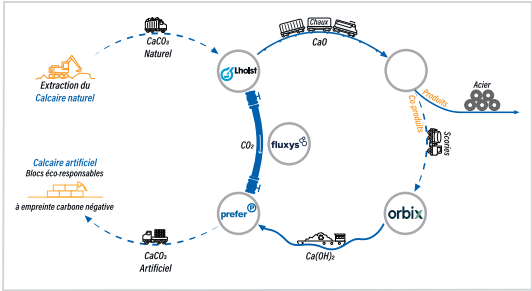


Illustration of the double circularity of the project.

CALCC**Decarbonizing lime manufacturing with Carbon Capture & Storage using cryogenic technology**lhoist.com/en/calcc**Scope of work**

The Lhoist site 'Chaux et Dolomies du Boulonnais' in Réty (Hauts-de-France region) is the biggest lime production site in France. Through the CalCC project, Lhoist and Air Liquide aim to decarbonize this plant using the Air Liquide Cryocap™ FG unit. This technology aims to capture and purify the CO₂ emitted from Lhoist's existing lime production site in Réty. Once captured, the CO₂ gas would be transported to an export hub currently under development in the area, before being permanently stored in the North Sea.

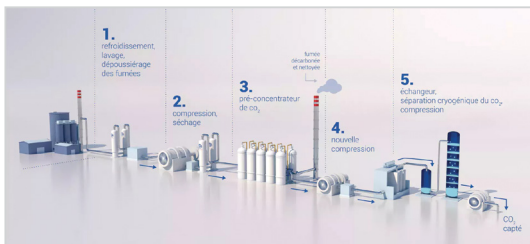
Thanks to this project, Lhoist aims to capture 80% of the CO₂ emissions from its Réty plant in France.

Status of the project

Under development. Lhoist and Air Liquide aim to secure additional funding to the European Innovation Fund support program for large-scale project.

Contribution to

Low carbon intensity lime – Carbon capture – CCS – CO₂ reduction.



Simplified block diagram of the Cryocap™ FG unit.

Type Carbon capture & storage (CCS)

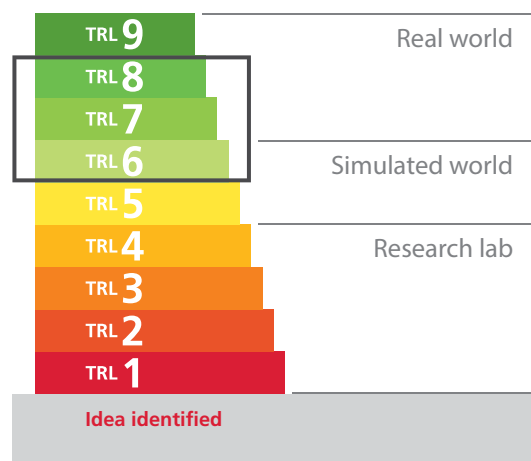
Partners Leader/Lime: Lhoist
Partner: Air Liquide



Funding Total project: not reported
EU contribution: not reported

Duration Construction: 2025 – 2027
Operation: 2028 – 2042

TRL Technology Readiness Level:
TRL 6-8

Commercial deployment

* The information provided in this document is intended solely for general informational purposes and does not constitute a binding commitment. It is based on current assumptions and projections and is therefore subject to change. No warranties or guarantees are made regarding the accuracy, completeness, or future validity of the content presented.

4. Innovation in Energy

- ADiREN4Lime
- WHeatRec4PG
- Energy optimisation
- Energy generation
- CHP Generation
- Hydrogen Fuel Energy Innovation
- FFL
- LIBS4FELS
- ZEQL
- Other company projects/initiatives



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

singletonbirch.co.uk

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, $\text{CH}_4 + \text{CO}_2$.
- 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 electricity per annum.
- Dryer using waste heat from the CHP engines to dry digestate as a high value fertiliser [1].
- Employs 5 people.

Contribution to

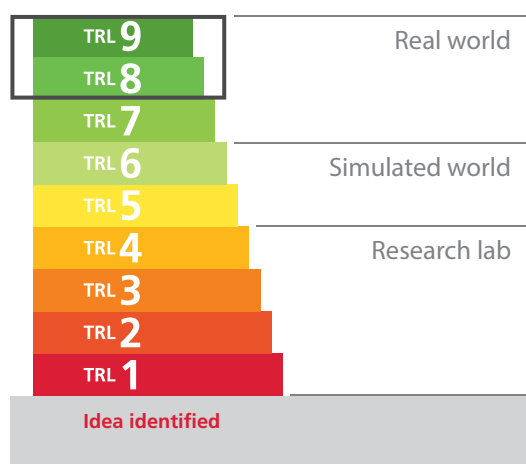
Energy efficiency – Renewable energy into the grid – Agriculture – Fertilizer – Waste management – Management – Employment.

REFERENCES:

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

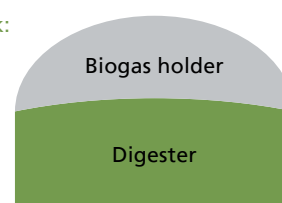
Type	Innovation action (pilot: renewable energy generation)
Partners	Leader/Lime: Singleton Birch (UK) 
Funding	Own initiative + UK Total project: 8.5 Mill £ UK contribution: yes
Duration	11.2014 – 04.2015
TRL	Technology Readiness Level: TRL 8-9

Commercial deployment



Biomass feedstock:

- Manures.
- Energy crops.
- Food waste.
- Agriculture by products.
- Biosolids.



Biomass feedstock and stirred tank.



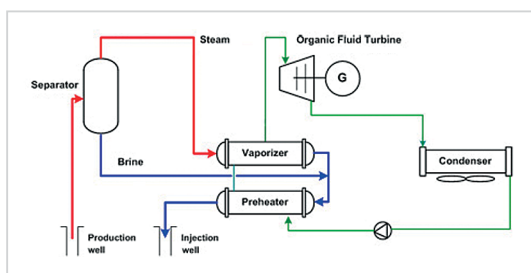
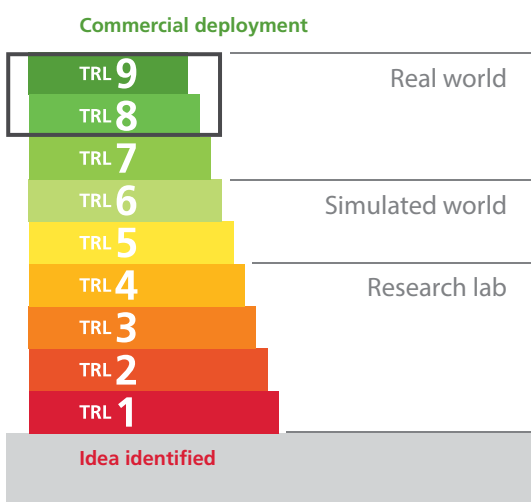
AD installation.

WHEATREC4PG ●

Waste Heat Recovery for Power Generation

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

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 – CO₂ mitigation – Power generation.

REFERENCES:

- [1] Bryant D. 2016. Waste not, Want Not. ENERGYST. Pp. 48-49.
- [2] 2013. Heatcatcher secures waste heat recovery project with Steetley Dolomite. Global Cement: Pp. 20.

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 Thrislington-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 CO₂ emissions will be reduced by 1,600 tonnes per year.
- The project offers an attractive return on investment, when considering 1.3 Mill £ investment against purchasing 3,000 MWh per year of electricity from the grid over the next 10 years [1, 2].

ENERGY OPTIMISATION ●

Reduced energy consumption through optimized processes and capacity use

nordkalk.com/sustainability-old/sustainability-reporting

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.

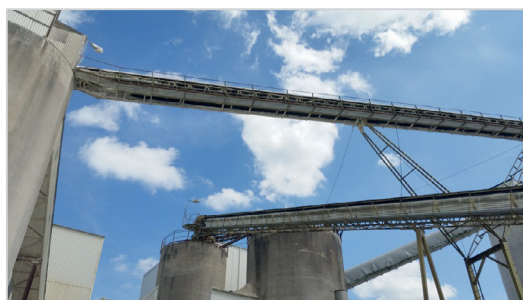
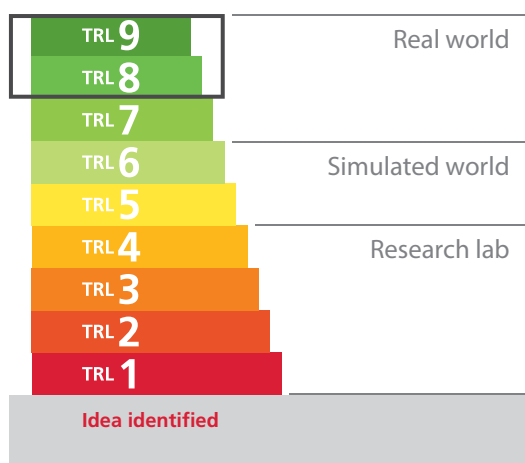
Status of the project ●

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 [1].
- 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 [1].
- In 2015, Nordkalk tested the use of bio-fuel 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" [1, 2].

