INNOVATION IN THE LIME SECTOR 3.0

The European Lime Association | Edition 2022

EuLA

Innovation that delivers on sustainability

EuLA

1. Executive summary

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

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

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

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

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

Dr **Burkhard Naffin**
EuLA president

Damien Grégoire
EuLA Technical Environment Committee Chairman

2. Lime Industry Sector

What is lime and its uses

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

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

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

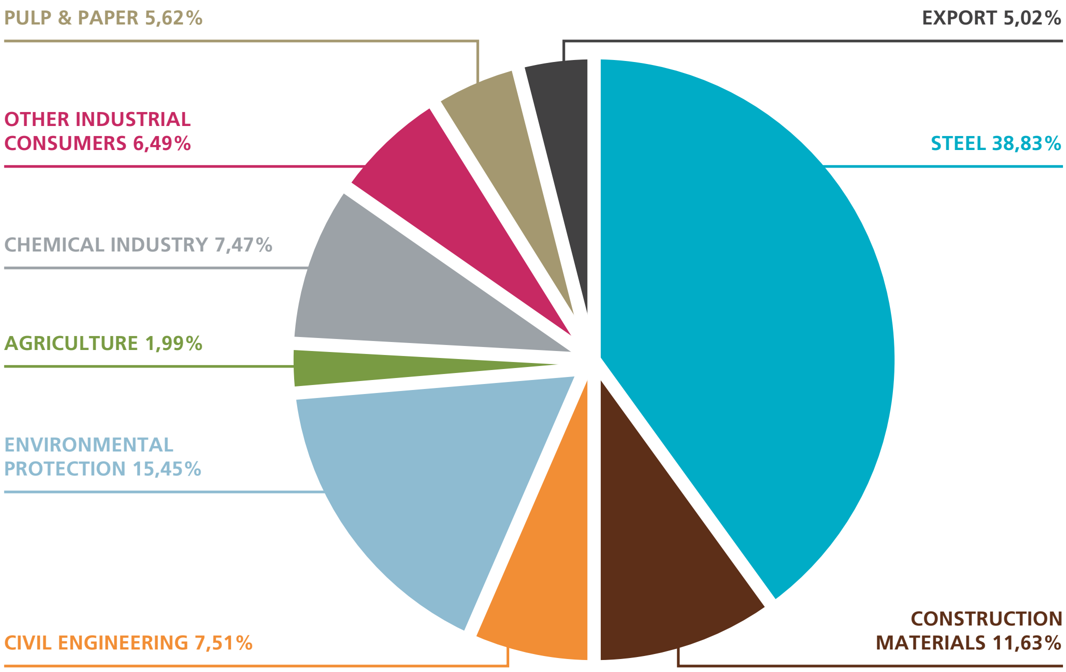
The Innovation in the lime sector is achieved through:

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

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

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

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



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

Did you know that...

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

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

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

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

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

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

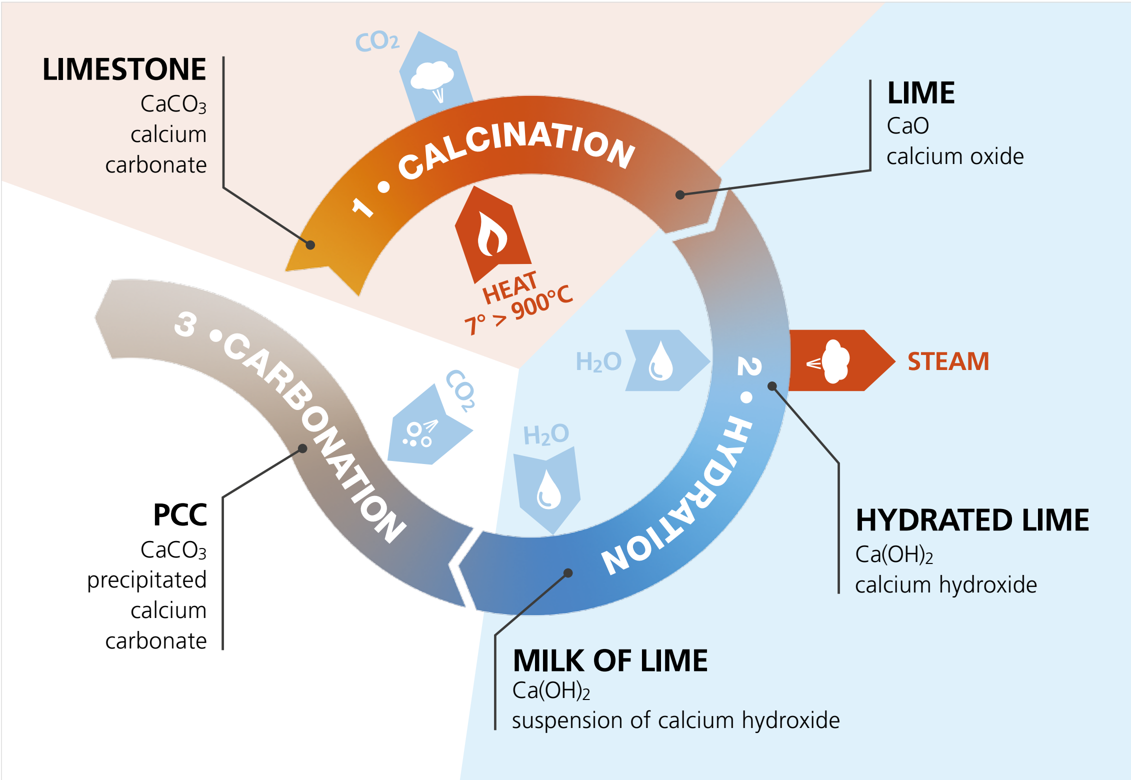
...LIME IS A SPONGE FOR CO_2?
In applications such as mortars and soil stabilization, lime functions as a carbon sink and absorbs up to 80% of the carbon emitted during its production process. In Precipitated Calcium Carbonate (PCC) for paper production, 100% of process CO_2 is re-absorbed.

...LIME IS THE MATERIAL HELPING TO PROTECT OUR ENVIRONMENT?
Environmental applications have been the main driver for new lime applications in recent. Acid rain causes lakes and streams to become acidic and can damage trees. Lime is used to treat industrial waste gases to remove acidic gases to reduce acid rain and so protect our forests.

...68% OF LIME IS RECYCLABLE?
Lime is used as an input in a wide range of applications and end-products. Most of those are recyclable. The recycling rate of lime in steel applications for instance, is estimated to be around 95%, in civil engineering works (concrete, bricks, lime mortars and soil stabilization) the recycling rate of lime is estimated to be around 65%. Lime can also help to add value to some by-product and wastes. For example, the use of lime in flue gas treatment allows to create gypsum, which is reused in construction markets such as plasterboards. The treatment of sludge with lime allows to recycle some wastes into bio-solids which are re-used in agriculture.

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

CYCLE OF LIME



Innovation in lime sector

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

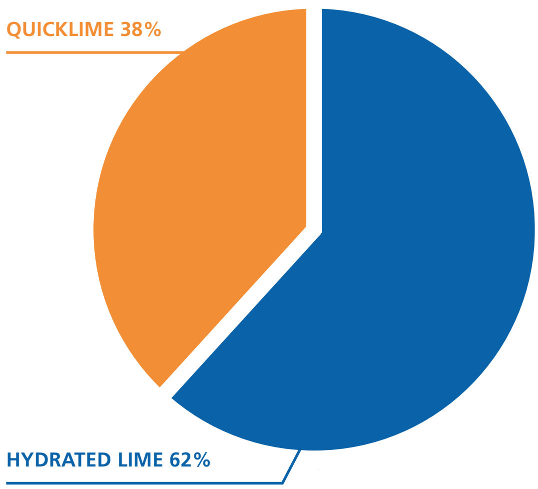
A comprehensive list of patents requested or granted inside and outside our industry is by far larger A query launched at WIPO searching for "**Hydrated lime**" while excluding "**Quicklime**" returns some **1300 patents** from WIPO and EPO over **the last 20 years**. Similarly, a query searching for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

Concerning products, the most significant innovation are "High Surface Hydrates" which feature an active reaction face of > 35 m²/g. Adding activated carbon and/or other ingredients can further customize these hydrates. They are applied to various flue gas streams in industry to effectively capture pollutants like HCl; Dioxins; Furans; Heavy Metals. Customized hydrates are considered BAT in several BREFs.

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

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

PATENT APPLICATION FOR LIME PRODUCTS



Definitions

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

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

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

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

Definitions

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

3. Innovation in Quarry

- Less fines
- Blast-Control
- Repurpose lime by-products
- Noise barriers
- Water Management Platform
- Life in Quarries
- Drinking water from quarry
- Gravity conveyer belt
- Resource optimisation
- Water Management
- Community relations

LESS FINES • Less fines production in aggregate and industrial minerals industry

cordis.europa.eu/project/rcn/54228_en.html

Scope of work

Every year in Europe the aggregate and industrial minerals industry produces around 1.35 billion tons of blasted rock. During the blasting operations, an amount of around 20% of the material is smaller than 10 mm to 20 mm and is too fine to be used efficiently and generally goes in the waste dump. The aim of the project is to reduce the amount of lost material by 50% through the adaptation of the explosives and timing procedure to the natural breakage characteristic of the rock.
The project consortium is formed of nine partners from four EU member states and consists of the two major producers of explosives in Europe, a large Swedish limestone producer, a Spanish cement and aggregate producer with 11 quarry sites and an Austrian aggregate producer (SME operation) with 3 quarries. Four blast research centers are partners in the project.

Status of the project

Project finalized in 2004. The following deliverables can be reported:

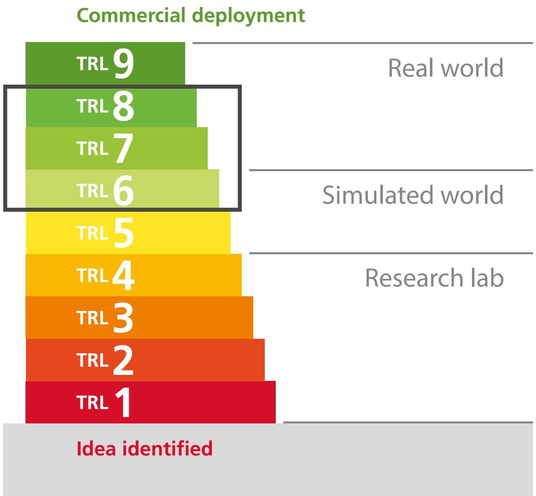
• Mining engineers defined a comprehensive methodology entitled Energy Controlled Blasting (ECB) was defined (Leoben); designed by the blast centers and tested at quarries [10, 11].

• Important insight into the way rocks fracture and disintegrate when blasted was gained by performing a battery of physical and chemical analyses on several rock samples in the laboratory.

• The environmental benefit of ECB is a significant reduction in the amount of fine material produced.

• Economic benefits to the quarrying operation in the form of reduced operating costs and increased output were also observed.

Type	Demonstration
Partners	Leader: Montan University (AU) Lime: Nordkalk (FI)
Funding	EU / FP5 / GROWTH Total project: 4.1 Mill EUR EU contribution: 2.4 Mill EU
Duration	03.2001 – 06.2004
TRL	Technology Readiness Level: TRL 6-8



Contribution to

Raw material optimization – Environmental protection – Optimize production flow – Technology transfer – Safety – Replicable results – Automatization – Circular economy.

REFERENCES:

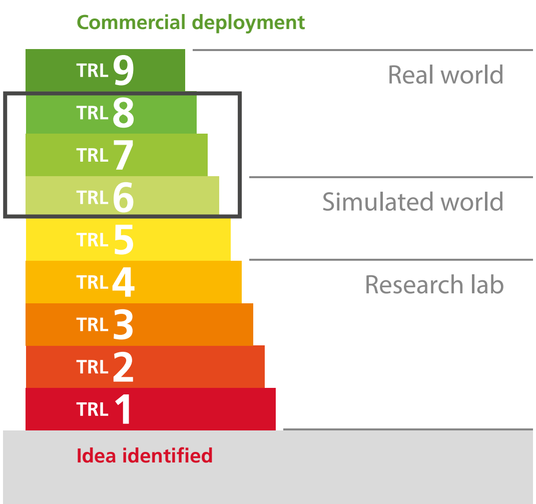
[10] Less-fines 2004. Project summary: Reducing the environmental impact of rock quarries. cordis.europa.eu/result/rcn/81974_en.html.
[11] Less fines. 2004. Project summary: Accurate predictions of rock fragmentation after blasting. cordis.europa.eu/result/rcn/82032_en.html.

BLAST-CONTROL

Productivity improvement in open-pit mining and quarrying by means of an integrated control system for blasting and production-flow optimization

cordis.europa.eu/project/rcn/44832_en.html

Type	Demonstration
Partners	Leader: Nitro Bickford (FR) Lime: Calcinor & Lhoist
Funding	EU / FP4 / BRITE Funding rate: not reported
Duration	09.1998 – 12.2001
TRL	Technology Readiness Level: TRL 6-8



Contribution to

Environmental protection – Optimize production flow – Materials technology – Safety – Raw material optimization – Replicable results.

REFERENCES:

[12] Blast-Control project summary: 2002. Blast oriented production control system for open-pit mining and quarrying. Pp. 1. cordis.europa.eu/project/rcn/44832_en.html.

[13] Blast-Control project summary: 2002. Neural Network system for fragmentation prediction. cordis.europa.eu/result/rcn/27963_en.html.

Scope of work

The use of blast, in open-pit exploitations is a challenging task due to rock-fragmentation issued from the blast and to rock-mass hazards. To respond to European environmental constraints, the control of risks and valorization of natural resources need to be addressed together.

This project aim to support industry for monitoring and blasting control to optimize the primary production process, including drilling, blasting, loading, haulage and primary crushing, as well as the impact of fragmentation of blasted rock. Solving this problem requires, first, to be able to monitor and to quantify continuously the impact of fragmentation on basic operations, and, secondly, to guarantee with blasting the resulting fragmentation which optimizes production-flow and minimizes costs.

Status of the project

Project finalized in 2001. The following deliverables can be reported:

- Blast oriented production control system adapted for open-pit mining and quarrying industry operations [12].
- Assist to rebuild the primary production chain starting with blasting, which is often discontinuous and fuzzy for analysis.
- It allows to control and analyze productivity of each single production chain starting at the blast stage.
- It allows to improve productivity of each single production chain, by acting on blasting or other production parameters.
- A methodology for systematic and accurate assessment of the blast geometry.
- Measurement and software system for blast control and blast design.
- Neural Network system for fragmentation prediction aligned with the continuous data acquisition methodology [13].
- The system is operational and is linked to the database of the production control system.

REPURPOSE LIME BY-PRODUCTS

ely-keskus.fi/web/ely/ely-kaakkois-suomi

Scope of work

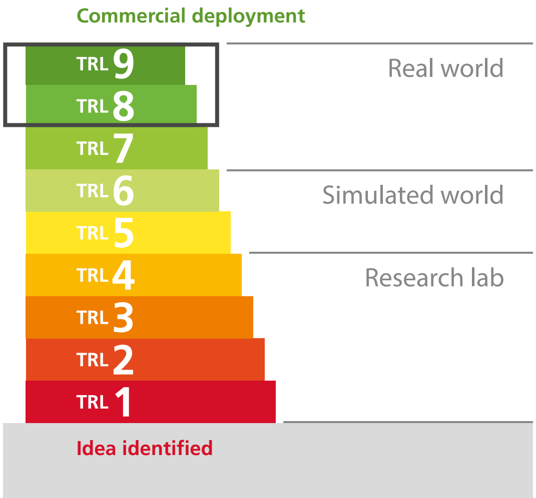
The optimization of the waste flows is a challenge during and after the operations to manage properly the raw material deposit and extend the lifetime of the quarry through better management of waste and by-products [14]. These practices were used by industrial minerals industry extensively even before EU policies (i.e. Waste Management BREF (2006) Mining Waste Directive (2006)) were in place. This project illustrates the repurposing and resource optimization from a limestone quarry operations in Finland by Nordkalk Corporation.

Status of the project

Ongoing practice. The following deliverables can be reported:

- The limestone, the main product, is extracted and processed (grounded and the concentrated calcite is separated from the slurry by flotation) in Finland operations and filter sand are a by-product estimated to be around 100 KT/year [15].
- The overall volume estimated for these by products is estimated in the range of 5.7MT from 1960 onwards [14].
- Filter sand minerals (such as calcite, wollastonite, dolomite and silicates) are produced as a by-product in the extraction and processing stage. Since the 1960’s a part of this filter sand has been used as a part of mixture of a lime fertilizer for organic agriculture as certified from Finnish Food Agency. The use for these two markets is 50/50.
- The company has also commercialized the filter sand to be used in earth and environmental construction.
- This is a good example of resource efficiency and repurposing of mineral material and minimize the waste volumes.