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

Commercial deployment



Biofuel tested at Ignaberga in Sweden.

Contribution to ●

Energy efficiency – Renewable fuels.

REFERENCES:

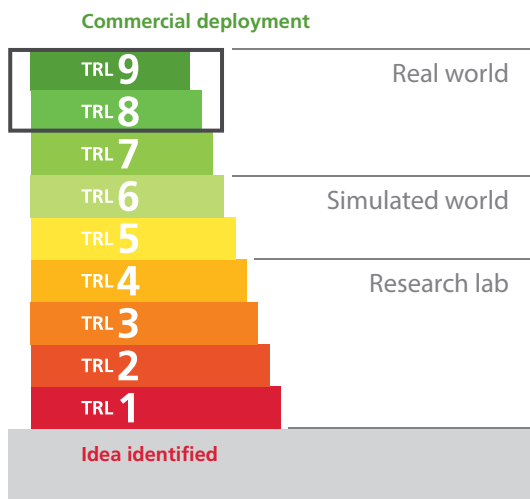
- [1] 2011. Nordkalk. Environmental report. Pp. 12.
[2] Reinson K. & Roioiose Antti. 2012. BioGas. Report prepared by University of Taru. Pp. 11.

ENERGY GENERATION ●

Largest Solar panel farm in Wallonia by a mining company

carmeuse.com

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).

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 CO₂ emissions.

CHP GENERATION ●

Combined Heat and Power (CHP) for Limestone Milling

lhoist.com/en-ND

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.

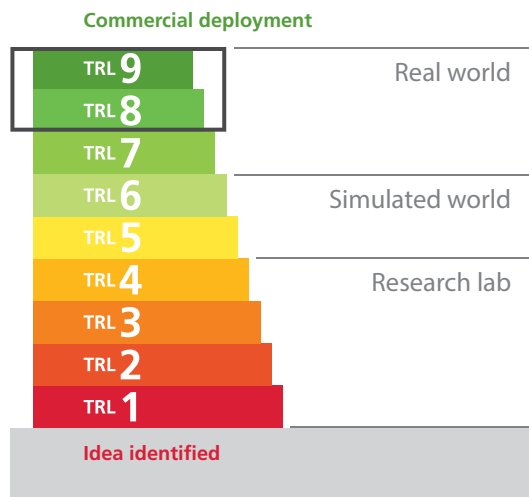
Few projects were implemented, and the following can be reported:

- 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.

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

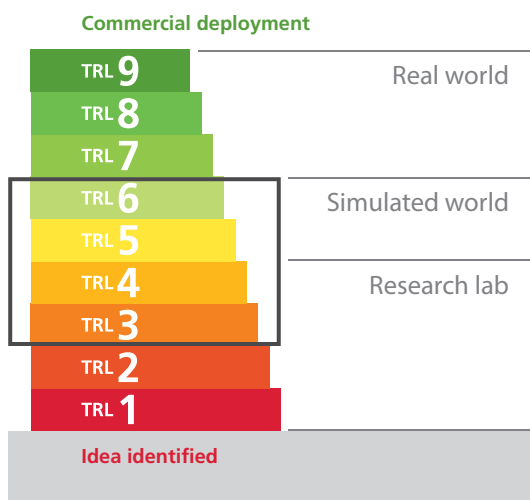


HYDROGEN FUEL ENERGY INNOVATION

● Alternatives to natural gas for high calcium lime manufacturing

mpalime.org

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.

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).

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

ssab.com/en/news/2021/07/ssab-has-launched-an-extensive-research-project-in-finland-to-replace-fossil-fuels-with-renewable-en

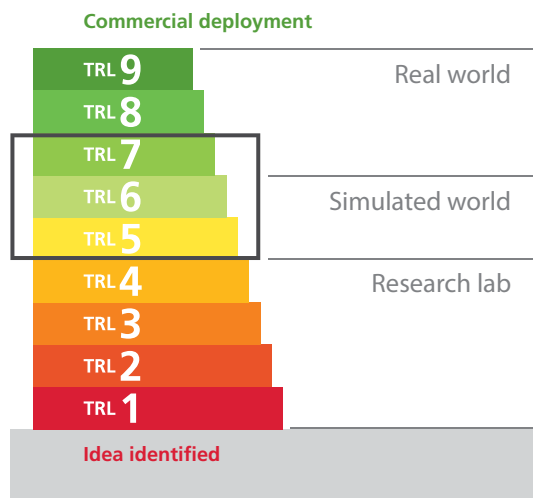
Scope of work

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 CO₂ mitigation options, so does the steel industry. One clear example of this is the

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



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 CO₂ emissions when producing steel [1].

Contribution to

Low carbon steel – Low carbon intensity lime.

REFERENCES:

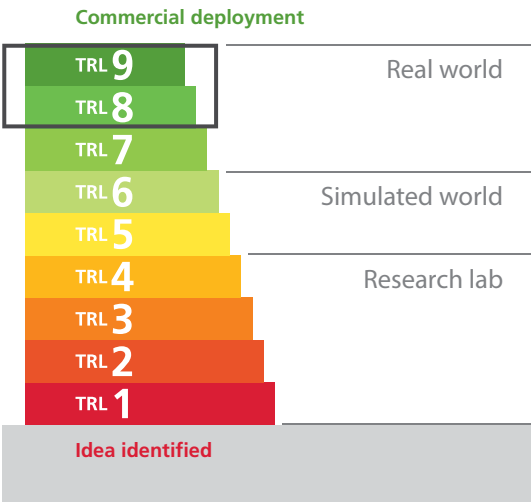
[1] nordkalk.com/news/news/2022/02/lime-in-steel

LIBS4FELS

Online analysis of the lime at the outlet of the kiln via Laser-induced breakdown spectroscopy

lyncis.lt

Type	Energy efficiency
Partners	Leader/Lime: Fels (DE) Partner: Lyncis UAB (LI) 
Funding	Funding: BAFA (DE) Total project: 0.6 Mill EUR National contribution: 0.15 Mill EUR
Duration	11.2022 – 10.2027
TRL	Technology Readiness Level: TRL 8-9



LIBS Spectrometer during Factory Acceptance Test.

avoidance); 3. Energy savings (up to 1%); 4. Expected process CO₂ emissions savings (up to 1%) have been observed.

Contribution to 
Process improvement – Laser-induced breakdown spectroscopy – Fuel reduction – CO₂ reduction.

Scope of work

The kiln technology in the lime sector is already very efficient, however in the frame of continuous improvement, EuLA members make use of measuring techniques that help to contribute to deliver multiple advantages. In the frame of this project, LIBS4FELS will measure the chemical composition of the freshly produced lime after leaving the kiln by exiting the lime to a plasma via Laser and analyzing the light emitted when the plasma cools down. The generated data will enable better operation of the furnaces and should lead to optimized fuel consumption and improved process stability. After successful system test in our plant Kaltes Tal (DE), the technology could be implemented in all Fels plants.

Status of the project

The project started in 2022. The following milestones were achieved:

- The analyzer and its auxiliary equipment such as belts and a crusher were installed at the Kaltes Tal plant and automated. The lime from six kilns can be analyzed via LIBS. The process begins at the outlet of the kilns, where a representative sample is taken. The material is transported to the crusher and crushed to a size of < 2 mm. After homogenization, the material is fed via belt below the analyzer. The height of the lime on the belt is measured and the Laser is focused on the surface of the sample. The light emitted from the sample is collected into two spectrometers and analyzed. The analyzer is connected to the process automation system of the kilns to allow training our A.I.-supported kiln control system in a future step of the project. The target accuracies for the main elements have been achieved. The accuracies for some trace elements are not yet within the target range. The calibration of the analyzer is currently ongoing. Other activities are the revamping of the sampling machine and the breeches chute after the sampling machine to better steer the flow of the lime after it has been analyzed. To date the following benefits: 1. Better lime product quality control to meet end users specifications; 2. Resource efficiency (waste

ZEQL • Zero Emission QuickLime

zeql.com

Scope of work

ZEQL is a concept for producing quicklime in a fully electrified process which eliminates fossil fuels. The CO₂ released from the limestone is highly concentrated and needs no further separation. ZEQL is a brand equally owned by the Swedish companies SMA Mineral and SaltX Technology.

Status of the project

The ZEQL brand was launched in June 2023 and has received great interest from the market. By the end of 2023, SaltX Technology finalized the construction of a new test facility in Hofors, Sweden. During spring 2025, lime from the test facility in Hofors was successfully used in the steel making process at one of SMA Mineral customers in Sweden.

SMA Mineral is receiving support from the Norwegian state-owned company Enova to build an innovative new lime kiln that runs on renewable energy and captures the carbon dioxide released during lime production while producing clean burnt lime. The planned location for the kiln is Mo i Rana, Norway.

The new technology, which uses a plasma generator, eliminates all greenhouse gas emissions from lime production. Instead, the captured carbon dioxide is intended to be used for the production of sustainable fuels, including for aviation, which will further contribute significantly to reducing greenhouse gas emissions.