Type	Innovation action
Partners	Leader/Lime: Nordkalk (FI)
Funding	Own company project Total project: not applicable
Duration	1960 – to date
TRL	Technology Readiness Level: TRL 8-9



Contribution to

Raw material optimization – Lime by-products – Earthworks – Sand filter – Waste reduction – Multiple policy objectives.

REFERENCES:

[14] Kojo I.V., Reuter M.A., Heiskanen K., 2013. Some examples of reuse, repurposing and recycling of minerals to improve the resource efficiency in mining: Nordkalk, Finland, commercialization of filter sand. 6th International Conference on Sustainable Development in the Minerals Industry (SDIMI), 30 June – 3 July 2013, Milos (Greece). Platform presentation. Pp. 4.

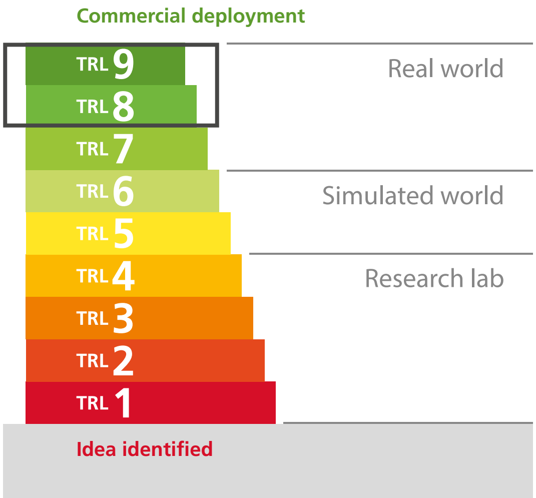
[15] Kajoniemi M., Eskelinen A., Keskitalo K., Rajamäki R., Rautanen H., Sahala L., Sääksniemi E., Timperi J., Tossavainen J., Vallius P., Vuokko J. 2008. Coordination of Groundwater Protection and Stone Conservation – South Karelia final report. Pp. 120.

NOISE BARRIERS

Noise barrier at Miedzianka (Poland)

nordkalk.com/sustainability/environmental/reducing-dust-noise-vibration

Type	Innovation action
Partners	Leader/Lime: Nordkalk (PL, FI) Nordkalk
Funding	Own company project Total project: not reported
Duration	2012 – 2016
TRL	Technology Readiness Level: TRL 8-9



Noise barrier at Miedzianka (Poland).

Contribution to

Nuisance avoidance measures – Community relations – BAT.

REFERENCES:

[16] Nordkalk Sustainability Report 2016. Pp. 8.

Scope of work

To avoid nuisance towards the local, multiple projects have been developed in coordination with the local communities and authorities. Sound insulation is improved by constructing noise barriers, planting trees and using various noise-damping materials at crushing plants, conveyor belts and loading places. In locations near residential areas, there are restrictions on night-time operations to avoid disturbances to the local residents.

Status of the project

- Vibration caused by blasting is measured; in Lohja, Finland, e.g. continuous measuring is carried out at three locations near the mine and at several temporary measuring points. Based on the results, necessary changes are made to blasting methods to reduce the amount of vibrations. Nordkalk has ensured the readiness of its production facilities for the Best Available Techniques (BAT) obligations deriving form the Industrial Emissions Directive (IED) [16].
- Noise barriers or acoustic baffles are the best way to "fight" noise, which is emitted by transport, trucks, trains and loaders. In 2015, the Miedzianka Plant in Poland finished building 700 metres of wall baffles along its traffic routes. The seven meters high walls are made of sound-absorbing material. The measurements carried out after the installing of acoustic baffles fulfilled the requirements of the contract concerning the reduction of noise emissions. In 2016, additional actions were taken to further reduce noise emissions at night. As a continuation to the sound-absorbing barriers built a year earlier, two new environmental investments were finished. Special octagonal noise reducers were installed on the upper edge of the barriers to absorb diffracted sound waves into the sound-absorbing mineral wool plate. Another improvement was replacing an old steel element gate with acoustic panels. The noise measurements carried out after finalizing the construction showed significant reduction of the noise level.

WATER MANAGEMENT PLATFORM

Multi-stakeholder Water Management Platform to manage water resources for quarrying activities

Scope of work

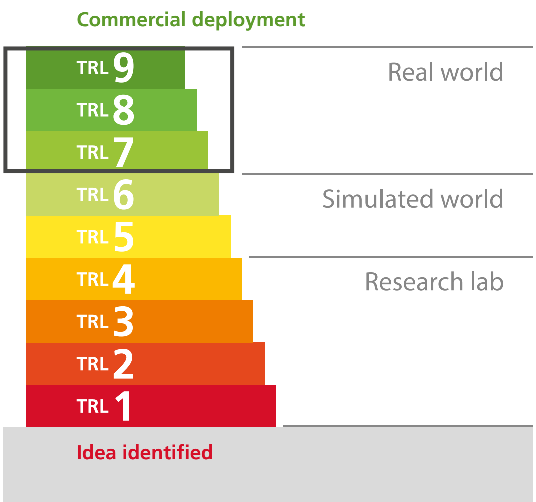
The operation of multiple stakeholders (drinking water. planning authorities, mining company) within the same area and the competition for water resources is a challenging task, which requires a multi-stakeholder management system that accommodates needs and secures access to all concerned stakeholders. The Water management projects consist in illustrating the establishment of this system and the modus operandi.

Status of the project

Water management platform is operational and the following can be reported:

- Motivation of all the working group members to put resources and arrive at a solution despite the sectoral differences to create a real common spirit between all the members towards a final common solution operational to all.
- All stakeholder inclusive platform that allowed the concerned stakeholders to establish a level of trust to share their respective data.
- The data sharing process, allowed the concerned stakeholders to explain their concerns and demands.
- The selection of a common and neutral Engineering Company to conduct the feasibility study.
- This exchange platform allowed the regional authorities to have a helicopter view and understand all constrains and demands and make the best decision on the condition to access the water resource.
- This platform allowed to ensure a cohesion between legislations (Ex: conditions of permit for water pumping in quarry are not the same as for a drinking water permit). This process allowed to find a pragmatic and compatible legal solutions [17].

Type	Demonstration
Partners	Leader/Lime: Carmeuse (BE)
Funding	Own company project Total project: not reported
Duration	2003 – 2011
TRL	Technology Readiness Level: TRL 7-9



Contribution to

Raw material optimization – Water management platform – Stakeholder involvement.

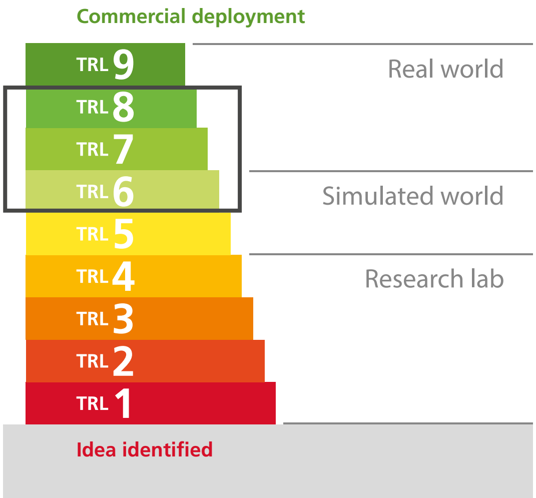
REFERENCES:

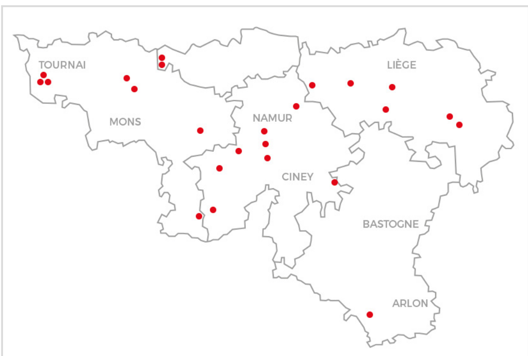
[17] Despotou E., 2012. Resource Efficiency for mining and processing in the lime industry – case studies. IMA-Europe 2012 Conference: Resource efficiency and the contribution of industrial minerals. 14 November 2014 in Brussels (Belgium). Platform presentation.

LIFE IN QUARRIES

lifeinquarries.eu

Type	Demonstration
Partners	Leader/Lime: Fediex (BE)
Funding	EU / LIFE+ Total project: 5 Mill EUR EU contribution: 2.8 Mill EUR
Duration	02.2015 – 01.2020
TRL	Technology Readiness Level: TRL 6-8





Map of Walloon quarries contributing to the project.

REFERENCES:

[18] Life in Quarries. 2016. ec.europa.eu/environment/life/project/Projects/index.cfm.

Scope of work

The LIFE IN QUARRIES project aims to develop biodiversity in active quarries by:

- Testing and defining methods for the restoration, maintenance and management of pioneer species and habitats.
- Testing and defining methods for preparing the physical quarry infrastructure during exploitation processes, to facilitate the establishment of restoration plans that will increase ecosystem services and biodiversity following exploitation.
- Identifying lock-in situations and challenges for biodiversity development in active quarries such as legal constraints, lack of biodiversity management awareness etc.
- Developing the awareness of quarry managers, public administration managers and other local stakeholders for biodiversity management.
- Demonstrating best practices of adapting management throughout the complete exploitation process for up to 24 Belgian quarries and sharing this experience in the European context.

Status of the project

Project is ongoing. Key objectives consist of:

- Training for CEOs and staff members of the 24 Walloon quarries (see fig.) and six EU quarries, including workshops, development of factsheets and guidelines for the creation and management of temporary habitats in quarries. Development of supporting videos and a picture database aimed at species recognition for quarry workers.
- Analysis & inventory of actual and potential ecosystem services and green infrastructure developed by the extractive industry.
- External communication, dissemination for other EU quarries and experience-sharing events with relevant partners in France, Germany [18].

Contribution to

Nature preservation – Temporary habitat – Biodiversity issues – Ecological coherence – Industry – Mining – Quarrying – Renaturation.

DRINKING WATER FROM QUARRY

The town of Lohja (Near Helsinki) acquires water from Nordkalk quarry and uses it as drinking water

nordkalk.com/sustainability/community/water-for-lohja

Scope of work

More than one million cubic meters of groundwater is pumped up yearly from the underground mine. About half of the water is delivered to the municipal waterworks, where it represents 23% of all raw water received. It is filtered through a sand bed before being led to the water distribution system.

Status of the project

• The Tytyri plant itself uses some 30.000 m^3 of water annually, also from the mine, but through a separate pumping station. The surplus water – about half a million cubic meters – is directed to the nearby lake Lohjanjärvi. This is mostly groundwater, but it includes a small portion of storm water gathered from the plant area. Yearly quality measurements show that the water released into the lake corresponds to household water quality.

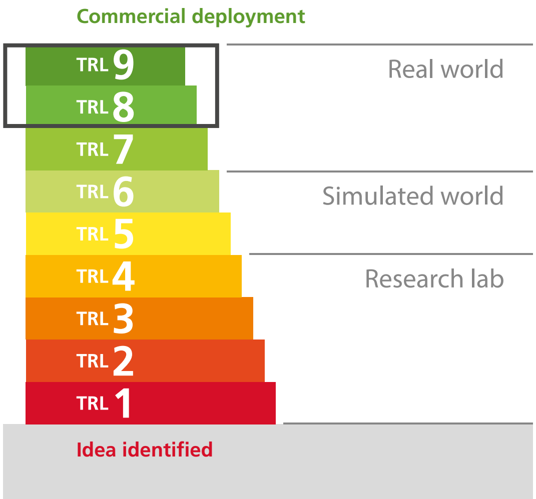
• In Tytyri, there is also The Tytyri Experience including a museum and other activities. The Tytyri Experience is operated by the city and visited by more than 10.000 people annually. KONE Corporation's high-rise elevator test laboratory is located in old mine shafts. One of the elevators is used to transporting visitors to the Tytyri Experience [19].

Contribution to

Stakeholder involvement – Community relations.

REFERENCES:
[19] Nordkalk Sustainability Report 2016. Pp. 37.

Type	Innovation action
Partners	Leader/Lime: Nordkalk (FI) Nordkalk
Funding	Own company project Total project: not reported
Duration	2012 – 2016
TRL	Technology Readiness Level: TRL 8-9



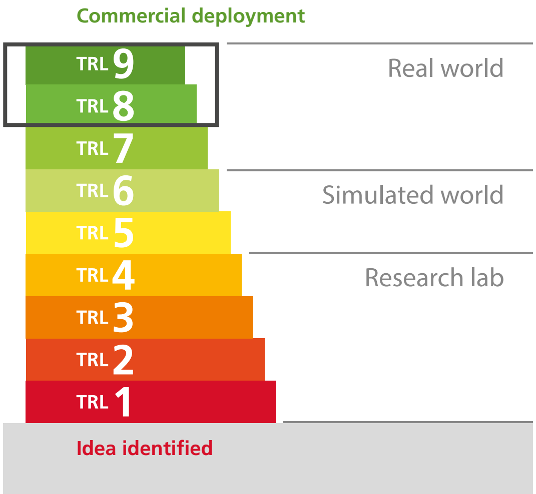
The town of Lohja acquires water from Nordkalk.

GRAVITY CONVEYER BELT

Gravity conveyor as a multi deliverable towards energy and environment footprint improvements

baumit.com
wopfingerbaustoffe.at

Type	Innovation action (demonstration)
Partners	Leader/Lime: Baumit (AT)
Funding	Own company initiative Total project: 0.75 Mill EUR
Duration	2001 – 2003
TRL	Technology Readiness Level: TRL 8-9



Dürnbach quarry in Waldegg.

REFERENCES:

[20] Schwingenschlögl, R., Tisch, M.2002. Abbauoptimierung im Steinbruch Dürrnbachtal der Wopfinger Baustoffindustrie GmbH. 3M – Congress (Mining, Metallurgy and Mineral Industries), 31.05.2002, TU – Wien, Vienna (Austria). In German.

Scope of work

In view of improving the performance of this lime manufacturing site in Austria the company invested in a multiple retrofit project which consisted of: two new crushers, two shafts, and an underground tunnel for a gravity conveyer belt. All these investments provided multiple benefits from an energy, CO_2 improved performance for the company and nuisance avoidance for the local neighbors.

Status of the project

Project commissioned in February 2003 and is was part of an integrated investment to refit, boost and optimize the operations of the site. Key achievements of this project are:

- Installation of two crushers (primary and secondary crusher).
- Two shafts (diameter 4 m, depth 144 m).
- A new tunnel (727 m, with the existing tunnel more than 1000 m).
- A new conveyor gravity belt (distance between axis 1020 m, width of belt 1000 mm, 200 kW generative operation).
- The conveyor belt, working with gravity, about 200 MWh per year of electricity can be generated. More than 150 tons of CO_2 can be saved per year, using the Commission CO_2--emission per MWh of 0,76 t.

It was a company initiative to improve the environment footprint and energy savings for the production of limestone. With this project conveying of limestone by gravity, noise, dust emissions and other nuisances for the local community in the vicinity could be reduced substantially due to the smaller number of tracks transporting the raw material from the quarry to the processing facility [20].

Contribution to

Energy generation & efficiency – Truck avoidance – CO_2 avoidance – Dust avoidance – Nuisance avoidance – Refit project.

RESOURCE OPTIMISATION

Efficient use of natural resources

nordkalk.com/sustainability/environmental/efficient-use-of-natural-resources

Scope of work

Nordkalk strives to optimize the use of all the extracted /processed raw materials, aiming for 100% material efficiency, which is sound from both financial and environmental point of view.

Status of the project

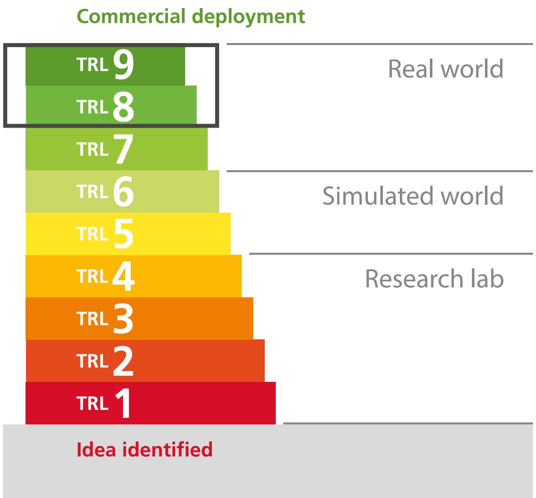
- The material-efficiency efforts include using all by-products: wall rock that is extracted in addition to regular limestone, fine sand produced in the flotation process, filter dust, which builds up in all lime kilns and at grinding plants, and residues created in lime burning and slaking. Nordkalk also assists its customers by handling their process by-products in a sustainable way.
- In 2016, Nordkalk was able to raise the material efficiency rate from 94.3% to 96.6%, thanks to focus on sales of lime kiln dust and especially of wall rock.
- Wall rock is used to build infrastructure, e.g. foundations for roads, airports and windmill parks. In addition to the Finland's domestic market, stone products are shipped e.g. to the Baltics and Russia for infrastructure projects.
- All of Nordkalk's stone material is CE marked, which supports sales, as does the growing environmental awareness in the society.
- Wall rock is typical of Finnish quarries for geological reasons. In the Lappeenranta and Pargas quarries, wall rock represents approximately one third of all quarried stone products [21].

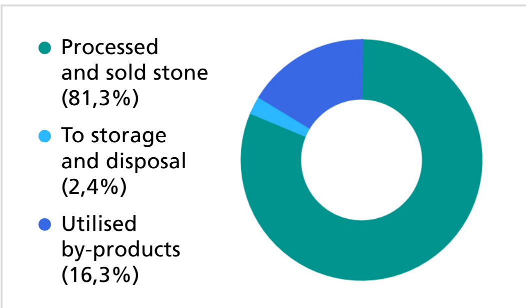
Contribution to

Resource optimization – Certification – Zero waste quarry.

REFERENCES:
[21] Nordkalk Sustainability Report 2016. Pp. 10.

Type	Demonstration
Partners	Leader/Lime: Nordkalk (FI) Nordkalk
Funding	Own company project Total project: not reported
Duration	2012 – 2016
TRL	Technology Readiness Level: TRL 8-9





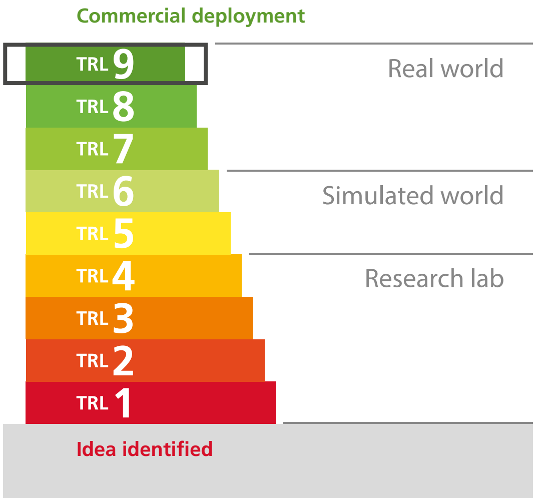
Material optimisation.

WATER MANAGEMENT

Water management at quarry post-closure

nordkalk.com/sustainability/environmental/planned-water--management

Type	Restoration
Partners	Leader/Lime: Nordkalk (SE) Nordkalk
Funding	Own company project Total project: not reported
Duration	2012 – 2015
TRL	Technology Readiness Level: TRL 9



An arched bridge has been built for more trout to be able to play further up the Klinthagen creek.

Scope of work

The guiding principle in each quarry water management plans is to carry out operations with minimal negative impact on both the surface water and groundwater. Today, the lake in Klinthagen quarry holds about 2.5 million cubic metres of water. When the quarry is closed and the lake completely filled, the lake will accommodate about five million cubic metres and be Gotland's deepest lake and the second largest lake in terms of volume after Lake Bästeträsk.

Status of the project

- In the autumn of 2015 a two-kilometre-long ditch was built to dewater the northern and central part of the quarry. When the pit is closed ditches will also be constructed to carry water to the pit exit point and onward to Klinthagen creek. The ditches create a self-regulating system with natural sedimentation of the water extraction.
- From the exit point the water will be transported to an area of maximally active wetland vegetation for further cleaning of the water downstream from the Klinthagen quarry and into the creek. Any limestone particles, clay particles and nitrogen resulting from limestone quarrying are removed, so that the water is crystal clear and has the same concentration levels as the natural creek water.
- An arched bridge has been built for more trout to be able to play further up the Klinthagen creek.
- Fish conservation efforts will be carried out in the creek, to promote spawning fish and other aquatic organisms. Spawning gravel has been deployed and ditches adjacent to the sea and farmland have been cleared. An arched bridge has been constructed under a minor road so that more trout will be able to spawn further up the creek. To promote the fry's hatching period, small flows will be pumped out into the creek from April to midsummer. Information on how the trout's spawning territories evolve over time, will be collected by counting the numbers of spawning pockets every autumn until two years after completion of quarrying [22].

Contribution to

Mitigation measures – Stakeholder involvement – Fish conservation.

REFERENCES:
[22] Nordkalk Sustainability Report 2016. Pp. 15.

COMMUNITY RELATIONS

Mining and community relations

carmeuse.com/neighbor-relationships

Scope of work

The operation of multiple stakeholders (drinking water; planning authorities, mining company) within the same area and the competition for water resources is a challenging task, which requires a multi-stakeholder management system that accommodates needs and secures access to all concerned stakeholders. The Water management projects consist in illustrating the establishment of this system and the modus operandi.

Status of the project

To preserve the technical aspects of the operations and minimize nuisance multiple measures are agreed with the local communities in the neighbor committee meetings and validated by the permitting authority and implemented by the mining company:

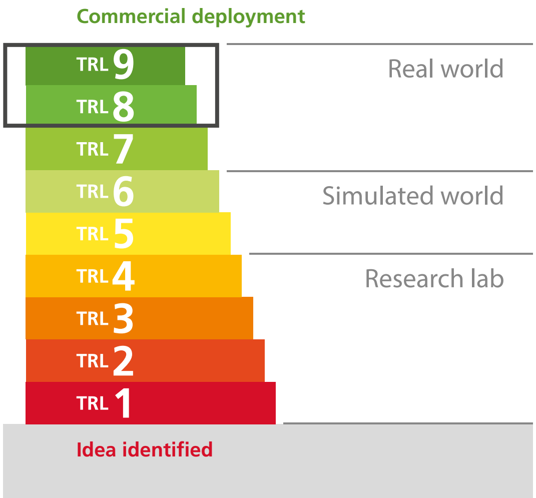
- The control blasting vibrations.
- Implementation of the programs to maintain the air quality.
- Dust emission can be minimized by different means: spraying products and roads, drilling with suction systems, having hooded conveyors and housings around crushing and processing units.
- To minimize noise, in multiple sites multiple measures were implemented: i.e. construction of a berm between the quarry and the houses, insulating the installations, replacing the traditional ear-splitting reverse horn by a softer horn that can be heard within the close surroundings of the truck and preventive maintenance of the installations by company staff [23].

Contribution to

Nuisance avoidance measures – Stakeholder involvement – Community relations.

REFERENCES:
[23] Carmeuse. Case Study. Neighbor relationships. Pp. 1.

Type	Demonstration
Partners	Leader/Lime: Carmeuse (BE)
Funding	Own company project Total project: not reported
Duration	continuous
TRL	Technology Readiness Level: TRL 8-9



Carmeuse places a high value on both people and its relationship with local communities.

4. Process Emissions Mitigation

- AGICAL+
- BiOxySorb
- CaO_2
- CARINA
- CaLEnergy
- ECO
- ECO_2
- LEILAC1
- LEILAC2
- SCARLET
- CSM
- CO_2-solid bed reactor
- NECAPoGEN 4Lime
- C4U
- Columbus
- $LOWCO_2$
- ZerCaL
- DinamX

AGICAL+

Microalgae as CO_2 capture solution

ec.europa.eu/environment/life/project/Projects/LIFE10_ENV_BE_000696_FTR.pdf

Scope of work

The objectives of this project were two:

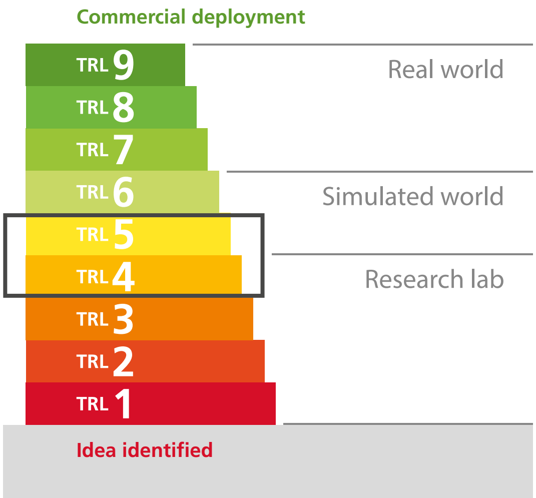
- Reducing the emissions of greenhouse gases and the consumption of fossil fuel linked to glass (high gas temperatures) and lime production with low temperatures).
- Capturing CO_2 in the flue gases using microalgae cultures, and then processing these microalgae to extract biofuel, to be used again in the product process to reduce the consumption of fossil fuels. The goal was to demonstrate that it is possible to capture 360 tonnes of CO_2 per year and per hectare of microalgae, thus producing 200 tonnes of biomass, and extracting up to 2460 GJ of biofuel.
- CO_2 is directly used by the algae in the photosynthesis process, and the heat contained in the gases is used for thermal control of the culture and to power surrounding process, thus maximizing the environmental benefit of the pilots. Hence, demonstration on both production processes would show the versatility of the technology.

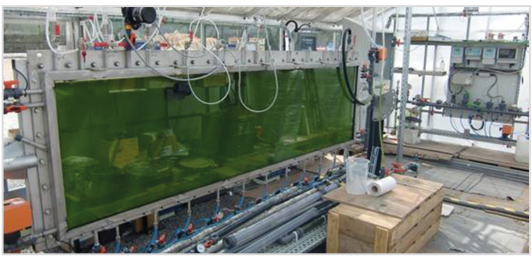
Status of the project

Project was terminated August 2013. Key deliverables of the project consist of:

- Two pilots. The pilots were to be implemented in two phases, first for the glass furnace, and then for the lime kiln, to allow for optimisation step. Therefore, the productivity of the first pilot was set at 150T/year, and the productivity of the second at 200 T/year.
- The evaluation of the pilot results led the partners to discontinue the project since.
- Throughout the 7 months testing period on the small pilot, the highest average yield was 10 tonnes/year/ha. Based on remaining findings the partners thus redesigned some parameters of the culture and estimated the absolute maximum potential biomass production to be 80 tonnes/ha/year. This would mean to capture 144 tonnes CO_2/year.
- Economic evaluation indicated that the cost of the biofuel produced would be in the order of 100-fold more expensive than commercially available (bio)fuels [24].

Type	Innovation action (pilot)
Partners	Leader: AGC (BE) Lime: Carmeuse (BE)
Funding	EU / LIFE+ Total project: 9.2 Mill EUR EU contribution: 3.6 Mill EUR
Duration	01.2011 – 11.2016 Project terminated on 08.2013
TRL	Technology Readiness Level: TRL 4-5





Pilot plant for the Algae growth.

Contribution to

Carbon sequestration – Renewable energy – Emission reduction – Multiple policy objectives.

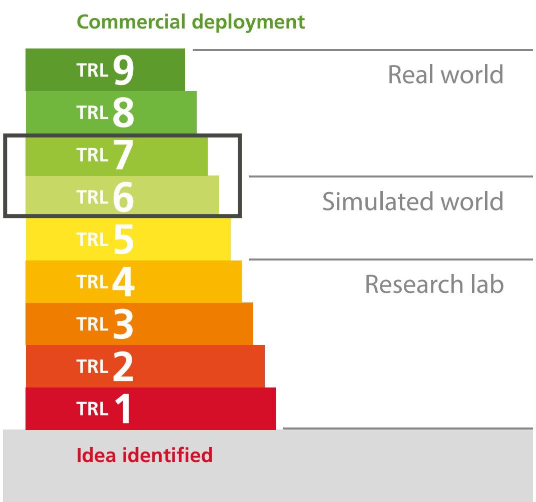
REFERENCES:

[24] AGICAL. 2013. Public version of Final Report. Project activities from 11/2011 to 08/2013.

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

bioxysorb.eu-projects.de

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:

[25] 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.

Scope of work

The main objective of BiOxySorb is two-fold:

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

Status of the project

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

- Assessment behaviour of emission (PM, HCl, CO, NO_x, SO_x and Hg) of various first and second generation biomasses and co-combustion shares under air and oxy-fuel conditions.
- Choice and evaluation of sorbents (e.g. alkalines, earth-alkalines, and activated carbon or lignite/coal coke) and investigation of their application for control of HCl, SO_2, SO_3 and Hg emissions under air and oxy-fuel firing conditions.
- Investigation of necessary plant modifications for high thermal share biomass co--milling and co-combustion and for injection of sorbents.
- Techno-economical study of different degrees of biomass co-combustion and emission control by sorbent injection under air and oxy-fuel conditions. Utility and technology and supplies manufacturer (E.ON, LHOIST, GBS) will use the data generated in the experimental small, technical and large scale tests to assess the impact of the co-combustion and sorbents on full-cycle, full-scale power plants and to determine their impact on cycle optimization, ash valorisation and emissions control [25].
- 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.

CaO_2

Calcium carbonate looping for coal power plants

cao2.eu

Scope of work

The objectives of this project were two:

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

Status of the project

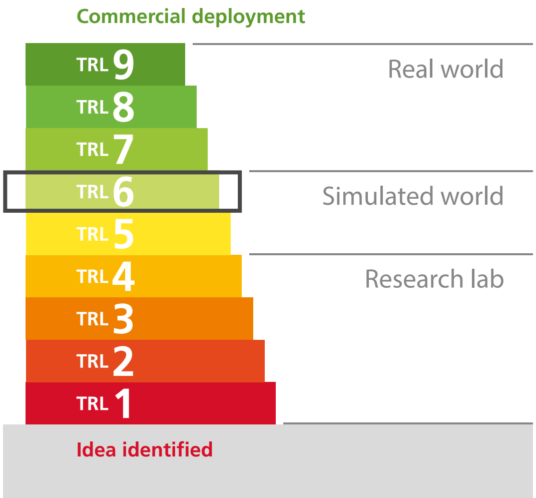
Project was terminated in 2017. Key deliverables of the project consist of:

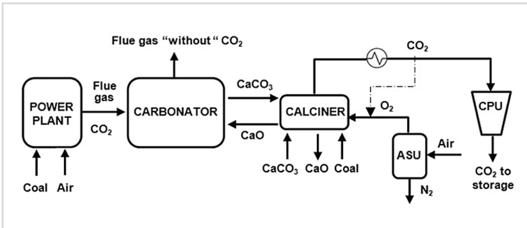
- Reduce the heat requirements in the calciner and therefore the consumption of coal and O_2.
- Reduce the calciner size for the same heat input (to keep similar gas velocities in the CFB calciner) and the size of the ASU, which implies a decrease of investment costs.
- The validation of the concept will be done in La Pereda CaL pilot plant in Asturias (Spain), the biggest CaL facility in the world. Basic mass and heat balance calculations reveal that the standard CaL system can reduce about 20-30% the energy requirements in the calciner by switching to a configuration as proposed in the CaO_2 project [26].

Contribution to

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

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





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

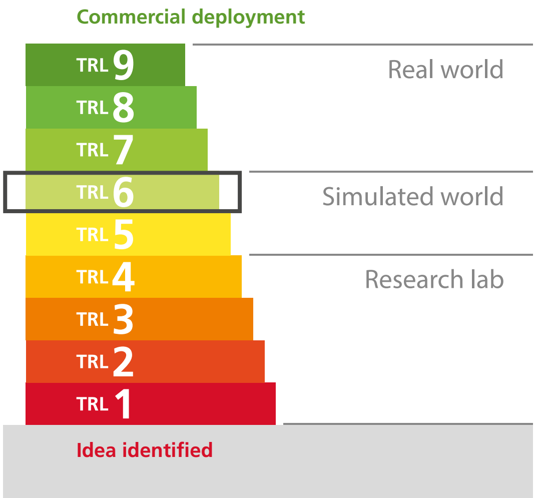
REFERENCES:

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

CARINA • Carbon Capture by Indirectly Heated Carbonate Looping Process

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

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



Contribution to

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

REFERENCES:

[27] Höftberger D., Karl J. 2013. Self-Fluidization in an Indirectly Heated Calciner, Chemical Engineering & Technology, Volume 36: 9. Pp. 1533-1538.
[28] Junk M., Reitz M., Ströhle J., Epple B., 2013. Thermodynamic evaluation and cold flow model testing of an indirectly heated carbonate looping process, Chemical Engineering & Technology, Volume 36: 9. Pp. 1479-1487.
[29] Kremer J., Galloy A. Ströhle J., Epple B., 2013. Continuous CO_2 Capture in a 1-MW_{th} Carbonate Looping Pilot Plant. Chemical Engineering & Technology. Volume 36: 9. Pp. 1518-1524.