The project has a potential to heavily reduce CO₂-emissions in the lime industry by:

- Replacing fossil fuels using green electricity.
- Using the highly concentrated CO₂ from the process for production of e-fuels (or possibly other usage or storage).
- By using a limestone powder as raw material, all limestone/dolomite quarried can be used and contribute to resource efficiency. Today, small fractions that cannot be used for burning are often considered as residual products.

Type Energy efficiency, electrification

Partners Leader/Lime: SMA Mineral

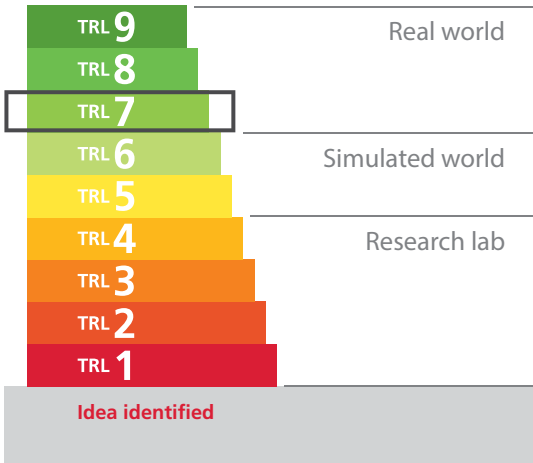


Funding Total project: confidential
EU contribution: –

Duration 06.2023 – ongoing

TRL Technology Readiness Level:
TRL 7

Commercial deployment



Contribution to

Kiln technology – Process emission innovation – Decarbonisation – Kiln electrification – Green.

EULA ●

Other company projects/initiatives

eula.eu/topics/climate-change-energy

Innovation in Energy

• Heat recovery in single shaft kilns

Energy losses induced by the off gas temperature exiting Lime kilns. To tackle some of these losses, Maerz-Ofenbau AG has developed a process incorporating heat exchangers as described in patent EP1148311 81 "Process for firing a material containing carbonates". According to the patent, part of the "combustion air to be supplied by means of the burning lances is heated within the preheating zone by being passed through heat exchange tubes which are positioned parallel to the shaft wall, distributed over the kiln cross-section and suspended in the preheating area of the kiln". Fels-Werke in Germany currently installs a different device but the principle is the same.

• Biomass in PFR kilns

Process innovation is emerging with PFR kilns, which are capable of combusting biomass rather than fossil fuels. Some 14 PFR kilns, two (captive) rotary kilns and one projected (captive) rotary kiln are known to be reengineered or newly built where finely ground wood is in use. Two more kilns are fuelled with cork. For the time being, wood and even contaminated wood is thought to be the easiest to handle and combust, but investigations also target olive stones; coconut cores, sugar cane, jatropha nuts and rice hull.

• Lean gas in PFR kilns

PFR kilns are normally designed to combust natural gas with net calorific values around 48 MJ/Nm³. Coke oven gas (16-35 MJ/Nm³) is also in use where Lime installations operate adjacent to steel mills. Current research focuses on reengineering the gaseous flows in a PFR kiln and make it capable to utilize lean gases which come with net calorific values of 7,5 MJ/Nm³ and less. The research has originally been triggered since existing sourc-

es like converter gas (8-12 MJ/Nm³) and/or blast furnace gas (4-6 MJ/Nm³) are available. Maerz-Ofenbau AG has accompanied a Chinese steel manufacturer who successfully operates a 500 tpd PFR kiln with lean gas of less than 5 MJ/Nm³.

Such lean gases also originate from installations producing biogas, sewage gas, landfill gas, etc. In future it might be an attractive symbiosis to combine a biogas plant dedicated to the supply of lean gas to a Lime plant.

• Oxyfuel combustion in PFR kilns

Off gases of Lime kilns normally contain CO₂ in the order of shortly less than 20% to shortly above 40% (by dry volume). The concentration is basically a function of fuel in use and amount of air intake. The lowest concentrations result from burning natural gas while the highest occur from burning coke.

In 2010 Messer Group was granted a patent "Verfahren und Vorrichtung zur Kalkherstellung" (publication number: EP 2 230 223 A1), followed by a patent granted to Maerz-Ofenbau AG in 2012 "Device and method for combusting and/or calcining fragmented material" (publication number: WO2012/072332). Both patents target the combustion of oxygen rather than air in Lime kilns. Similar to theoretical projects in other industries, this will enlarge the CO₂ concentration and thus ease a potential CO₂ stripping from the off-gases. These reflections are at a very early stage of development. Oxy fuel combustion substantially increases the temperature of the kiln atmosphere, which will be harmful to Lime, as sintering immediately will occur. Other industries tackle the issue by recycling part of the off gas into the combustion chamber and use it as a cooling agent. This is also possible in a Lime kiln but needs far more engineering and process control. The recycled gas flow may not get in contact with the Lime. If so, immediate recarbonation will take place and the Lime quality will be diluted.

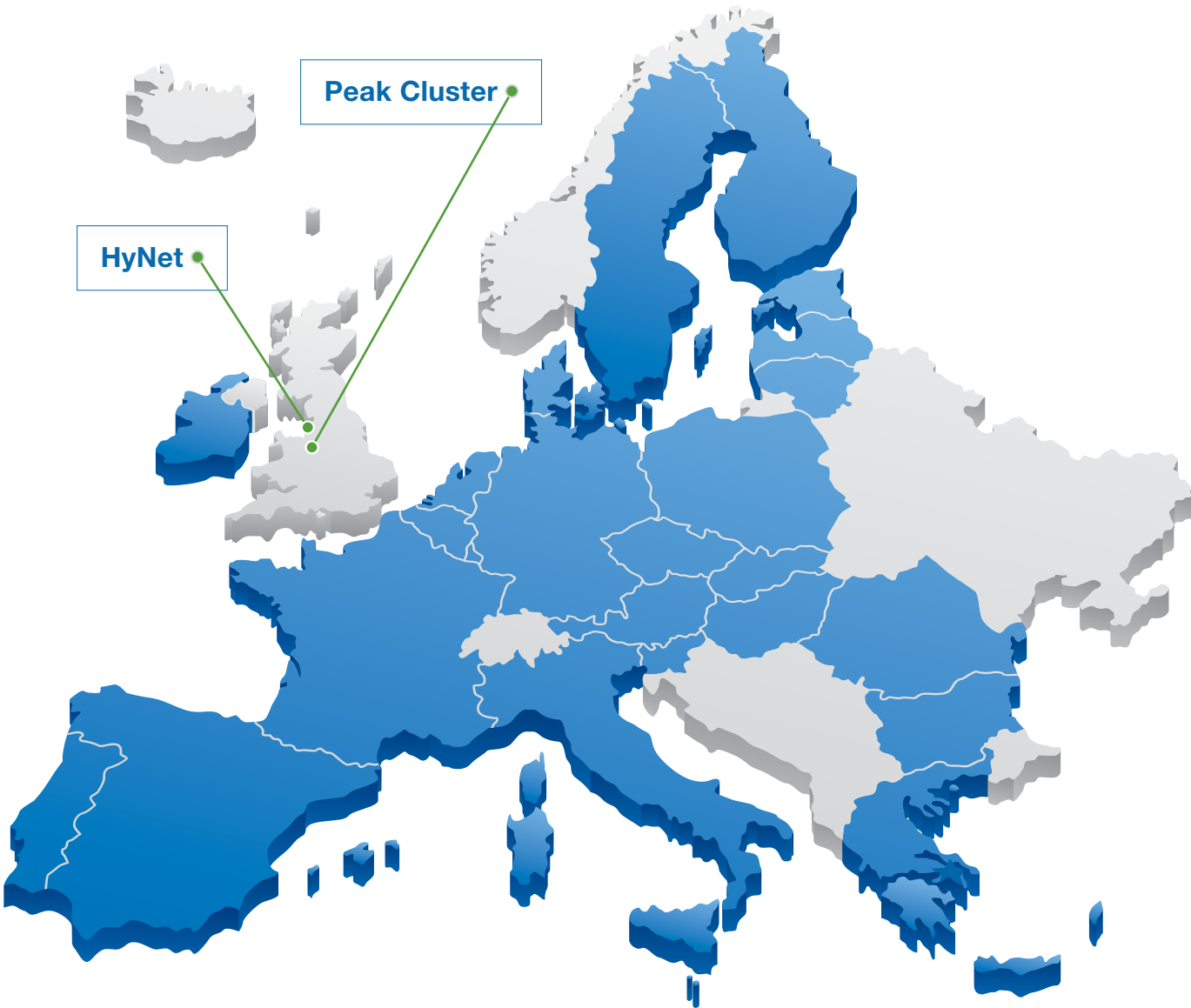
5. Innovation Infrastructure

- Map of innovation infrastructure
- Peak Cluster
- HyNet



EULA ●
Map of innovation infrastructure

eula.eu



PEAK CLUSTER ●

peakcluster.co.uk

Scope of work ●

The Peak Cluster is an innovative collaboration project to capture, transport and permanently store carbon dioxide (CO₂) emissions from the cement and lime industry in Derbyshire, Staffordshire and Cheshire (UK). Five cement and lime plants owned by Tarmac, Breedon, Aggregate Industries and SigmaRoc, have come together with Progressive Energy to form Peak Cluster. The project will capture and transport carbon dioxide emissions from industry across the region, before permanently locking it away beneath the eastern Irish Sea. From 2030, the project will remove over three million tonnes of CO₂ emissions each year. In addition to enabling the continuation of these industries in a sustainable manner, Peak Cluster will help support around 1000 skilled jobs [1].