Scope of work

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

Status of the project

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

- The proposed concept is based on a fluidized bed heat exchanger system transferring heat from a combustor to the calciner by means of heat pipes. The main advantage of an externally fired calciner is the avoidance of oxygen production by an air separation unit. The estimated gain in electrical net efficiency is around 2-3% points, compared to a directly fired calciner [27].
- The heat input into the calciner is no longer effected directly, but indirectly by means of heaters. This results in a multitude of process engineering advantages.
- The standard carbonate looping promises low energy penalties for post-combustion CO_2-capture and is particularly suited for retrofitting existing power plants [28].
- 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 [29].

CALENERGY

Chemical Looping 4 Combustion Technology

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

Scope of work

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

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

Status of the project

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

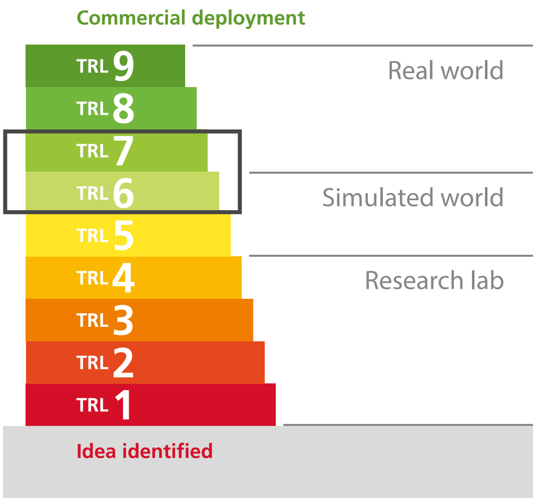
- This project focuses on development of the limestone chemical looping combustion system [30].
- The low-cost limestone oxygen carrier along with less-expensive more-efficient reactors drives down capital and operating costs relative to conventional systems.
- This project addressed technology gaps and generating data to support scale-up via continuous, stable operation of a 1 MWe prototype system [31].

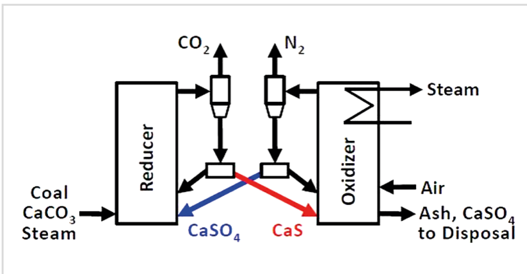
Contribution to

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

REFERENCES:
[30] Chamberland R. 2015. Alstom's Chemical Looping Combustion Technology with CO_2 Capture for New and Existing Coal-Fired Power Plants. Alstom Power, Inc., 2015 NETL CO_2 Capture Technology Meeting June 2015, Pittsburgh, PA.
[31] Marion J. 2016. Alstom's Chemical Looping Combustion Technology with CO_2 Capture for New and Existing Coal-Fired Power Plants, GE Power, 2016 NETL CO_2 Capture Technology Project Review Meeting Aug 2016, Pittsburgh, PA.

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



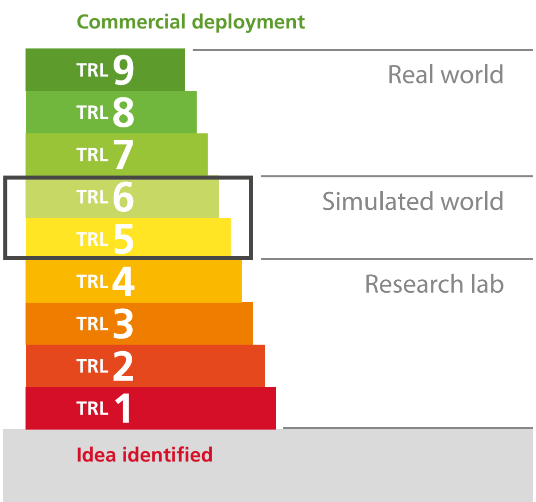


Alstom's LCL-C process implementation.

ECO
Ecological CO_2 scrubbing (ECO)

fg-kalk-moertel.de/forschungsberichte.html

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



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

Scope of work

The aim of this research project was to investigate the recycling of anthropogenic CO_2 into the natural carbon cycle using lime products. In practice, the capture of CO_2 from flue gases with the help of a limestone-CO_2-washing process similar to the naturally occurring carbonate weathering process. Subsequently after the CO_2 cleaning process the "produced" calcium bicarbonate-rich solution (mineralized water) should be returned to limnic and marine environments as natural buffer [32].

Status of the project

The project was finished in 2012. The CO_2 scrubbing process with limestone powder in solution was successfully demonstrated at the waste water facility in Bad Orb. During performance tests a reduction of CO_2 within the flue gas by up to 13% was achieved [32]. A four-five stage cleaning system could lead to a CO_2 reduction of up to 80%, as modelling and calculations revealed [33].

Contribution to

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

REFERENCES:

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

[33] 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.

ECO_2

Economical CO_2 scrubbing

fg-kalk-moertel.de/eco2.html

Scope of work

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

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

Status of the project

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

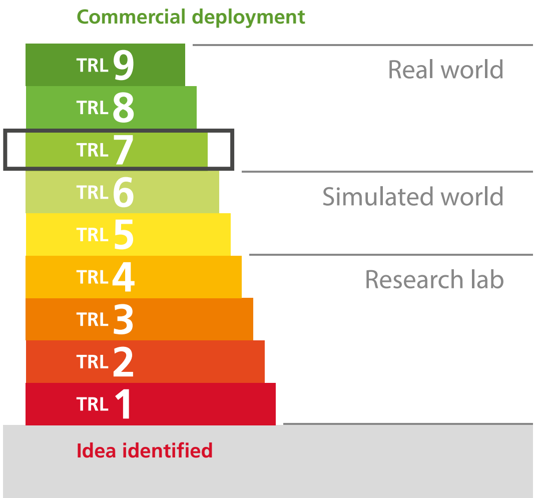
- Cascaded scrubber system to remove CO_2 with limestone powder and produce ready to use buffered water.
- Pre-trial finished. Pilot plant build. Tests at IUTA (Duisburg)
- Bio- and ecological modelling to test the harmlessness of process water discharge and biochemical effects are ongoing.
- Location for pilot plant: coal-fired plant Wilhelmshaven (Uniper). Test campaign from March to June 2017 [34].

Contribution to

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

REFERENCES:
[34] ECO_2 reports in German are available upon request. info@eula.eu.

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



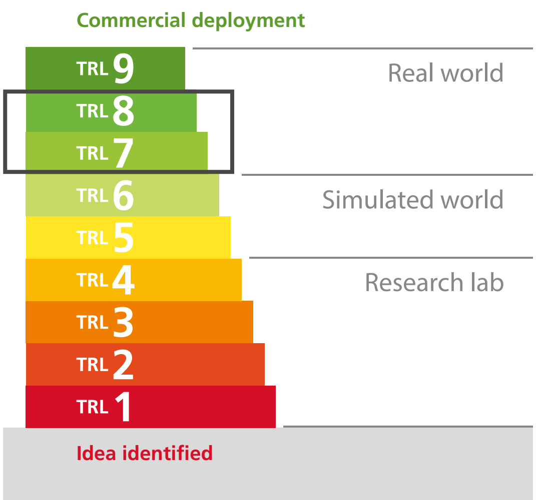
Pilot CO_2 scrubber of ECO_2 project, Wilhelmshaven coal-fired power plant, where pilot testing is carried out.

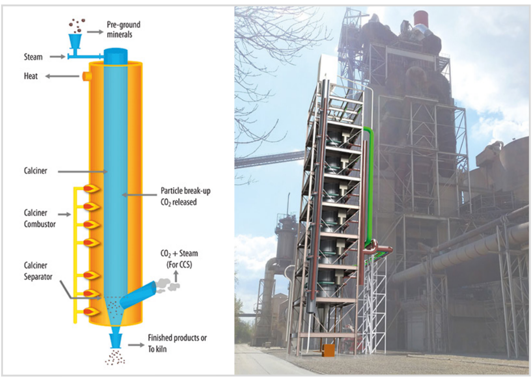
LEILAC1

Low Emissions Intensity Lime And Cement

project-leilac.eu

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





Original DSR and DSR superimposed in the Lixhe plant.

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

Scope of work

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

• LEILAC1 will pilot the Direct Separation Reactor (DSR) advanced technology that has the potential to capture unavoidable process emissions and enable both Europe's cement and lime industries to reduce emissions by around 60% to 70%.

• Direct Separation provides a common platform for CCS in both the lime and cement industries. Calix's DSR technology has been used successfully to produce niche "caustic MgO" since 2012, while trapping the plant's process CO_2 emissions. The DSR is an in-situ CO_2 capture technique that requires no additional chemicals or equipment.

• LEILAC1 project innovation consists in the temperature scale up the DSR.

Status of the project

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

• LEILAC1 will develop, build, operate and test at 8 tons per hour limestone feed rate (~100 tons per day lime) pilot plant at Heidelberg Cement's plant in Lixhe (BE), demonstrating that over 95% of the process CO_2 emissions could be captured [35].

• This technology can be proven at a suitable scale (approximately within 5 years for the lime industry, and likely more than 10 years for larger cement plant).

• In a lime plant, the unit will just replace the kiln. This design could also work with alternative fuels.

• Techno-economic analysis, and Life Cycle Analysis will be conducted at pilot scale to assess opportunity for technology's scale and deployment via a Roadmap [35, 36].

Contribution to

CCU/CCS – Process emissions reduction – CO_2 mitigation.

REFERENCES:

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

LEILAC2

Low Emissions Intensity Lime And Cement

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

Scope of work

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

Status of the project

The project was launched in April 2020 and will run until March 2025.
It successfully passed the pre-FEED phase (process design) in April 2021. It is presently in the FEED stage (Front End Engineering & Design) [37].

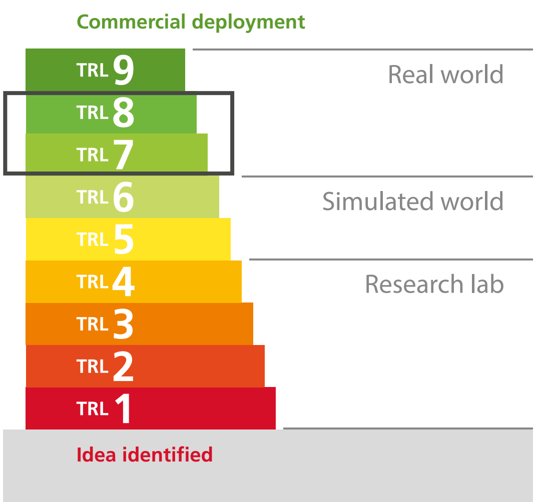
Contribution to

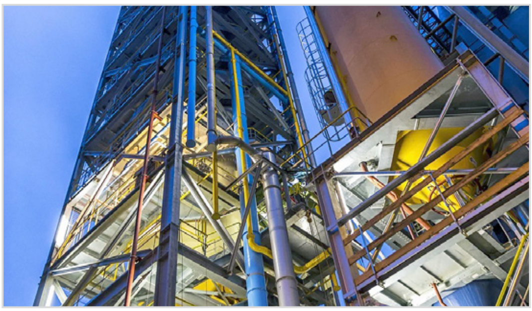
CCU/CCS – Process emissions reduction – CO_2 mitigation.

REFERENCES:

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

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





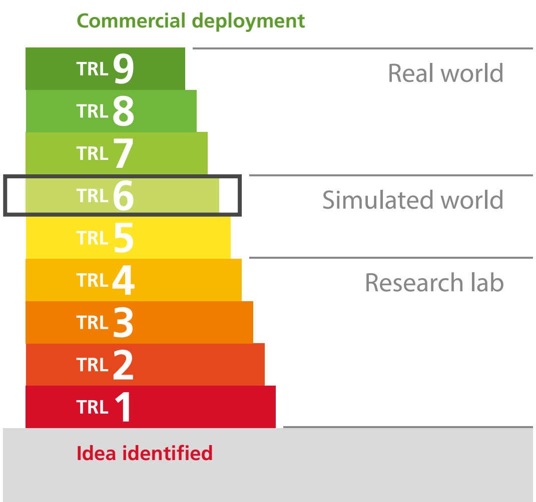
HeidelbergCement hosts the LEILAC2 Demonstration plant.

SCARLET

Scale-up of Calcium Carbonate Looping Technology for Efficient CO_2 Capture from Power & Industrial Plants

project-scarlet.eu

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



Contribution to

Carbon looping – Lime technology – CCU.

REFERENCES:

[38] Stroh A., Alobaid F., Ströhle J., Hasenzahl M.T., Hilz J., Epple B., 2015. Comparison of three different CFD methods for dense fluidized beds and validation by acold-flow experiment. Particuology 2015, Article in Press.

[39] Zeneli M., Nikolopoulos A., Nikolopoulos N., Grammelis P., Kakaras E., 2015. Application of an advanced coupled EMMS-TFM model to a pilot scale CFB carbonator, Chemical Engineering Science: 138, Pp. 482-498.

Scope of work

Calcium Carbonate Looping (CCL) is a technology tested for low-cost post combustion CO_2 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 CO_2 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, CO_2 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 [38, 39].

CSM

Carbon Storage by Mineralisation

ccspfinalreport.fi/print

Scope of work

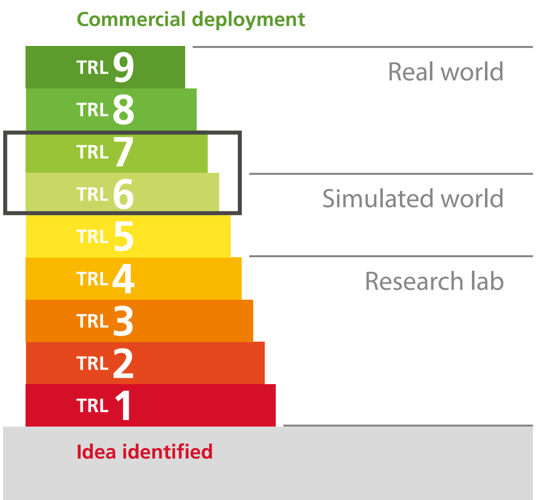
The stepwise carbonation of serpentinite, a rock composed mainly of magnesium silicate mineral serpentine reacts with the CO_2 to form a stable compound, thus fixing the CO_2 permanently. The reaction kinetics have received attention but the work done in Carbon Capture Storage Program (CCSP) is unique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

Status of the project

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

- The recent study shows that operating at 80 bar carbonation pressure with ~22%-vol CO_2 flue gas without capture, mineral sequestration may be accomplished at an energy penalty of 0.9 GJ/t CO_2 electricity besides 2.6 GJ/tCO_2 heat which can be extracted from the kiln gas [40].
- Direct mineralisation of flue gas instead of separated and compressed CO_2, eliminates the need of ex-pensive and energy intensive processes to isolate and compress CO_2, thus significantly lowering the materials and energy requirements for the overall CCS process chain [40, 41].
- An exergy analysis is used to optimise process layout and energy efficiency, and at the same time max-imise the amount of CO_2 that can be bound to $MgCO_3$ given the amount of waste heat available from the lime kiln.
- Also, experimental results are reported for producing $Mg(OH)_2$ (and $Fe,Ca(OH)_2$) from local rock material.
- Operating without CO_2 separation makes CSM an attractive and cost-competitive option when compared to conventional CCS involving underground storage of CO_2 [41].

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 CO_2 capturing mineral looked promising, but replicating to limestone minerals technical difficulties and the results were quite poor [41, 42].

Contribution to

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

REFERENCES:

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

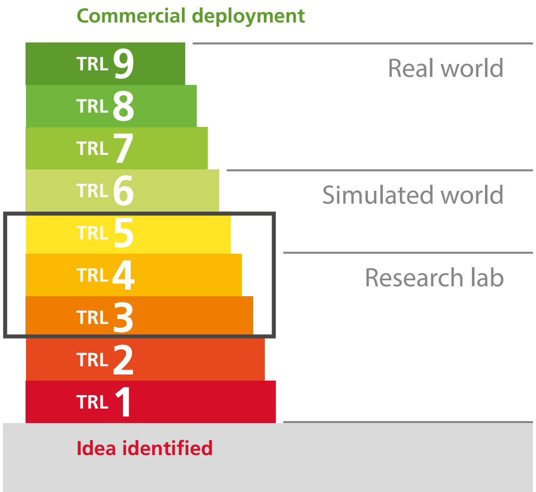
[41] CCSP Carbon Capture and Storage Program 1.1.2011 – 31.10.2016. Final report. Pp. 1-248. ccsp-finalreport.fi/reports/CCSP_Final_report.pdf.

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

CO_2-SOLID BED REACTOR

Solid bed reactor for separating CO_2 from flue gases with internal recovery of reaction enthalpy

Type	Innovation action (CO_2 separation)
Partners	Leader: University of Magdeburg (DE), University of Bochum (DE) Lime: BVK
Funding	Federal Ministry for Economic, Affairs and Energy (AiF/BMWi) Total project: 0.75 Mill EUR
Duration	07.2020 – 31.12.2022
TRL	Technology Readiness Level: TRL 3-5



Contribution to

Climate change – Carbon capture – Carbon dioxide removal.

Scope of work

The aim of the project is to develop a fixed bed reactor which can separate CO_2 (> 90%) from kiln flue gases much more energy--efficiently than with the previously known looping methods. The special feature of the process is that the Carbonization (CO_2 absorption according to $CaO + CO_2 \rightarrow CaCO_3$) is carried out at overpressure and the calcination ($CaCO_3 \rightarrow CaO + CO_2$) at negative pressure. This is how the carbonization takes place at a higher temperature level than calcination. The reaction enthalpy getting released during carbonization is stored within the solid bed. The bed heats up from around 820 °C to 910 °C. The stored energy is then used for calcination, whereby the fixed bed cools down again accordingly. Compared to other / previous methods, an oxyfuel combustion for the calcination (~950 °C) is not necessary and the inefficient use of heat during carbonization (~650 °C) is no longer used. Another advantage is, that no material has to be transported between reactors and therefore no abrasion and dust accumulates, which otherwise must be replaced by fresh material. Instead of powdery material, (dolo)stones are used. There were preliminary tests carried out showing no signs of sinter processes. In addition, > 100 cycles were run without a decrease in CO_2 binding. This is another decisive advantage, since the sorbent shows long-term stability and no "dead-burned" lime has to be replaced. The reactor (see picture) will be operated within the technical centre of the University of Magdeburg. Reaction kinetics in dependence of the temperature, particle size and origin of bed materials as well as the heat transfer within/ between the solid bed need to be examined.

Status of the project

First lab tests are performed. The solid bed reactor is installed and will be tested within the next project phase.

NECAPOGEN 4LIME

NEgative-CAarbon emission POwer GENeration from integrated solid-oxide fuel cell and lime calciner

Scope of work

The Paris Agreement is the global commitment to limit by 1.5 to 2°C temperature increase above pre-industrial levels. In addition to low carbon processes, there is also a requirement for negative emissions technologies which can remove 7 gigatonnes of CO_2 from the atmosphere. Energy intensive sectors are under pressure to find ways to meet this societal challenge. Origen Power's 'negative emissions technology' supplies natural gas to a solid oxide fuel cell. About half the chemical energy is converted into electricity and the remainder into high-grade heat which is used to thermally decompose limestone ($CaCO_3$) in a calciner to produce) lime (CaO) and carbon dioxide. The system is configured so that all the CO_2 generated is pure, making it cheap and easy to either use or store. The lime that is produced can be used in a range of industrial processes and, in being used, removes carbon dioxide from the air.

Status of the project

Advanced modelling has shown the technical and economic viability of the technology [43]. A detailed techno-economic assessment of the process [44] indicates that if the electricity and the lime are sold at wholesale market prices, then the costs are covered without a carbon price – even as it removes carbon dioxide from the air. A bench scale demonstrator has been built by Cranfield University and the UK Government Energy Entrepreneurs fund has awarded a grant to build a 400 kW prototype at the Singleton Birch facilities in UK.

Contribution to

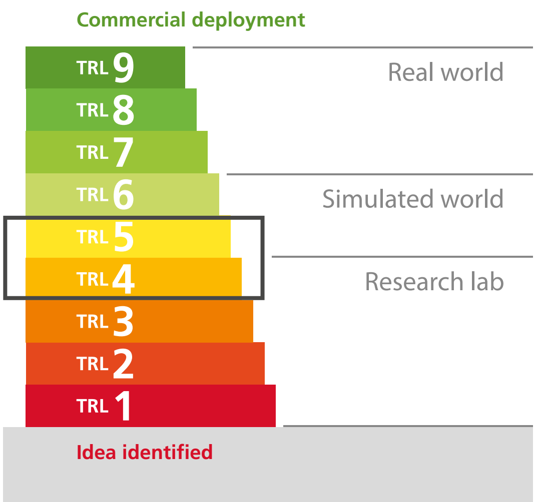
Negative emissions technolgies (NETs) – Greenhouse gas removal (GGR) – Net zero emissions – Paris agreement.

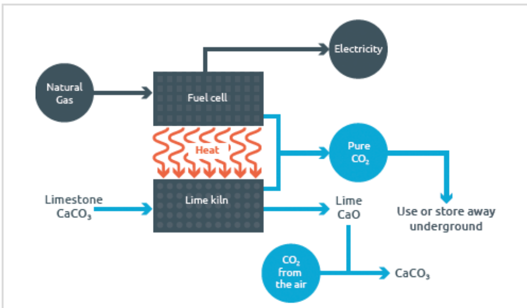
REFERENCES:

[43] Hanak D., Jenkins B., Kruger T., Manovic V., 2017. High-efficiency negative-carbon emission power generation from integrated solid-oxide fuel cell and calciner. Applied Energy 205. Pp. 1189-1201.

[44] £1M for Greenhouse Gas Removal tech. Innovators Magasine. 22 March 2018.

Type	Innovation action (demostration)
Partners	Leader: Origen Power (UK) & Arcola Energy (UK) Lime: Singleton Birch (UK)
Funding	1 Mill £
Duration	08.2018 – 08.2021
TRL	Technology Readiness Level: TRL 4-5



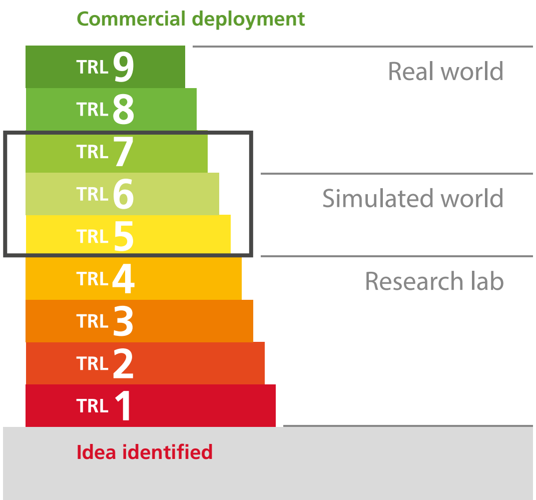


The process integrating the solid oxide fuel cell and lime calciner.

C4U
Carbon for You

cordis.europa.eu/project/id/884418

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



Scope of work

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

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

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

Status of the project

The project started in 2020.

Contribution to

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

COLUMBUS
Power to Methane

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

Scope of work

The scope of the project covers:

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

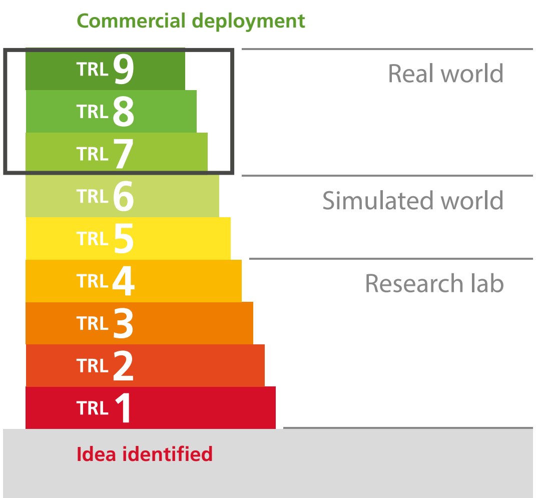
Status of the project

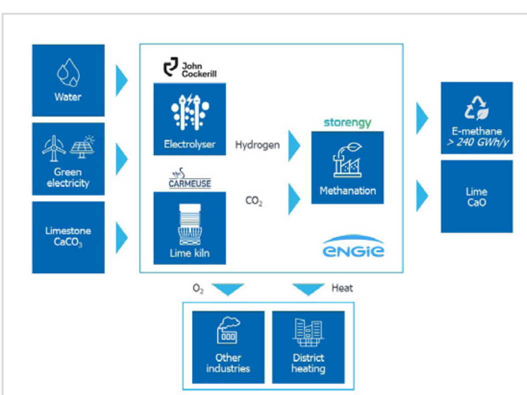
The project will start in 2022.

Contribution to

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

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

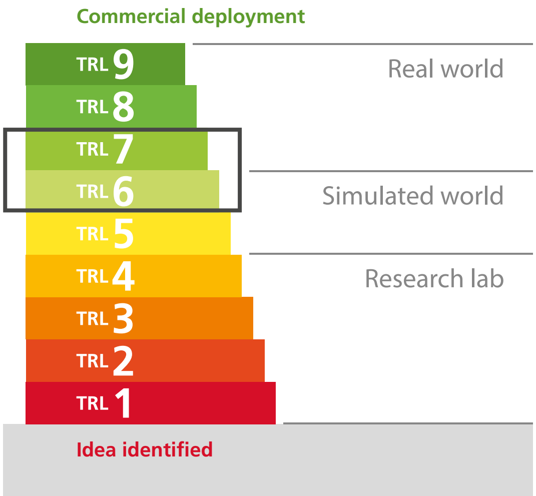




LOWCO$_2$

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

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



Scope of work

The LOWCO$_2$ project objective is to innovate towards competitive technologies of capture and valorization of industrial CO_2. With a duration of 4 years, some technologies of capture and valorisation of industrial CO_2 will be developed and validated. Several strategic innovations are piloted: new materials and processes for the capture of CO_2; technologies for the carbonation of residues (incorporation of the CO_2 in the residual materials) that allow the improvement of its performances as a raw material for construction; the production of methane and methanol obtained from CO_2 transformation.
The processes of CO_2 capture that are being studied are focused on the use of new materials to the end of reducing the current operating costs.

Status of the project

To meet the climate objectives of the Paris agreement, approximately 12 Giga-tons of CO_2 ($GtCO_2$) should be captured and stored between 2015 and 2030, and more than 100 $GtCO_2$ at a global level during the 2030-2050 period whereas. Now only 1% of the released CO_2 is reused. In this context, the LOWCO$_2$ 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 LOWCO$_2$ project contributes to reduce the carbon footprint, improves European competitiveness and it gives an answer to the challenges set forth by the global heating from a point of view of sustainability and of business development. This project is focused in three main CO_2 uses:

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

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

Contribution to

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

ZERCAL

Zero-Carbon Lime pilot plant

origencarbonsolutions.com

Scope of work

Singleton Birch and Origen have partnered to develop a new design of lime kiln which is able to capture all the CO_2 generated during the lime production process – both the CO_2 generated by the calcination of calcium carbonate and the CO_2 generated by the combustion of natural gas. They have completed construction of a pilot plant at Singleton Birch's Melton Ross site which will have the capacity to produce 3000 tonnes of lime per year. The oxy-fuel flash calcination process results in the production of a highly reactive lime and a flue gas that is > 95% CO_2. This flue gas can be cleaned up and pressurized to CO_2 pipeline standards and geologically sequestered. This will allow for the production of 'zero-carbon lime' – lime produced without emission of CO_2. Lime, in use, carbonates with CO_2 from ambient air (the proportion that carbonates depends on the particular application of the lime, but varies from 23% for lime used in steel production and 100% for lime used in the softening of water) [45]. As the lime has been produced without emissions, the overall use of zero-carbon lime results in net negative emissions.

Status of the project

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

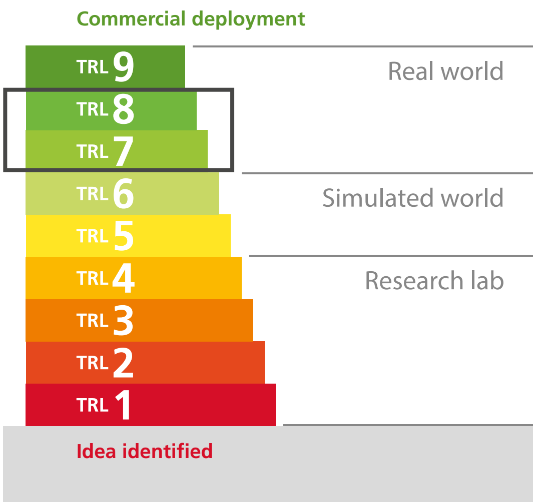
Contribution to

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

REFERENCES:

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

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



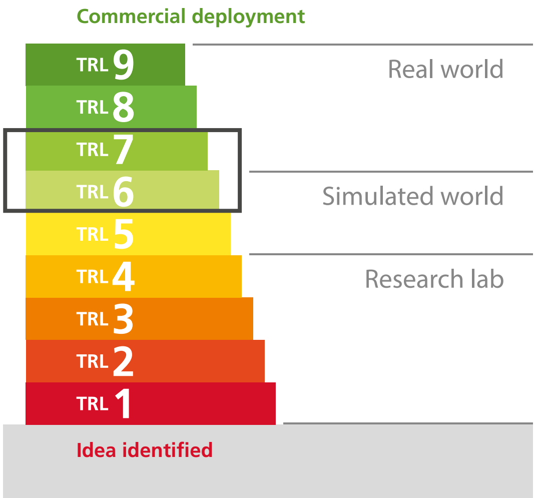
Zero-Carbon Lime pilot plant in final stages of construction (April 2022).

DINAMX

Demonstration and DMX Innovative Application

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

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



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

Scope of work

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

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

The DMX process is applicable to decarbonize a large variety of gas streams, including flue gases from various sources, as confirmed by laboratory pilot tests performed by IFPEN. As part of the ADEME funded DinamX project the potential application of DMX technology at the Rety site have been evaluated [46, 47].

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.

REFERENCES:
[46] info-chimie.fr/captage-de-co2-lhoist-rejoint-le-projet-dinamx,114399
[47] carboncapturejournal.com/news/launch-of-dinamx--industrial-co2-capture-pilot-in-france/4440.aspx?Category=all

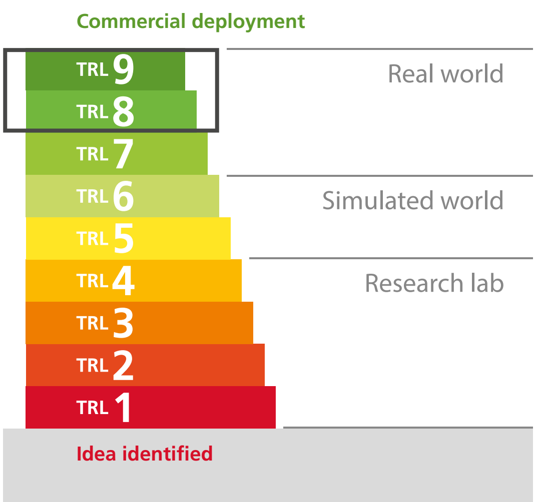
5. Innovation in Energy

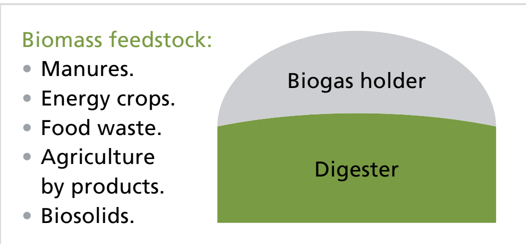
- ADiREN4Lime
- WHeatRec4PG
- Energy optimisation
- Energy generation
- CHP Generation
- Hydrogen Fuel Energy Innovation
- FFL
- NKL
- Other company projects/initiatives

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

birchenergy.co.uk

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





Biomass feedstock and stirred tank.

AD installation.

Scope of work

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

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

• Invest in gas or electricity generating projects.

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

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

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

Status of the project

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

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

• Uses 45,000 tonnes of feedstock annually.

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

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

• Dryer using waste heat from the CHP engines to dry digestate as a high value fertiliser [48].

• Employs 5 people.