Status of the project ●

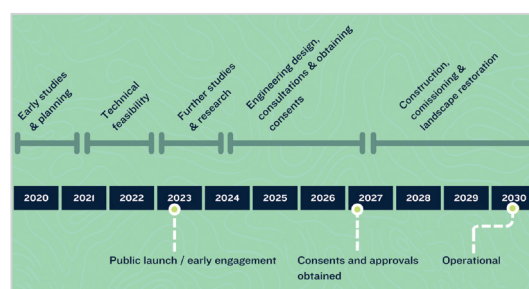
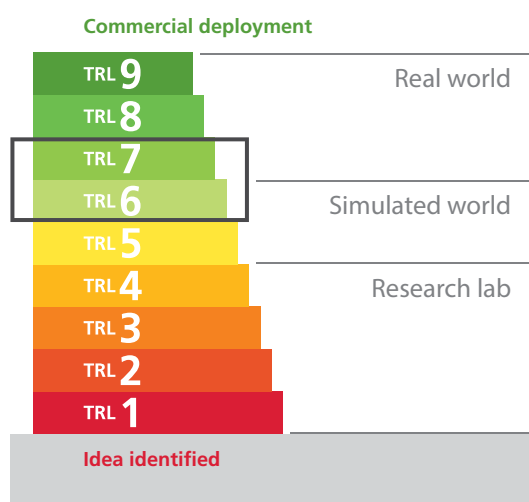
A pioneering major infrastructure project, such as Peak Cluster, is complex to design, develop and build. To make it a reality, a timeline is proposed.

Peak Cluster will use the Carbon Capture and Storage (CCS) technology. This process captures carbon dioxide emissions before transporting them to secure storage sites where they will be permanently locked away. To transport the CO₂, all options are considered: trucks, trains and a pipeline. To minimise further transport emissions and traffic on the road, a pipeline was found to be the best solution. The pipeline will transport the captured CO₂ emissions from the industrial sites to storage in the eastern Irish sea. The pipeline will be buried underneath the ground.

We are currently undertaking initial studies to determine where the pipeline could be routed. These studies are identifying what are known as potential 'pipeline route corridors' in which a pipeline of a diameter of 24-36 inches could be constructed.

The studies consider existing infrastructure, such as built-up areas, and environmental factors such as sensitive landscapes and protected habitats. A few above ground installations spaced along the route of the pipeline will be necessary for inspection and maintenance as well.

Type	Innovation infrastructure
Partners	Leader/Lime: SigmaRoc Lime: Tarmac
	   
	 
Funding	Total project: 2.82 Mill £ Contribution: UK Department for Business, Energy and Industrial Strategy (BEIS) Energy Innovation Programme
Duration	2020 – 2030
TRL	Technology Readiness Level: TRL 6-7



Timeline of Peak Cluster project.

Contribution to ●

Decarbonisation – CCS – Industrial symbiosis
– Cross sectoral innovation.

REFERENCES:

[1] Jackson A. 2021. Participation in the peak district zero carbon cluster of the HyNet project. UK-Lime Research Symposium. British Lime Association (BLA) Symposium 13 October 2021, London (UK).

HYNET

Participation in the peak district zero carbon cluster

hynet.co.uk

Type	Innovation infrastructure
Partners	Leader: Lime: Tarmac (UK) Partners: 
Funding	Total project: 2.82 Mill £ Contribution: UK Department for Business, Energy and Industrial Strategy (BEIS) Energy Innovation Programme
Duration	11.2019 – 03.2022
TRL	Technology Readiness Level: TRL 3-6

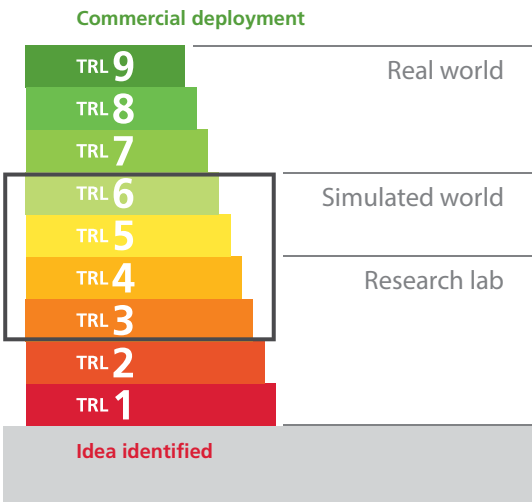


Illustration of the HyNet North West infrastructure.

Contribution to

Decarbonisation – Hydrogen – Low Carbon Fuels – Industrial Symbiosis – Cross sectoral innovation.

REFERENCES:

[1] Jackson A. 2021. Participation in the peak district zero carbon cluster of the HyNet project. UK-Lime Research Symposium. British Lime Association (BLA) Symposium 13 October 2021, London (UK).

Scope of work

Hydrogen Network (HyNet) is an Integrated CO₂ reduction project involving CCS + Hydrogen Production in the North West of England. At the centre is a blue H₂ production facility at Stanlow (Essar) using Johnson Matthey technology with capacity for 3 TWh low carbon hydrogen. Furthermore, a hydrogen network is planned, provided by Cadent. Finally, CCS in Liverpool Bay at the former gas fields of ENI – with capacity of 10 MT from a proposed pipeline.

The Peak Cluster comprises 2 to 2.5 million tonnes/yr CO₂ from the 3 cement/lime companies present in the region. The production of these materials is the largest single contributor of CO₂ emissions in NW England, 25% of the region's entire CO₂ – so it is critical that it is covered within the decarbonisation plans. The goal is to develop a shared CO₂ pipeline transporting captured CO₂ to the core HyNet system for permanent storage. The initiative is a collaborative effort between companies, addressing the challenges of dispersed sites through partnership – recognising infrastructure needed and a proactive push towards government for support.

Clearly there are challenges connecting remote sites in the Peak District, for example pipeline permitting; plus, all Carbon Capture projects require focus around Capture technology & Energy requirements. Nevertheless, these issues can be overcome given the overarching goals, commitments and fundamental need to act.

Ultimately the benefits will be that several million tonnes per year of CO₂ can be captured via integration with a highly developed network / cluster in the North West. The activity is clearly aligned with Global, National, Societal and Company goals around sustainability and would lead to the long-term production of low carbon mineral products, potentially carbon negative with use of low carbon fuels ("BECCS") [1].

Status of the project

Kiln modelling and safety assessments are complete. Full scale demonstration is expected by the end of 2021.

6. Innovation in Recarbonation

- Recarbonation
- Steel
- Construction: Pure airline mortars
- Construction: Mixed airline mortars
- Construction: Hemp lime
- Environment: Drinking water
- Environment: Flue gas cleaning
- Pulp and paper: PCC
- Non-Ferrous: Aluminum
- Civil Engineering: Soil Stabilization
- Environment: RETAKE I+II
- Environment: Sludge-Recarb

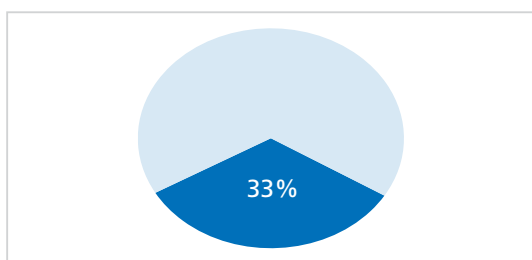
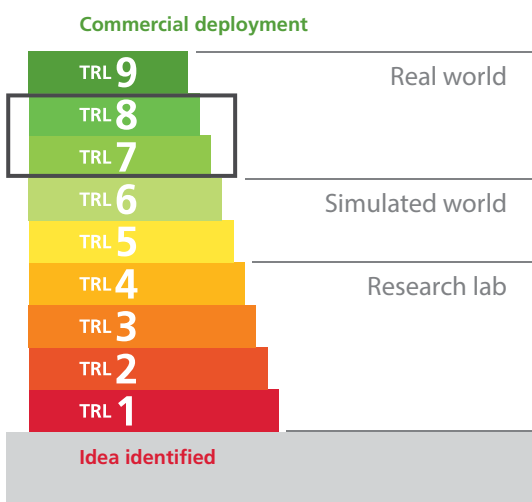


RECARBONATION ●

Recarbonation of lime (summary)

eula.eu/resources/carbonation

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 CO₂ captured by recarbonation.

REFERENCES:

[1] 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.

Scope of work

The production of lime involves heating limestone (CaCO₃) to transform it into high purity quicklime (CaO), releasing carbon dioxide (CO₂) as part of the chemical reaction called "process CO₂". This means lime production is inherently a carbon intensive process. The European lime sector (EuLA) 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 Politecnico di Milano (PoliMI) to carry out an extensive literature review and assess the potential of recarbonation (spontaneous and enhanced carbonation) from various lime applications. Recarbonation rate is the percentage ratio between the amount of CO₂ absorbed during recarbonation and the amount of process CO₂ emitted during calcination.