Contribution to

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

REFERENCES:

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

WHEATREC4PG

Waste Heat Recovery for Power Generation

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

Scope of work

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

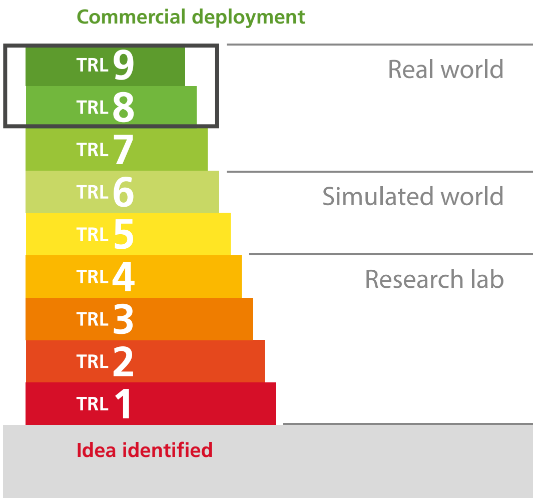
- Waste heat recovery systems integrate organic rankine cycle (ORC) technology into renewable heat sources, industrial kilns and furnaces.
- The ERC generator can convert waste heat temperatures as low as 85°C into electricity.
- Waste heat from heat intensive industrial processes can be recovered by: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

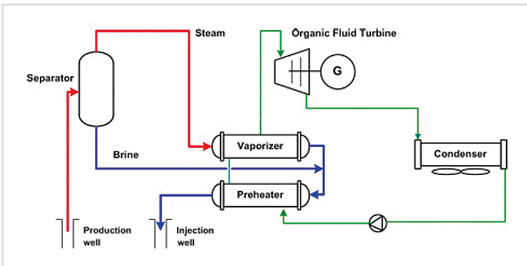
Status of the project

Project is already operational. The following can be reported:

- A waste heat to power system was commissioned in September 2013 at Lhoist-Steetley Dolomite facility in Thrislinton-UK.
- The WHRPG system recovers 4 MW of thermal power from a rotary kiln exhaust gas, and converts it to 0.5 MWe of low carbon electrical power.
- The new system delivered 25% improvement in electrical efficiency of the plant.
- it can generate net power of around 3,000 MWh annually, equivalent to 7,500 hours of carbon-free electricity.
- In total, kiln CO_2 emissions will be reduced by 1,600 tonnes per year.
- The project offers an attractive return on investment, when considering £1.3m investment against purchasing 3,000 MWh per year of electricity from the grid over the next 10 years [49, 50].

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





Organic rankine cycle (ORC).

Contribution to

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

REFERENCES:

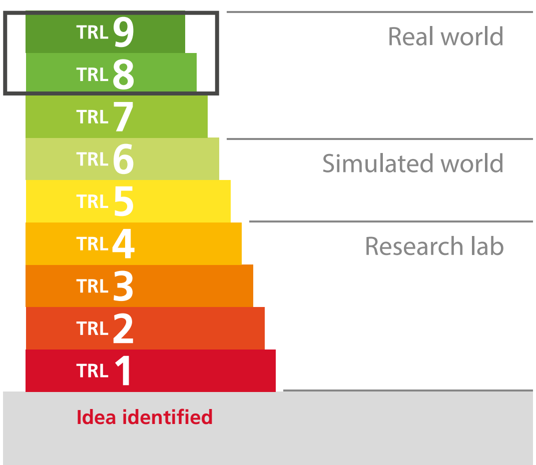
[49] Bryant D. 2016. Waste not, Want Not. ENERGYST. Pp. 48-49.
[50] 2013. Heatcatcher secures waste heat recovery project with Steetley Dolomite. Global Cement: Pp. 20.

ENERGY OPTIMISATION

Reduced energy consumption through optimized processes and capacity use

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

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



Biofuel tested at Ignaberga in Sweden.

Contribution to

Energy efficiency – Renewable fuels.

REFERENCES:
[51] 2011. Nordkalk. Environmental report. Pp. 12.
[52] Reinson K. & Roioiose Antti.2012. BioGas. Report prepared by University of Taru. Pp. 11.

Scope of work

Lime processing needs large amount of energy (kiln, hydrator, crushers, mill). Objective:
- Improve energy efficiency and introduce renewable fuels.
- Reducing energy consumption, a priority in new investments and repairs in the lime processing facilities.

Status of the project

Few projects were implemented, and the following can be reported:
- The automation system of the lime kiln in Pargas was renewed in 2016; the new automatic optimization system adjusts the kiln's operation parameters for obtaining uniform lime quality and low energy consumption. The system monitors constantly the measurements of the process and product quality to level out changes in the process. It also decreases the possibility for production interruptions. The automatic process optimization has been calculated to save annually up to 4000 MWh heat energy [47].
- The grinding plant in Vampula uses biogas supplied through a 1.5 km pipeline by the local biogas producer Vambio. The gas is produced from by-products of the food industry, slaughterhouses and livestock-breeding as well as wastewater sludge [47].
- In 2015, Nordkalk tested the use of biofuel in Ignaberga (Sweden) facility. The fuel is a surplus product from ecological feed production. The tests have given good results, and so in 2016, Nordkalk invested in equipment to adjust the production and equipment for the switch from fossil fuels to biofuels. The stone drying in Ignaberga runs now 100% on biofuel. Nordkalk was granted climate investment support for the Ignaberga project by the Swedish Environmental Protection Agency in December 2015. Nordkalk is one of twelve companies receiving support for "measures that demonstrate the greatest sustained reduction of greenhouse gas emissions per crown invested" [51, 52].

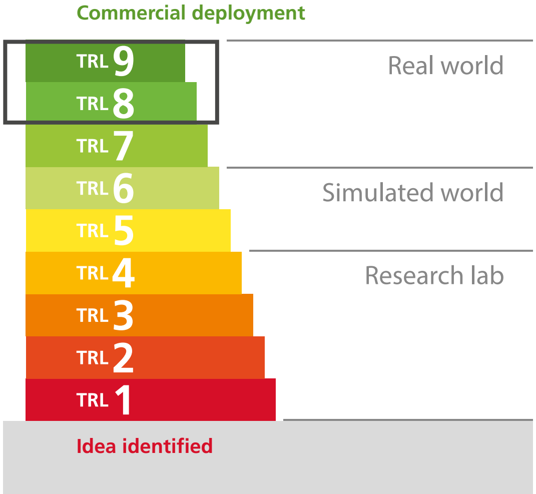
ENERGY GENERATION
Largest Solar panel farm in Wallonia by a mining company

Scope of work
Limestone processing to make, quicklime & hydrated lime needs large amount of energy (crushers, kiln, hydrator, mill). Objective of this project is multifold:
- Invest in renewable energy generating project.
- Generate renewable energy to be used for the lime operating facilities.
- Improve the energy mix of the lime manufacturing.
- Reducing the overall energy consumption, a priority in new investments and repairs in the lime processing facilities.

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

Contribution to
Renewable energy production – Lower CO_2 emissions.

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

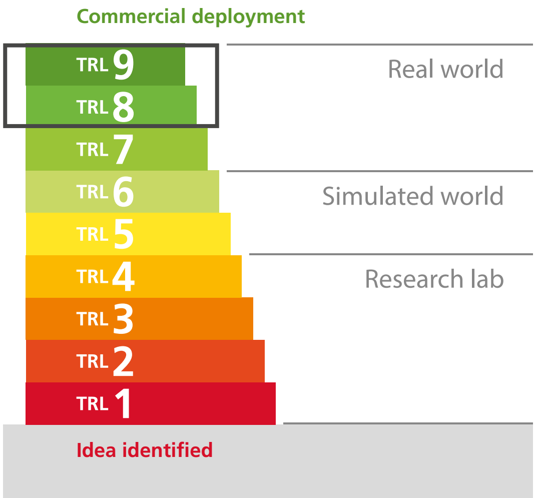


Solar panel farm at Moha (Wallonia).

CHP GENERATION

Combined Heat and Power (CHP) for Limestone Milling

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



Scope of work

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

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

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

Status of the project

Project realized in 2012 with commissioning in 2013.

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

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

Contribution to

Energy efficiency – Off heat utilisation.

HYDROGEN FUEL ENERGY INNOVATION

Alternatives to natural gas for high calcium lime manufacturing

Scope of work

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

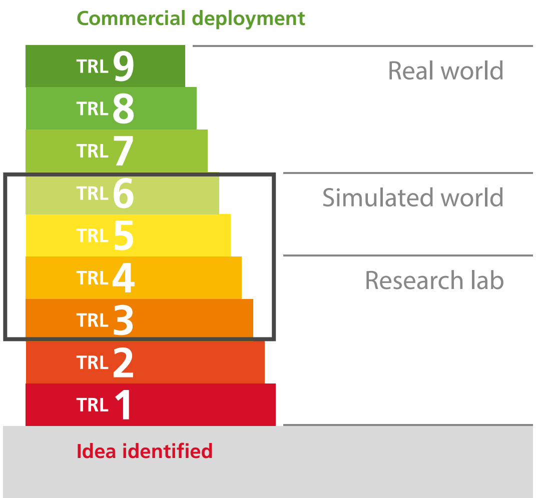
In the UK, lime is manufactured using two types of gas-fired kiln; vertical shaft kilns and parallel flow regenerating (PFR) kilns. PFR kilns are widely considered to be the most energy efficient. Vertical shaft kilns use similar technology and processes but are less efficient. However, by their nature,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

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

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

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

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



Status of the project

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

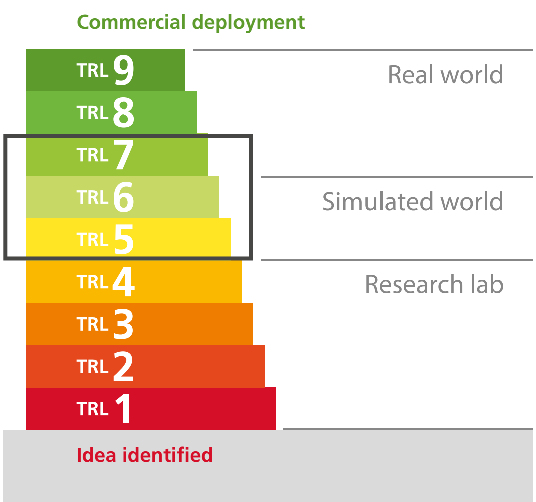
Contribution to

Climate change – Low carbon fuels – Hydrogen.

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

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

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



Scope of work

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

Status of the project

Lime is a common slag former, used by steel industry since a very long time. The properties of lime, contributing with CaO-molecules, enable the steel plant to have the right basicity in the steel slag during the first metallurgical steps of the steel production process. This property of the slag is important during removal of impurities from the steel, as the right slag property enhances the transfer of the impurities from melt into the slag.

Different steel plants have different demands for slag chemistry: e.g. amount and type of impurity to be removed, refractory chemistry, type of melting process etc. This means that different steel plants have different demands and a challenge for a lime supplier is to meet all these demands at once. However, a common demand is low sulphur and phosphorus content in lime, as these are some the most common elements to be removed from steel melt when generating steel slag.

But, as lime producers are looking into different CO_2 mitigation options, so does the steel industry. One clear example of this is the Hybrit project, where steel is to be produced with the help of hydrogen instead of carbon. This will not only be the end of the blast furnaces in the Nordics, but it will also change the demands for lime size fraction and chemistry. All in all, things will change, new lime products will be introduced, alternative fuels will be used. But all this has the clear target of lowering the total CO_2 emissions when producing steel [53].

Contribution to

Low carbon steel – Low carbon intensity lime.

REFERENCES:

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

NKL

Neutral Kero Lime

Scope of work

Study of an innovative e-Kerosene process using CO_2 from a lime kiln and hydrogen produced from green electricity. The capture of CO_2 at the lime plant would leverage some energy recovery from the synthetic kerosene via the Fischer-Tropsch process that converts a mixture of carbon monoxide and hydrogen or water gas into liquid hydrocarbons.
The challenge to be addressed (regulatory / societal / national / global):

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

Policy & Market drivers:

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

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

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

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

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

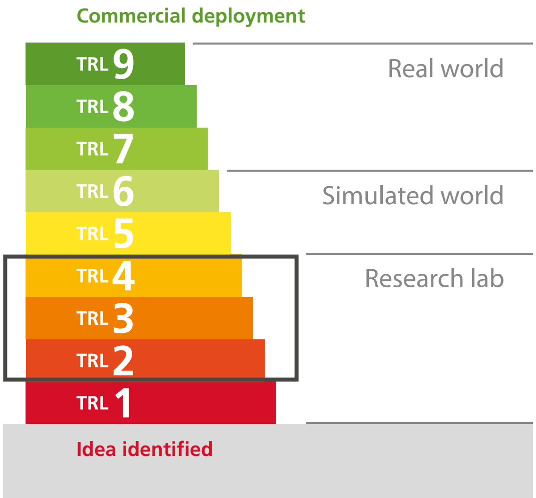
Status of the project

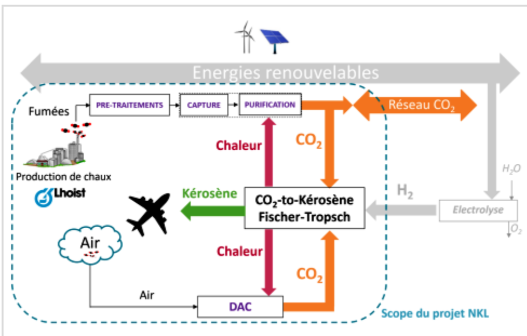
Funding awarded and project has started.

Contribution to

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

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





EULA

Other company projects/initiatives

eula.eu

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/Nm^3. Coke oven gas (16-35 MJ/Nm$_3$) 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/Nm^3 and less. The research has originally been triggered since existing sources like converter gas (8-12 MJ/Nm^3) and/or blast furnace gas (4-6 MJ/Nm^3) 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/Nm^3.
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.

• Oxy fuel combustion in PFR kilns

Off gases of Lime kilns normally contain CO_2 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 CO_2 concentration and thus ease a potential CO_2 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.

6. Innovation in Use Phase

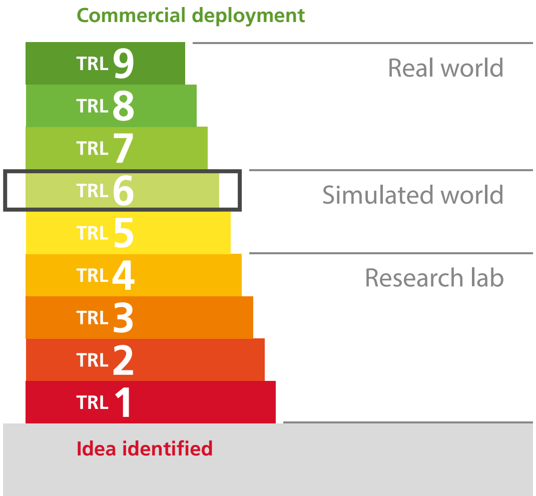
- Steel: ULCOS
- Steel: LIMEFLOW Steel
- Construction: ECO-SEE
- Construction: ISOBIO
- Construction: Compact mortar pellets
- Construction: Hempcrete
- Construction: SUBLime
- Civil Engineering: HMA LCA study
- Environment: Lime pellets for marine SOx reduction
- Environment: Lime in FGT and WTE
- Environment: Harbour Sludge Stabilisation
- Environment: Cleaner Port (Renere Havn)
- Agriculture: P runoff avoidance
- Agriculture: Lime in AGRI 1
- Agriculture: Lime in AGRI 2
- Agriculture: Soil-water use efficiency
- Glass: Lime in Glass making
- RETAKE
- LCC

ULCOS

Ultra-Low CO_2 Steel Making

cordis.europa.eu/project/rcn/80229_en

Type	Innovation action (pilot)
Partners	Leader: Arcelor Mittal (FR) & 47 partners (15 EU countries) Lime: Lhoist
Funding	EU / FP6 Total project: 35.3 Mill EUR EU contribution: 20 Mill EUR
Duration	09.2004 – 08.2010
TRL	Technology Readiness Level: TRL 6



Contribution to

CCU – CCS – Lime technology – Low CO_2 steel-making.

REFERENCES:
[54] Van der Stel J., 2013. Development of the ULCOS-Blast Furnace: Working towards technology demonstration. The ULCOS-BF developments in Europe. IEAGHG/IETS Iron and Steel Industry CCUS and Process Integration Workshop. 4-7 November 2013 in Tokyo, Japan.