Enhanced carbonation, it is the process by which the recarbonation 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 recarbonation 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 recarbonation & enhanced carbonation potential from lime.

Status of the project

Finalized [1].

Contribution to

Carbon removal – Carbon sink – Recarbonation – Enhanced carbonation – CCU.

STEEL ●

Recarbonation in steel (study)

eula.eu/resources/carbonation

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 recarbonation rate in the steel application. Out of 72 publications, 55 contained relevant information on the recarbonation process and recarbonation rate values for this application.

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

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

Status of the project

Finalized [1].

Contribution to

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

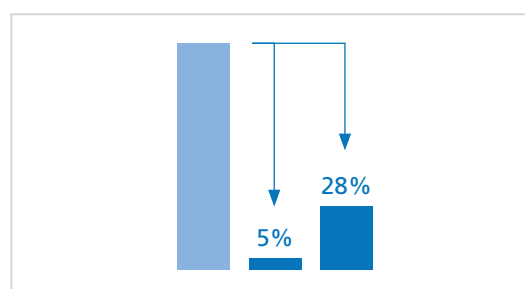
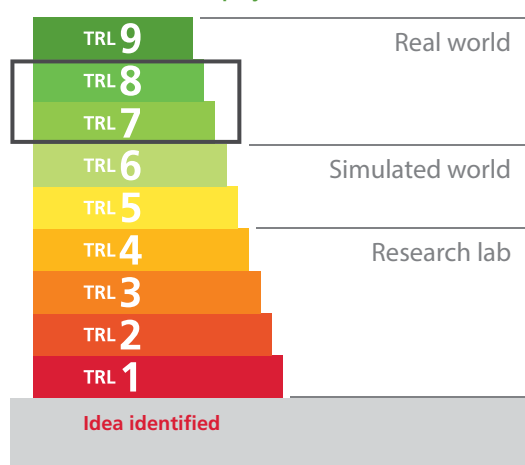
REFERENCES:

[1] 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. doi.org/10.1080/21622515.2021.1982023.

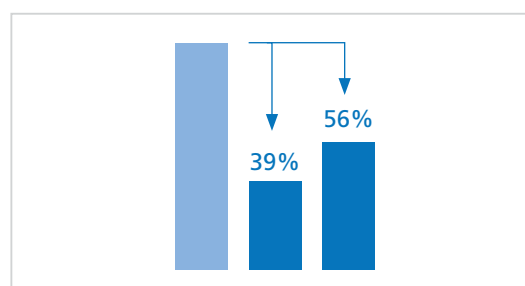
Type	Innovation action (demonstration)
Partners	Leader: Politecnico di Milano (PoliMI-IT) Lime: EuLA (EU)
Funding	EuLA EU contribution: not applicable
Duration	12.2018 – 03.2021
TRL	Technology Readiness Level: TRL 7-8



Commercial deployment



Recarbonation rate (gradual increase over time).

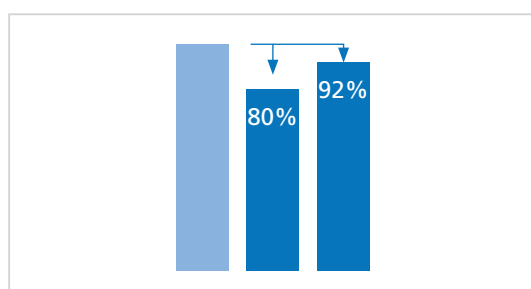
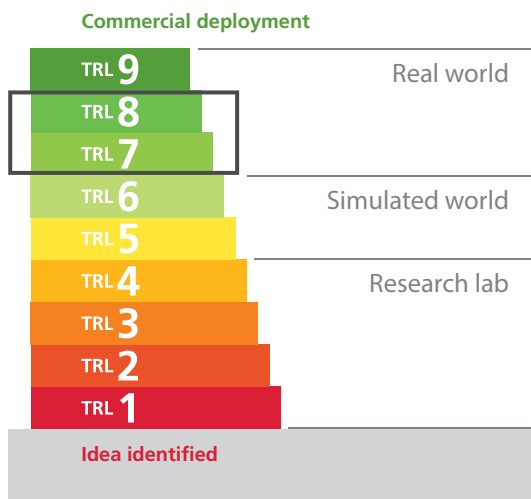


Enhanced carbonation rate (gradual increase over time).

CONSTRUCTION: PURE AIRLINE MORTARS ● Recarbonation pure airline mortars (study)

eula.eu/resources/carbonation

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).

Scope of work

The main objectives of this project were:

- Assess the literature on the recarbonation 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 recarbonation front moves progressively from mortar surface exposed to the atmosphere to depth of the mortar.
- Recarbonation levels in ancient and new air lime mortars is: 80 to 92% generally [1, 2, 3].
- The recarbonation front progresses around 190 mm for 100 years. Fastest recarbonation rate is within the first years (i.e. 20 mm end of first 400d).
- The LCA results show that, the impact of the recarbonation is the highest for the mortars or renders with the highest lime content. CO₂ footprint is reduced by 3% (cement based mortars) to 17% (lime based mortars).
- Considering recarbonation, will change the overall carbon footprint for the lifetime of mortars/plasters [88, 89].

Contribution to

Lime recarbonation – Lower carbon footprint
– Intelligent building skins.

REFERENCES:

- [1] 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.
- [2] 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.
- [3] 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

● Recarbonation mixed mortars (study)

eula.eu/resources/carbonation

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, recarbonation is part of the hardening and self healing process of air lime mortars. In mixed air lime mortars the hydrated lime will set by recarbonation 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 recarbonation rate is: 20 to 23%.

Status of the project

Finalized [1, 2, 3].

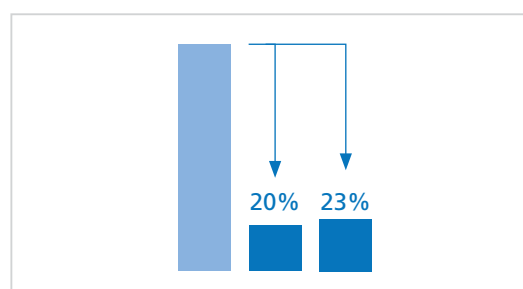
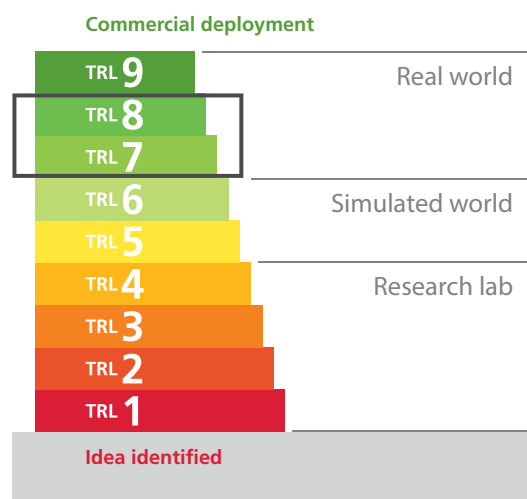
Contribution to

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

REFERENCES:

- [1] 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.
- [2] 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. doi.org/10.1080/21622515.2021.1982023.
- [3] 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



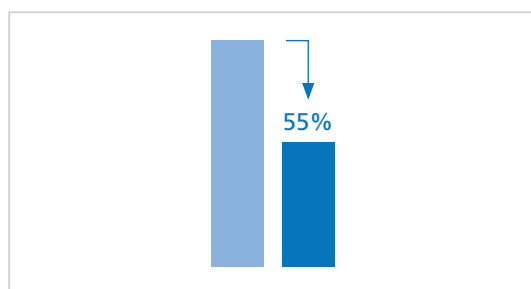
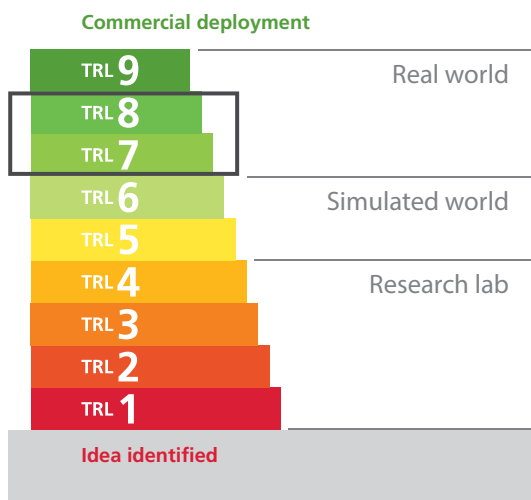
Mixed air lime mortar (gradual increase over time).

HEMP LIME

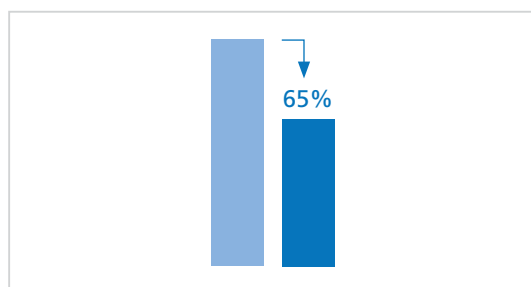
Recarbonation in hemp lime (study)

eula.eu/resources/carbonation

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



Recarbonation rate (gradual increase over time).



Enhanced carbonation rate (gradual increase over time).

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 surfactants.

The air lime binder is hydrated lime ($\text{Ca}(\text{OH})_2$). 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 recarbonation rate is: 55%
- The enhanced carbonation rate is: 65%.

Status of the project

Finalized [1, 2, 3].

Contribution to

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

REFERENCES:

- [1] 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.
- [2] 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. Pp. 224-237. doi.org/10.1080/21622515.2021.1982023.
- [3] Campo F.P., Grosso M. 2021. Lime based construction materials as carbon sink. *Proceedings of MSSM2021*, 4-6 August 2021, Brunel University London.

DRINKING WATER ●

Recarbonation in treating drinking water (study)

eula.eu/resources/carbonation

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.

Recarbonation 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).

Recarbonation timeframe: the recarbonation 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 [1, 2].

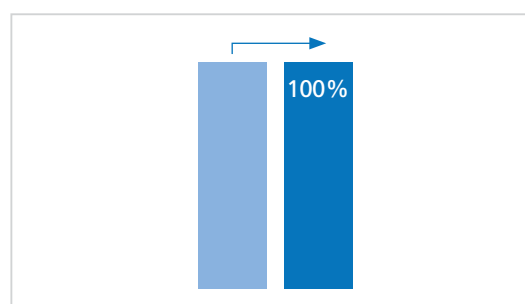
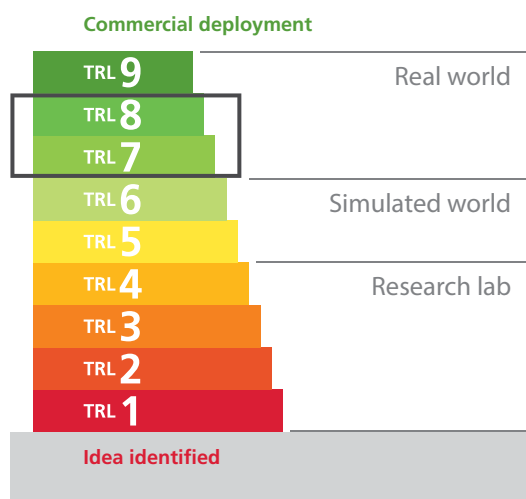
Contribution to

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

REFERENCES:

- [1] 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.
- [1] 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. Pp. 224-237. doi.org/10.1080/21622515.2021.1982023.

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



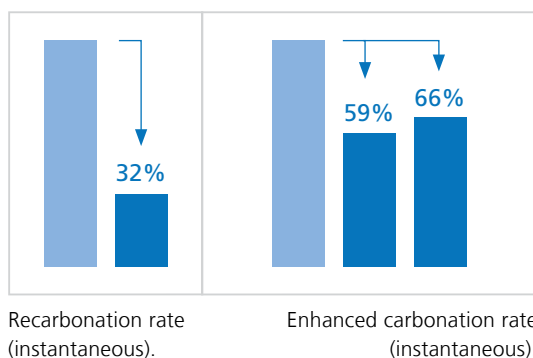
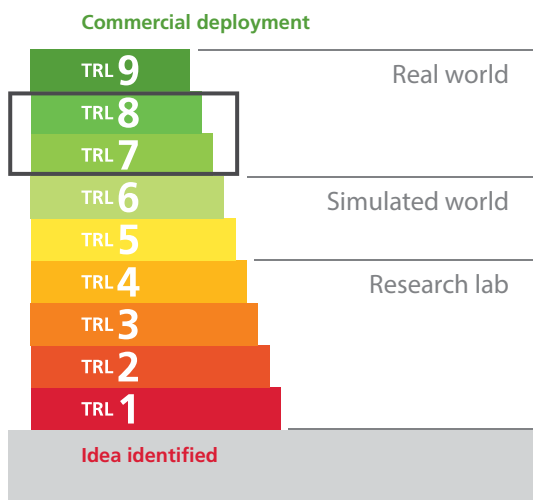
Recarbonation rate (instantaneous).

FLUE GAS CLEANING ●

Recarbonation in flue gas cleaning (FGC) (study)

eula.eu/resources/carbonation

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:

- [1] 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.
- [2] 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. Pp. 224-237. doi.org/10.1080/21622515.2021.1982023.

Scope of work ●

Use of lime in treating FGC: lime is used for removing the acid gases (HCl, SO_x, 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 suspension, 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 processes, hydrated lime (Ca(OH)₂) powder is directly supplied as sorbent. For both processes the reaction products are separated in a conventional dedusting unit (typically a baghouse filter).

Recarbonation process: during the flue gas treatment, lime reacts with HCl, HF and SO_x but also with CO₂, forming calcium carbonate. The solid residues generated by the process, referred to as Air Pollution Control Residues (APCR), contain some amounts of free lime available for recarbonation. Enhanced carbonation of APCR has been largely proposed as a technology to improve their chemical stability and their leaching behaviour before their final disposal or recycling. Furthermore, enhanced carbonation of APCR allows for a contextual CO₂ sequestration directly at a CO₂ point source emission where these residues are generated.

Status of the project ●

Finalized [1, 2].

Contribution to ●

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

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

eula.eu/resources/carbonation

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 (CO₂) with lime (CaO) under controlled operating conditions. Hydrated lime slurry is put in contact with flue gases containing CO₂, leading to recarbonation 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 CO₂ 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 recarbonation rate is: 85 to 93%.
- The enhanced carbonation rate is: 100%.

Status of the project

Finalized [1, 2].

Contribution to

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

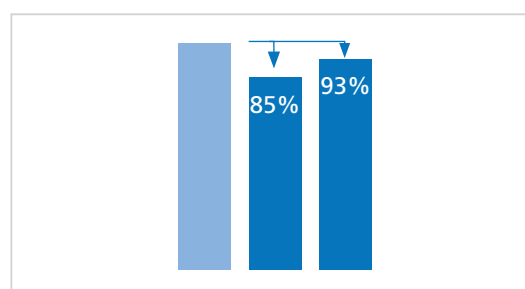
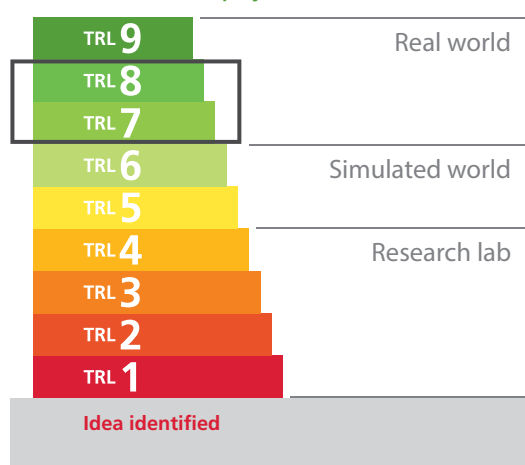
REFERENCES:

- [1] 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.
- [2] 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. doi.org/10.1080/21622515.2021.1982023.

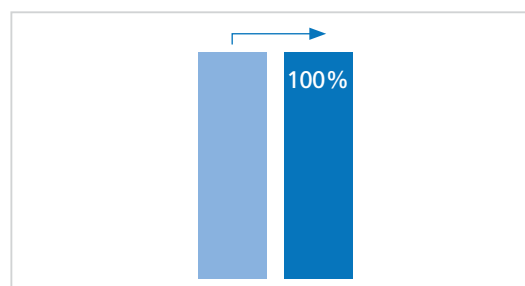
Type	Innovation action (demonstration)
Partners	Leader: Politecnico di Milano (PoliMI-IT) Lime: EuLA (EU)
Funding	EuLA EU contribution: not applicable
Duration	12.2018 – 03.2021
TRL	Technology Readiness Level: TRL 7-8



Commercial deployment



Recarbonation rate (instantaneous).



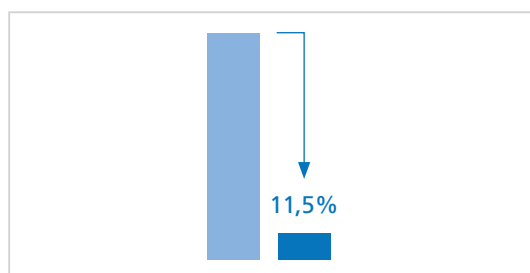
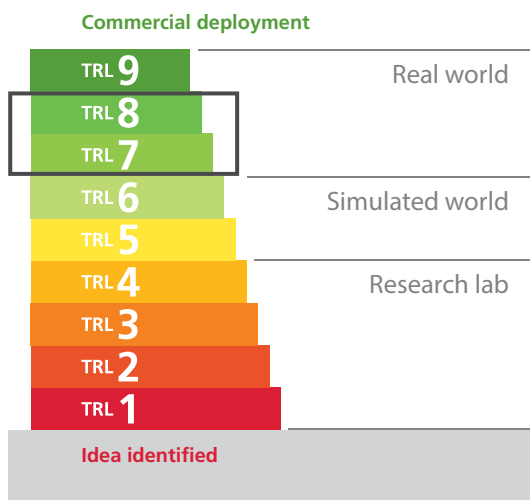
Enhanced carbonation rate (instantaneous).