Scope of work

ULCOS is a major RTD program, which plans to find innovative and breakthrough solutions to decrease the CO_2 emissions of the Steel industry. The target is reduction of specific CO_2 emissions of 50% as compared to a modern Blast Furnace. The project aims to deliver a concept process route, based on iron ore, with a verification of its feasibility in terms of technology, economic projections and social acceptability. The project hence starts by assessing a panel of technologies, which have passed a first prescreening but need to be investigated further. This approach is believed to be the most efficient in terms of resources and lead-time necessary to develop the new technology.

Status of the project

Project finalized in 2010. The following achievements can be reported [54]: ULCOS has tested four process concepts that could lead to a reduction of Carbon dioxide (CO_2) emissions by more than half compared to current best practice. The four breakthrough technologies identified are:

- Top Gas Recycling Blast Furnace with CO_2 Capture and Storage (CCS): this removes the CO_2 and recycles the carbon monoxide (CO) back into the blast furnace, potentially using less than half the emissions of today's state-of-the-art blast furnaces. ULCOS has already successfully pilot tested top gas recycling at an experimental blast furnace that produces 35 tonnes of steel per day in Lulea, Sweden.
- HIsarna with CCS: this processes iron ore almost directly into steel, thus skipping the manufacturing of pig iron pellets. More energy-efficient than traditional steelmaking processes, it could reduce the carbon footprint by up to 20%.
- ULCORED with CCS: producing direct-reduced iron (DRI) from iron ore with a reducing gas [54].
- Electrolysis: already used in industrial nickel, aluminium and zinc production. It could eventually replace the blast furnace altogether by passing an electric charge through an alkaline solution to separate the iron from iron ore.

LIMEFLOW STEEL

Lime Injection & Flowability in Steel Making

astm.org/DIGITAL_LIBRARY/STP/PAGES/STP104319

Scope of work

Steel is one of the main markets where lime is used. The challenge of the market is to improve the flowability of the lime injection during the steelmaking. Project objectives were to improve the flowa-bility of lime as well as the handling system delivering better performance and efficiency during the steel making.

Status of the project

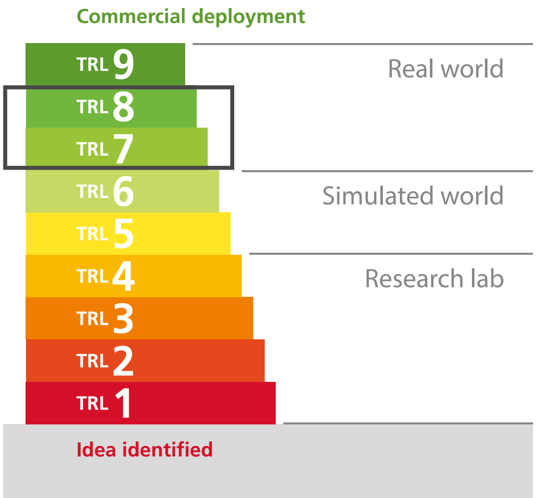
Project finalized in 2008. Key deliverables of this project address the technology development and innovation aspects:

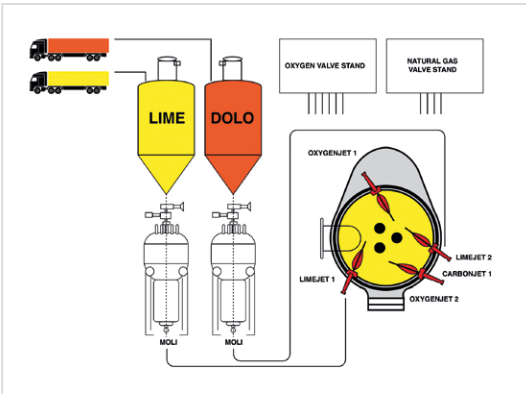
- Multiple point injectors located close to the slag allows lime dispersion into the slag/metal interface.
- Since 100% of lime is managed by pneumatic injection, the lime flow management is easier [55].
- Small particles of quality dolomitic lime and high calcium lime delivered into the molten slag/metal interface using injection technology.
- These particles quickly dissolve providing the steelmaker very responsive control of slag chemistry.
- Due to automatization, the control of lime additions compared to other methods of lime additions is easier.
- Reduced cost related to maintenance compared to mechanical handling systems [56].
- 10% reduced lime loss, due to baghouse and lower disposal.
- Cleaner environment and improved safety for workers is also achieved [57].
- This technology developed in the USA is also being sued expensively in the EU steel making sector [58].

Contribution to

Steel technology – Resource use optimization – Improved H&S – Multiple policy objectives.

Type	Innovation action (process)
Partners	Leader/Lime: Carmeuse (BE)
Funding	Own company initiative Total project: not reported
Duration	2004 – 2006
TRL	Technology Readiness Level: TRL 7-8





The lime injection scheme.

REFERENCES:

[55] Iacuzzi M. Marcuzzi S., Tolazzi D., Candusso C., 2008. New developments and operational results in the use of fixed side-wall injectors in the electric arc furnace, Scanmet III, June 2008.

[56] Wolfe L., Massin J.P., Hunturk T., Ripamonti J.P., 2008. Lime injection technology – a viable tool for the electric arc furnance. SCANMET III: 3rd International Conference on Process Development and Iron in Steelmaking. 8-11 June at Lulea (Sweden). Platform presntation.

[57] 2016. New developments and operational results in the use of fixed side-wall injectors in the Electric Arc Furnaces 47th International SteelMaking seminar. 27-29 September 2016 in Rio De Janeiro, Brazil. Platform Presentation. more-oxy.com/news/fee384cc516bacc2104ca442c1b0bb8fdcdea80b/47th-international-steelmaking-seminar-brazil.html?cat=news&year=2016.

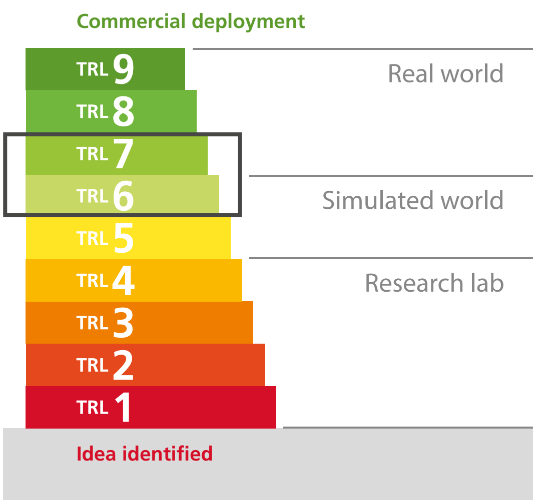
[58] D. Wolfe L.D. 2007. Overview of lime injection in the electric arc furnace.

ECO-SEE

Eco-innovative, Safe and Energy Efficient wall panels and materials for a health-ier indoor environment

eco-see.eu

Type	Innovation action (pilot)
Partners	Leader: Bath University (UK) Lime: BCB Lhoist Group
Funding	EU / FP7 Total project: 9.4 Mill EUR EU contribution: 6.5 Mill EUR
Duration	09.2013 – 08.2017
TRL	Technology Readiness Level: TRL 6-7



Contribution to

CCU/CCS – Mortar – Eco material – Healthier indoor environment – Multiple policy objec-tives.

REFERENCES:

[59] Nuño M., Ball R.J., Bowen C.R., 2016. Photocatalytic Properties of Commercially Available TiO2 Powders for Pollution Control. InTech Semiconductor Photocatalysis – Materials, Mechanisms and Applications 2016. Chapter 22. Pp. 613-633. dx.doi.org/10.5772/62894.

[60] Tobaldi D.M., Pullar R.C., Seabra M.P., Labrincha J.A., 2014. Fully Quantitative X-ray characterization of Evonic aeroxide TiO2 P25 ®. Materials Letters, Volume 122. 1 May 2014. Pp. 345-347. doi:10.1016/j.matlet.2014.02.055.

Scope of work

The project aims to:

- Use natural eco-materials for healthier indo-or environments through hygrothermal (heat and mois-ture) regulation and the removal airborne contaminants through both chemical capture and photoca-talysis.
- Advancing state of the art in the technology and application of multifunctional bio-based insulation materials, vapour permeable and hygrothermal and moisture buffering finishes, together with wood panel and lime products, to create both internal partition and external highly insulated wall panels.
- Novel chemical treatments and processes will be used to enhance volatile organic com-pound capture capacity of materials.
- Development of highly novel photocata-lytic coatings using nanoparticle technology, which will be suitable for use in interior spa-ces and compatible with lime and wooden surface materials.

Status of the project

Project ongoing until 2017. The following progress can be reported:

- Successful developed to demonstration sta-ge a range of innovative construction mate-rials to improve comfort.
- Innovative materials include: photocatalytic treated wood panel and lime plaster systems. clay and lime based plasters with enhanced moisture buffering properties.
- A range of designs for external (insulating) and internal wall panels have also been pro-duced. Combined these innovative products will deliver solutions with significantly redu-ced embodied energy and through design achieve longer life at lower build cost.
- Techno-economic analysis, and Life Cycle (Cost) Analysis will be conducted as well to assess environmental benefits and costs [59, 60].

ISOBIO
Natural High Performance Insulation

isobioproject.com

Scope of work

The ISOBIO project aims to develop a new approach to insulating materials through the novel combination of existing bio-derived aggregates (i.e. straw, clay, wheat or grasses) with low embodied carbon with innovative binders to produce durable composite construction materials with:

- Lower embodied energy and carbon 50% compared with traditional oil based insulation panels.
- Increase thermal insulation compared with traditional systems by at least 20%.
- Reduce costs by at least 15% over traditional systems, thanks to the vertical integration from raw material production through to finished systems.

Status of the project

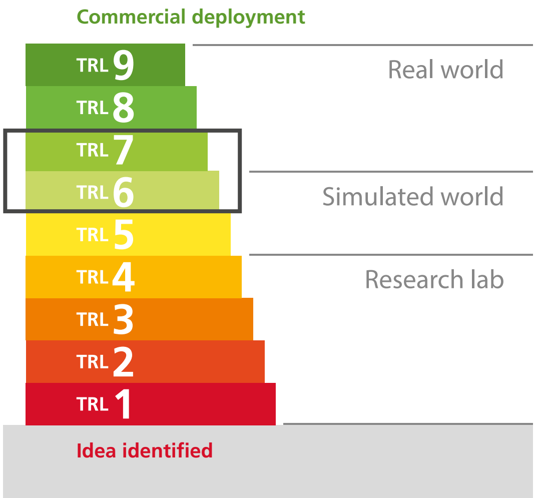
Project ongoing until 2019. The following progress can be reported:

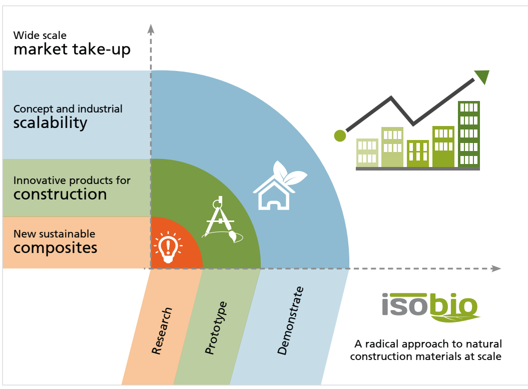
- The new materials improve upon the performance of conventional materials, they also offer new features. Hemp shiv, which is the core of the hemp stalk, for example, has a porous structure that provides moisture buffering to maintain humidity at a more constant level.
- The ISOBIO materials take advantage of the natural moisture sorption/desorption characteristics of bio-based materials, which is known to passively manage the indoor environment resulting in improved indoor air and environmental quality, whilst at the same time reducing the demand for air conditioning.
- As part of its life cycle analysis, the project is analysing over 100 existing materials.
- On the supply side, sourcing local organic materials helps reduce transportation costs, while using waste or byproducts as inputs helps control the cost of the final product [61].

Contribution to

CCU/CCS – Mortar – Eco material – Better insulation performance.

Type	Innovation action (pilot)
Partners	Leader: TWI (UK) Lime: BCB Lhoist Group
Funding	EU / H2020 Total project: 6.3 Mill EUR EU contribution: 5.5 Mill EUR Horizon 2020
Duration	02.2015 – 01.2019
TRL	Technology Readiness Level: TRL 6-7





Schematic view of the project upscale stages.

REFERENCES:

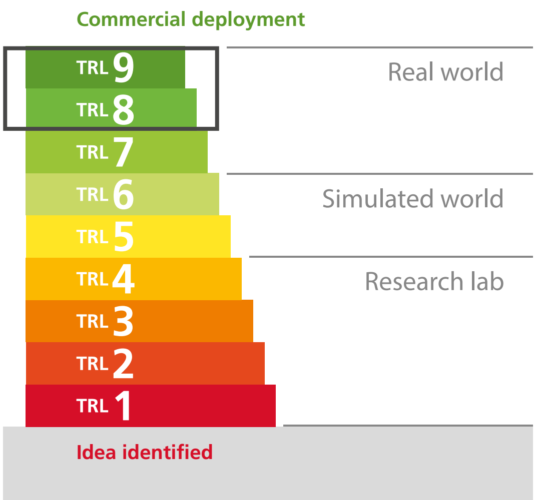
[61] 2014. Le béton de chanvre gagne en performances. lemoniteur.fr/article/le-beton-de-chanvre-gagne-en-performances-32129630.

COMPACT MORTAR PELLETS

Dust-free building site using Compact mortar pellets

youtu.be/Q3WfMngEcDw

Type	Innovation action (product)
Partners	Leader/Lime: Fels (DE)
Funding	Company own initiative Total project: not reported EU contribution: not applicable
Duration	02.2015 – 2020
TRL	Technology Readiness Level: TRL 8-9



The preparation of traditional mortar (first photo) versus compact mortar pellets.

Scope of work

In the building sector employers need to reduce workers' exposition to comply with Occupational Exposure Limits (OEL). In Germany, these are set by TRGS 900 (Technical rule hazardous substances) and have been made more restrictive for dust exposure in 2014. The limit for alveolar dust – previously was 3 mg/m³ – now it is 1.25 mg/m³:

- In building industry, only 50% of all measurements comply with < 2.0 mg/m³. This applies for Germany, according to "Justification of new general dust limit in TRGS 900", Ausschuss für Gefahrstoffe 2014.

Status of the project

To address this challenge, the research and development is finalized and the product "low-dust compacted mortar pellets" have won and award [62]. The following advantages of the novel product can be reported:

- Pouring the compact mortar in the mixing recipient reduces drastically the dust and minimizes the worker exposure.
- Total self-dissolution time is 90 sec and results in a very homogeneous mixture ready to use.
- Up to 20% more efficient than ordinary mortar.

Contribution to

Mortar – Eco material – Low dust exposure – Occupational hazard management – Product innovation.

REFERENCES:

[62] German Labor Protection Award. 2015. Potential: new technological standard for bagged products. 1st place in category for technical solutions, large companies: Fels-Werke GmbH for "Compacting of dry mineral ready-mixed mortars into pellets". October 2015.

HEMPCRETE

Hemp-lime Based Construction Materials – an Ecological, Sustainable and Carbon Negative Solution

carmeuse-construction.com/your-applications/building-materials/hempbuilding

Scope of work

Residential and commercial buildings are the world's biggest energy consumers and CO_2 emitters. In the European Union, the buildings consume about 40% of the Union Energy. More than 50% of the building energy consumption goes for heating/cooling. To make EU buildings energy efficient the focus is to increase the market value of green construction materials. The objective of this project is to illustrate how hemp-lime based construction material can respond to these EU multifaceted policy objectives.