ALUMINUM ●

Recarbonation in aluminum (study)

eula.eu/resources/carbonation

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



Recarbonation rate (timeframe not reported in the assessed literature).

REFERENCES:

- [1] 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.
- [2] 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. Pp. 224-237. doi.org/10.1080/21622515.2021.1982023.

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.

Recarbonation process: the recarbonation of red mud involves both pore water recarbonation 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 technologies that use artificial Ca and Mg rich brines. Another neutralisation is based on CO₂, i.e. a carbonation under enhanced conditions.

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

The literature review shows that for aluminium:

- The recarbonation & enhanced carbonation rate is: 11.5%.

Status of the project

Finalized [1, 2].

Contribution to

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

SOIL STABILIZATION ●

Recarbonation in soil stabilization

eula.eu

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 recarbonation reaction although known, has not been quantified. The main objectives of this project were:

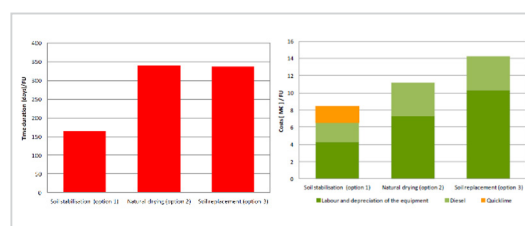
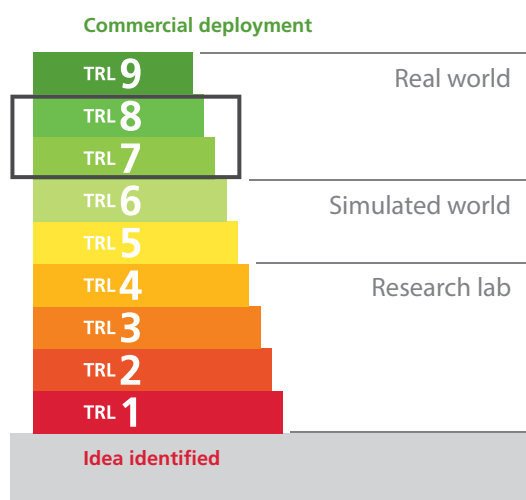
- Perform tests to a German road build 34 years ago to measure qualitatively and quantitatively the carbonation of lime in soil stabilization at a depth of 10 m. The selection of the site was relevant because similar study was performed 11 years after construction. The findings from the German study, were applied to a real soil stabilization project in France.
- As this was the only study with real on-site measurements, EuLA engaged the University of Lille to develop an testing programme to develop the testing to other soil types (during 2021-2024).

Status of the project

Project finalized in 2014; 2024. 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%. In addition 10-15% still available as free CaO and 50% is used for puzzolanic reactions [1]. The re-carbonation & enhanced carbonation values were confirmed by the Lille University research team [2].
- These results were obtained from the application of various techniques, such as X Ray Diffraction, Phenolphthalein as well as geo-chemistry modelling [1, 2].
- When comparing: 1. Soil stabilisation with quicklime for the reuse of wet soils. 2. Natural drying of wet soils before reuse 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) [3].

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.

Contribution to

Lime carbonation – Lower carbon footprint – Soil stabilization.

REFERENCES:

- [1] Haas S., Ritter H.J. 2018. Soil improvement with quicklime – longtime behavior and carbonation. Journal Road Materials & Pavement Design by Francis & Taylor. Accepted. doi.org/10.1080/14680629.2018.1474793.
- [2] Kleibb J., Lesueur D., Maherzi W., Benzerzour M., Carbonation of a lime treated soil subjected to different curing conditions. Transportation Geotechnics 44 (2024) 101174. doi.org/10.1016/j.trgeo.2023.101174.
- [3] Shtiza A. 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. 6974. In English with French abstract.

RETAKE I+II

Carbon Dioxide Removal by Alkalinity Enhancement: Potential, Benefits and Risks (CDR)

retake.cdrmare.de/en

Type	Research & innovation
Partners	Leader: Geomar, Alfred-Wegener-Institute Lime: BVK
	
Funding	Federal Ministry of Education and Research (BMBF) Total Project: ~8 Mill EUR (both project phases)
Duration	RETAKE I: 08.2021 – 07.2024 RETAKE II: 08.2024 – 07.2027
TRL	Technology Readiness Level: TRL 5-6

Scope of work

The project will assess the potential, feasibility and side effects of various forms of alkalinity enhancement (AE) as a means to reliably and sustainably remove CO₂ from the atmosphere. Increased ocean alkalinity reduces the activity of CO₂ in seawater, and prompts an enhanced flux of CO₂ from the atmosphere into the ocean, thereby reducing the atmospheric CO₂ concentrations. a range of mineral alkalinity sources (limestone and olivine) will be examined with respect to dissolution kinetics, CO₂ sequestration potential and side effects on chemistry and biology. Laboratory studies and mesocosm experiments of AE in benthic and pelagic systems will simulate realistic environments with focus on the Baltic and the North Sea. a hierarchy of numerical models will be used to simulate deployment in German coastal waters and else-where, and to extrapolate experimental results from local to regional and global scales.

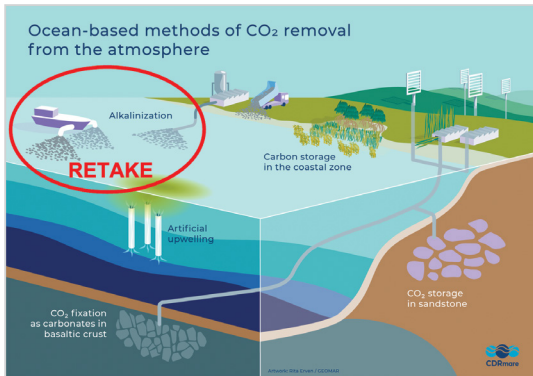
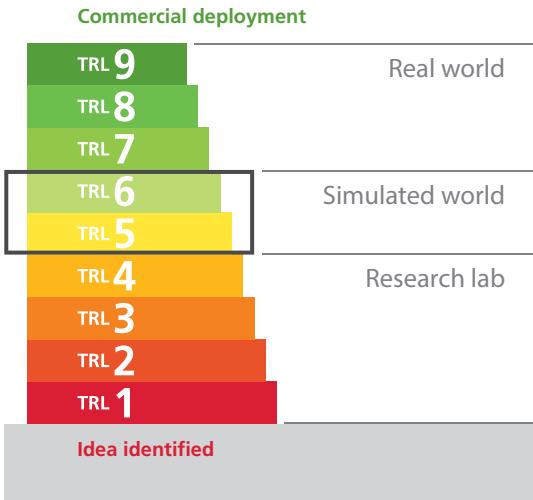
Permanence and accounting of carbon storage as well as monitoring, detection and attribution issues will be examined against the background natural variability. An investigation of economic aspects, the legal situation and the relation to the U.N. sustainability development goals will complete the comprehensive assessment in order to inform policymakers about the feasibility, overall sequestration potential and environmental risks of ocean alkalinity enhancement.

Status of the project

RETAKE I was successfully finished.
RETAKE II started in August 2024.

Contribution to

Climate change – Carbon dioxide removal – Alkalinity enhancement.



SLUDGE-RECARB

Waste Water Treatment Plant (WWTP) or Sewage Sludge (SS) Recarbonation

eula.eu

Scope of work

Following the PoliMI study data gaps identified [1, 2], EuLA developed an action plan with multiple research universities interested to work on various lime applications. Giessen University responded positively to the call for offer and helped to identify sites using lime in their WWTP, design the lab tests and conditions to measure the recarbonation and enhanced carbonation rate in the waste water treatment.

Giessen performed a thorough assessment of all WWTP sites in multiple German landers and identified two sites in Germany using lime in different steps of the WWTP and samples were collected on-site by the researchers. Sample characterisation, defined the test protocol, developed the lab equipment to measure the recarbonation and enhanced carbonation on these samples for a period of 6 months. To enhance the accuracy of the study outcome a combination of multiple quantification techniques were deployed. The key study findings confirm that:

- The lime contained in SS is readily accessible to carbonation.
- Full recarbonation is complete after 3-4 months.
- Enhanced carbonation: Theo. CO₂ can be achieved after 24 h for most of the samples.

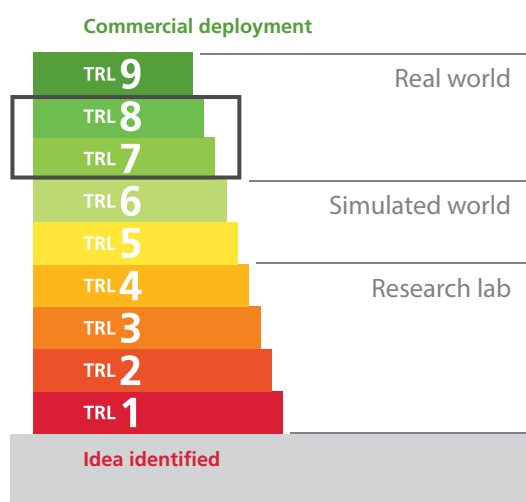
Status of the project

The study is finalized and the results are conclusive for the recarbonation & enhanced carbonation rate of sewage sludge. A peer-review paper is in preparation by the Giessen team of researchers.

Contribution to

Sewage sludge (SS) – Waste water treatment plant (WWTP) – Recarbonation – Circular economy.

Type	Innovation action (demonstration)
Partners	Leader/Lime: EuLA (EU) 
Funding	Own initiative Total project: not reported
Duration	11.2023 – 03.2025
TRL	Technology Readiness Level: TRL 7-8



REFERENCES:

- [1] 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.
- [2] 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. Pp. 224-237. doi.org/10.1080/21622515.2021.1982023
- [3] Giessen report. 2025. (Peer-review paper in preparation).

7. Future Technological Innovation Priorities for the lime sector



The lime industry sector although is little known, is an important sector due to its enabling nature and embedded in different value chains. Being an energy intensive sector, (70% of its CO₂ emissions are due to the decarbonation of the raw material), the lime industry's first priority is to find ways to mitigate those [1]. As you can see from this brochure extensive work has been done by the sector to address this challenge through multiple innovation actions/projects.

To transition from pilot-scale demonstrations to full industrial deployment, it is essential to secure financing that can absorb the high risk associated with advancing technologies from TRL 6 to TRL 9. This challenge is further compounded by substantial CAPEX requirements, which often deter investment unless mitigated by strong market signals or policy incentives.

While technically and economically viable Carbon Capture and Utilization (CCU) solutions have emerged, their widespread uptake hinges on several enabling factors: the evolution of the regulatory framework, especially within the EU compared to other regions; unfavorable market conditions exemplified by the termination of the Columbus project (BE); and strategic corporate decisions, such as the ZERCAL initiative (UK), which reflect a firm's regional focus for R&D activities. Navigating technology-specific hurdles and aligning innovation with both policy and market conditions will be key to unlock viable, scalable, sustainable solutions for industrial emissions.

In a recent assessment, the lime industry agreed to focus on projects providing solutions on getting the CO₂ in some form of fuel and make it part of the fuel chain, as for instance:

- Oxyfuel.
- Bioethanol.
- Biomass.

Few ideas for future innovation projects could be:

- Increase CO₂ concentration e.g. by looping.
- Indirect calcination.
- Storage of renewable energy by combination of Lime "Oxyfuel Process" with CO₂ – looping and methanization.
- Methanisation.
- Low concentration CO₂ => Direct use for e.g. plant/algae/bacteria growth/feeding or flue gas cleaning.
- Recarbonation of mortars.
- Carbon dioxide Storage by Mineralisation (CSM).
- Carbon Dioxide Removal (CDR).
- Ocean Liming.

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:

[1] EuLA. 2024. a pathway to negative CO₂ emissions by 2025: the contribution of the lime industry to a carbon-neutral Europe (Lime Roadmap). Pp. 42.

8. Annexes



Annex 1: Technology Readiness Levels (TRL scale)

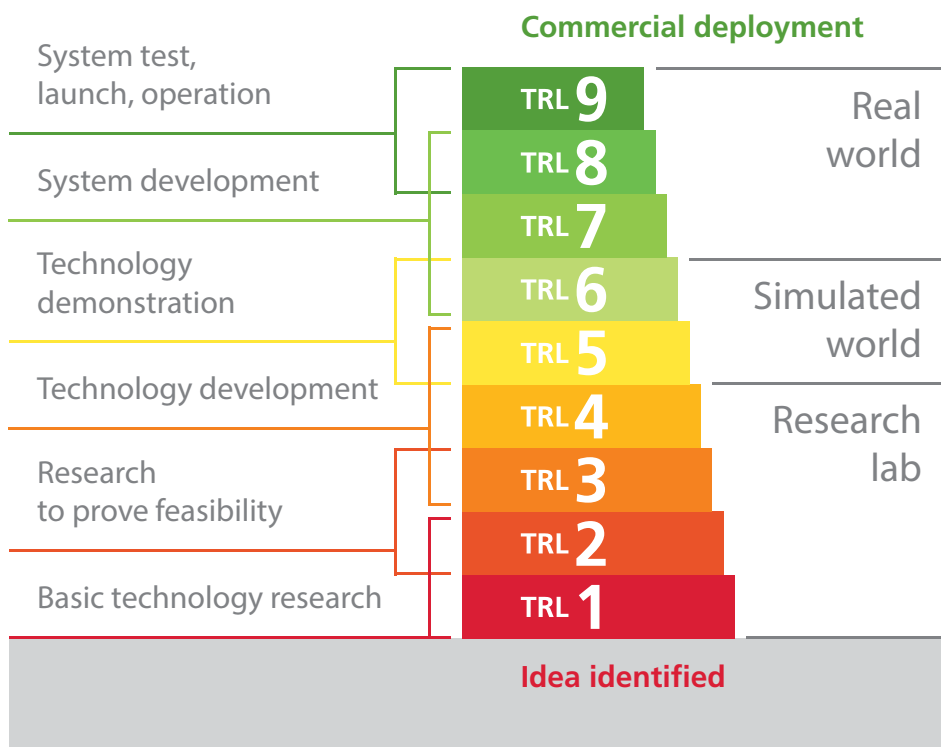
Where a topic description refers to a TRL, the following definitions apply, unless otherwise specified [1]:

- 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 relevant environment 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:

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



Annex 2: List of projects and duration

Project	Company	Project type
CO₂ process emission 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
SCARLET	Lhoist	Carbonate looping
CSM	Nordkalk	Mineralization
C4U	Carmeuse	CCU
LOWCO ₂	Calcinor	Ongoing pilot plant tests
DinamX	Lhoist	Carbon capture
CaLby2030	Carmeuse	Innovative application
Butterfly	Carmeuse	CCU & CCS
HECO2 Axe 5: SATURN	Carmeuse	Carbon capture
IS2H4C	Calcinor	Oxyfuel – CCU
CO ₂ ncreat	Lhoist	Carbon capture & use (CCU)
CalCC	Lhoist	Carbon capture & storage (CCS)
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	Alternative fuels
FFL	Nordkalk	CO ₂ free fuels
LIBS4FELS	Fels	Energy efficiency
ZEQL	SMA Mineral	Energy efficiency, electrification
Other company projects/initiatives	EuLA	Energy (varia)
INNOVATION INFRASTRUCTURE		
Peak Cluster	SigmaRoc & Tarmac	Innovation infrastructure
HyNet	Tarmac	Innovation infrastructure
INNOVATION IN RECARBONATION		
Recarbonation	EuLA	Recarbonation
Steel	EuLA	Recarbonation
Construction: Pure airline mortars	EuLA	Recarbonation
Construction: Mixed airline mortars	EuLA	Recarbonation
Construction: Hemp lime	EuLA	Recarbonation
Environment: Drinking water	EuLA	Recarbonation
Environment: Flue gas cleaning	EuLA	Recarbonation
Pulp and paper: PCC	EuLA	Recarbonation
Non-Ferrous: Aluminum	EuLA	Recarbonation
Civil Engineering: Soil Stabilization	EuLA	Recarbonation
Environment: RETAKE I+II	BVK	Recarbonation
Environment: Sludge-Recarb	EuLA	Recarbonation

[illegible]

Annex 3: 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. 2025. CO₂ Innovation in the lime sector 4.0. Pp. 1-70.



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

Active Members EuLA Innovation TF

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Arnott Edward (Singleton Birch)
Berégi-Amneus Anna-Maria (SMA Mineral)
Bernardi Lorenzo (Fassabortolo)
Bodén Per (SMA Mineral)
Connolly Joe (Clogrennane Lime)
Costea Bogdan (Carmeuse)
Cowling Tim (Tarmac/CRH)
Creveceour Stephane (Carmeuse)
Degerstedt Erik (Nordkalk)
Fielding Svante (SMA Mineral)
Foucart Fabrice (Carmeuse)
Frisch Klaus-Ruthard (BVK)
Gambin Amandine (UP Chaux)
Grégoire Damien (Carmeuse)
Hynes Mike (MPA Lime)
Jacquet Alain (Saint Hilaire)
Lammela Matti (Nordkalk)
Marbehant Jean (Lhoist)
Markussen Eek (Franzefoss Minerals)
McCabe David (Tarmac/CRH)
Mehling Christine (Fels)

Mendizabal Gorka (Calcinor)
Mengede Martin (Franzefoss Minerals)
Mikael Furu (Nordkalk)
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Perrin Nicolas (Lhoist)
Pettiau Xavier (Lhoist)
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Pust Christopher (Lhoist)
Reilly Brendan (Clogrennane)
Roine Tiina (Nordkalk)
Rott Christopher (Fels)
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