Status of the project

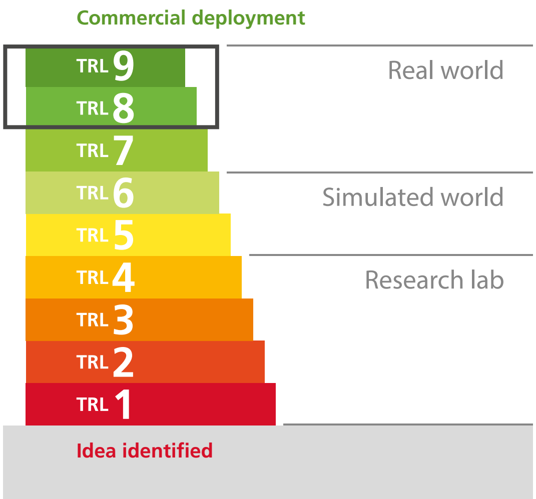
Project was terminated in 2015. Product on the market in Multiple EU countries (BE. NL. RO). Key deliverables of the project consist of:

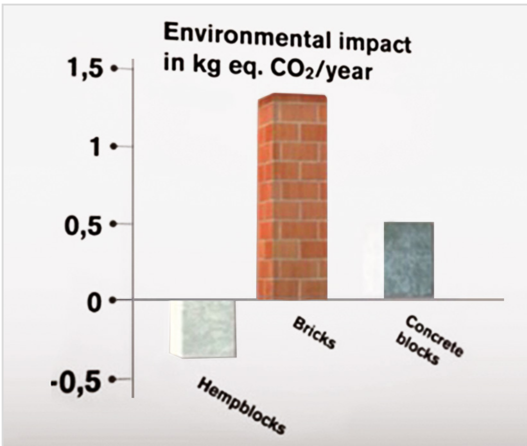
- 100% of the hemp plant can be used in many different applications such as textiles, plastics, food products, papers, oils, paints, building material. The later, accounting for around 60% of the hemp, fibers and shives.
- Grows quickly and locally with one of the highest yielding – 4 to 6 months from seeding till harvest – without need of pesticide chemicals.
- 1 kg of dry hemp stores 0,38 kg of carbon, equivalent to 1,4 kg CO_2.
- Mixing lime with hemp, improves comfort and health thanks to better breathability. no condensation build-up. lower thermal conductivity. antibacterial activity. more flexibility than concrete, which reduces cracks.
- Other benefits.
- Durability: stronger than conventional fibers such as glass and rock fibers since it can be used for inner/outer masonry and/or insulation.
- Carbon sequestration during the growth and Carbon negative footprint & sustainable during use phase in a building [63].

Contribution to

Mortar – Eco material – Carbon capture and storage – Product innovation.

Type	Innovation action (pilot)
Partners	Leader/Lime: Carmeuse (BE)
Funding	Own company project Total project: not reported
Duration	2013 – 2015
TRL	Technology Readiness Level: TRL 8-9





CO_2 footprint of hemp versus bricks concrete.

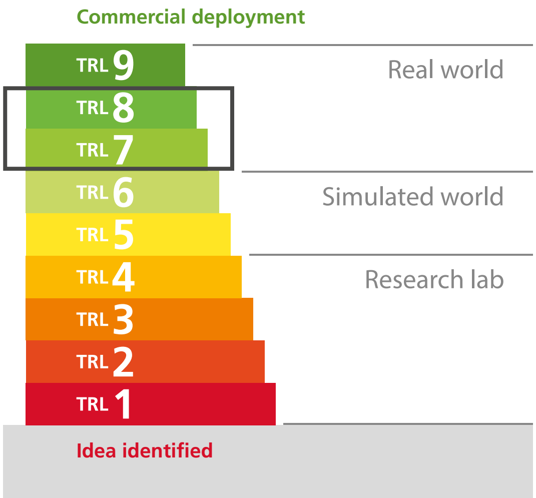
REFERENCES:

[63] Van Rompay G., 2015. Hemp-lime Based Construction Materials – An Ecological, Sustainable and Carbon Negative solution. ILA Conference. 8 October 2015 in Istanbul (Turkey).

SUBLIME

SUstainable Building Lime

Type	Research & innovation
Partners	Leader: UMinho (PT) & 17 partners Lime: EuLA & Companies
Funding	Horizon 2020 under "Marie Skłodowska-Curie Innovative Training Networks" Total project: 3.7 Mill EUR EU contribution: 3.7 Mill EUR
Duration	2021 – 2025
TRL	Technology Readiness Level: TRL 7-8



Scope of work

The main scientific objective of the SUBLime network, in the context of lime-based applications in construction, is to:

- Develop/transfer biomimetic-based sustainable technologies targeted to reduce CO_2 emissions, to support current and future needs of society, by using advanced computational and experimental multi-scale strategies.
- The focus is on new construction and the conservation of the built heritage.
- The project covers the main features of lime-based applications in the masonry construction (both joints and plastering mortars), including material characterization, numerical non-linear modelling of multi-physics behaviour, functionality and sustainability in lime use, all within a framework of performance-based design. Recognition of Carbon Sequestration in buildings is part of the project.
- This project/network will finance 15 PhDs and is dedicated to educate/train researchers in multiple scientific and engineering fields aiming a better understanding and development of sustainable innovation solutions for lime mortars/plasters in new construction and conservation of the built heritage.

Status of the project

The project was launched in 2020 and will run until 2024.

Contribution to

CCU/CCS – CO_2 mitigation – Intelligent building skins.

HMA LCA STUDY

Life Cycle Assessment of Hot Mix Asphalt using lime to improve road durability & low carbon footprint

sciencedirect.com/science/article/pii/S1361920916304631

Scope of work

The main objectives of this project were:

- Assess 110 publication/reports on the effect of lime in asphalt [64].
- Assess environmental footprint of all the life stages of a Hot Mix Asphalt (HMA) road (raw materials, transport, construction, maintenance, recycling, end of life) by means of life cycle assessment tools.
- Comparative assessment between classical HMA vs Modified HMA.

Status of the project

Project finalized in 2015. The following findings can be reported:

- Hydrate increases road durability with 25% based on science and testimonies from users [64].
- For the lifetime of the road, modified HMA has the lowest environmental footprint compared to classical HMA (43% less primary total energy consumption resulting in 23% lower GHG emissions) [65, 66].

Contribution to

Road durability – Sustainability – Circular economy – Traffic jam avoidance.

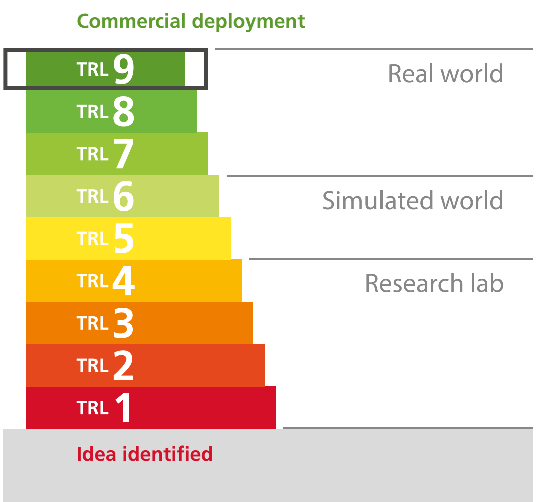
REFERENCES:

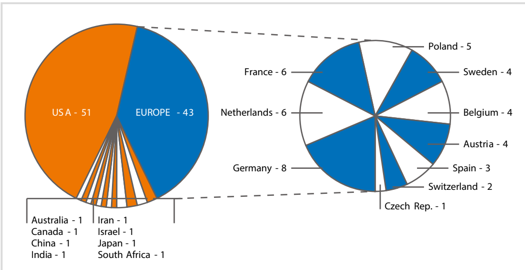
[64] Lesueur D., 2011. Hydrated Lime: A Proven Additive for Durable Asphalt Pavements – Critical Literature Review. EuLA Ed., Brussels. Pp. 1-81.

[65] Schlegel T., Puiatti D., Ritter H.-J., Lesueur D., Denayer C., Shtiza A., 2016. The limits of partial life cycle assessment studies in road construction practices: A case study on the use of hydrated lime in Hot Mix Asphalt. Transportation Research Part D: Transport and Environment. Volume 48. Pp. 141-160.

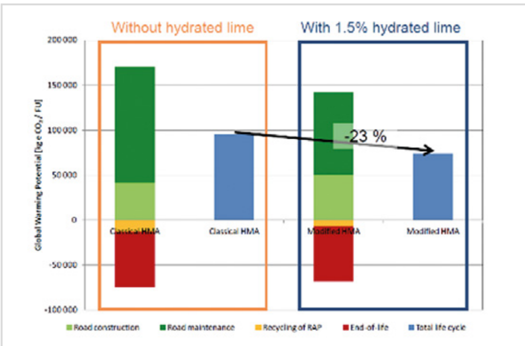
[66] Ritter H-J., 2014. Use of Hydrated lime in asphalt in Europe: current state. International Lime Association Meeting. Vancouver, Canada. October 2014. Platform presentation.

Type	Innovation action (sustainability)
Partners	Leader/Lime: EuLA (EU)
Funding	Own initiative Total project: not applicable
Duration	2011 – 2015
TRL	Technology Readiness Level: TRL 9





Summary of literature review sources [59].

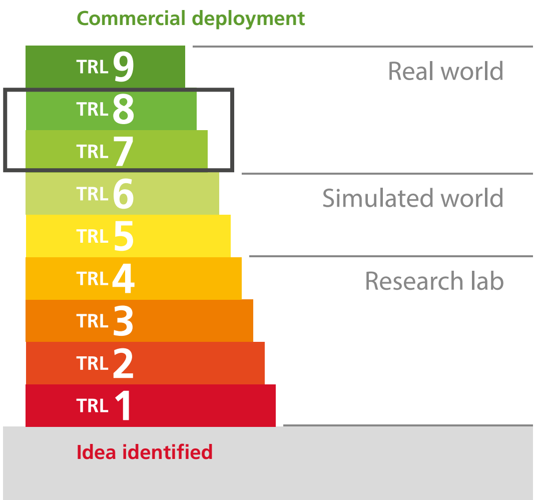


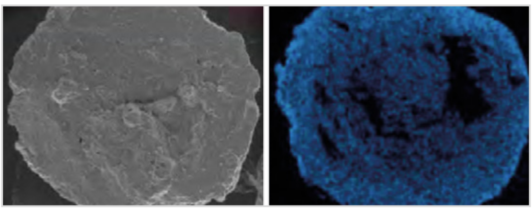
Results from the comparative LCA [60, 61].

LIME PELLETS FOR MARINE SO_x REDUCTION

doi.org/10.15480/882.1216

Type	Innovation action (product)
Partners	Leader/Lime: Fels (DE)
Funding	Own initiative (DE) Total project: not reported
Duration	2011 – 2016
TRL	Technology Readiness Level: TRL 7-8





Sulphur absorption core before (left) and after (right).

Contribution to

Environmental protection – Innovative technology – Fuel optimization – Energy efficiency.

REFERENCES:

[67] Schladör C., 2014. Schladör C., 2013. Theoretische und experimentelle Untersuchungen an einer trockenen Entschwefelungsanlage für Schiffsabgase. PhD thesis at University of Hamburg. In German. Pp. 199. tubdok.tub.tuhh.de/handle/11420/1218.

[68] Schladör C., 2014. Integration and operation of a dry scrubber system on a ConRo vessel. Ship & Offshore 2014, N 2.

Scope of work

55,000 merchant ships annually account for more than 90% of global trade volume: 22 Mill tonnes SO_2 per year. The sulphur emission corresponds to approx. 400 large coal-fired power plants without flue gas treatment.

As from 2015, in the emission control areas (ECA) the allowed sulphur content in marine fuels is reduced down to 0.1%. For the North Sea and the Baltic Sea, this for example, corresponds to 500 thousand tonnes. The current sulphur threshold for global shipping is at 3.5%, but from 2020 on the maximum is reduced down to 0.5%.

In order to have the opportunity to run vessels with low cost heavy fuel oil, two existing gas cleaning systems are in usage: 1. Dry EGCS (Exhaust Gas Cleaning System) – hydrated lime pellets in a packed bed filter) and 2. Wet ECGS (sodium hydroxide solution).

Status of the project

The following results have been proven and can be reported:

- High efficient process and free of waste water and sludge. In contrast to the wet scrubbers, the sulphur is bounded and not released into the hydrosphere. Moreover, this environmentally friendly reacted product, responds to numerous other industries.
- Installation of subsequent catalytic reduction of NO_x is possible without reheating the flue gas. Efficiency of SO_2 removal > 95% reliably achieved in successful large-scale trials on container and bulk vessels in a 12 month continuous operation. The expectations of the shipowners were fulfilled.
- Further usage of cost-effective heavy oil.
- Due to the compact design, a subsequent installation on existing vessels is possible with little effort and cost attractive.
- The Dry EGCS process stands for comparatively low investment and operating costs. The return of investment (RoI) is within 3-4 years.
- Eco-friendly reaction products, oxidation of soot on alkaline pellets.
- No shifting of the pollutants from the atmosphere to the hydrosphere [67, 68].

LIME IN FGT AND WTE • Lime in Flue Gas Treatment and Waste to Energy Incinerators

sciencedirect.com/science/article/pii/S0956053X14005030
sciencedirect.com/science/article/pii/S0956053X14005054

Scope of work

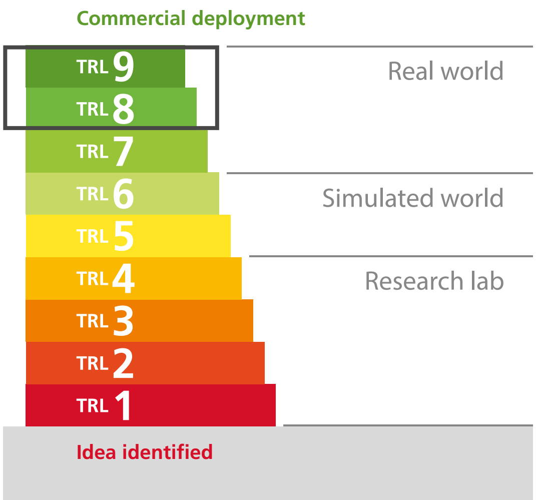
In recent years, several waste-to-energy plants in Italy have experienced an increase of the concentration of acid gases (HCl, SO_2 and HF) in the raw gas. This is likely due to progressive decrease of the amount of treated municipal waste, which is partially replaced by commercial waste which is characterised by a higher variability of its chemical composition because of the different origins, with possible increase of the load of chlorine (Cl), fluorine (F) and sulphur (S). To address this challenge, intensive long-lasting tests were performed in four waste-to-energy installations in Italy using a specific dolomitic sorbent as a pre-cleaning stage, to be directly injected at high temperature in the combustion chamber.

Status of the project

Project finalized in 2012. The following results can be reported:

- By injecting around 6 kg of sorbent per tonne of waste, the decrease of acid gases concentration downstream the boiler was in the range of 7-37% (mean 23%) for HCl, 34-95% (mean 71%) for SO_2 and 39-80% (mean 63%) for HF [69].
- This pre-abatement of acid gases allowed to decrease the feeding rate of the traditional low temperature sorbent (sodium based) in all four tested plants by about 30%.
- Furthermore, it was observed by the plant operators that the sorbent helps to keep the boiler surfaces cleaner, with a possible reduction of the fouling phenomena and resulting in improved energy efficiency during the operation and reduce the climate change impact by 28% [69].
- LCA study underlines that is an eco-friendly and sustainable technology and in the comparison with the traditional operation 17 impact categories out of 19 are reduced [70].

Type	Innovation action (product)
Partners	Leader/Lime: Unicalce (IT)
Funding	Own initiative (IT) Funding rate: not reported
Duration	02.2010 – 12.2012
TRL	Technology Readiness Level: TRL 8-9



Contribution to

Environmental protection – Improved technology – Raw material optimization – Energy efficiency.

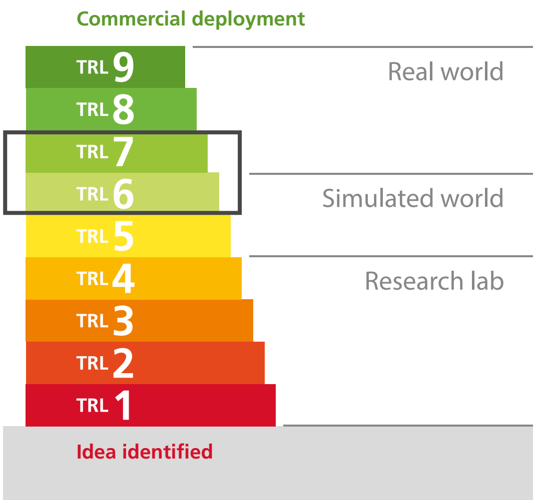
REFERENCES:

[69] Binganzoli L., Racanella G., Rigamonti L., Marras R., Grosso M., 2015. High temperature abatement of acid gases from waste incineration. Part I: Experimental tests in full scale plants. Waste Management 36: 98-105.

[70] Binganzoli L., Racanella G., Marras R., Rigamonti L., 2015. High temperature abatement of acid gases from waste incineration. Part II: Comparative life cycle assessment study. Waste Management 35: 127-134.

HARBOUR SLUDGE STABILISATION

Type	Innovation action (pilot)
Partners	Leader/Lime: Clogrennane (IE)
Funding	Own company funding
Duration	02.2014 – ongoing
TRL	Technology Readiness Level: TRL 6-7



Lime stabilization practice applied on a barge.

Scope of work

A prominent harbour in southern Ireland required dredging for the safe passage of commercial and tourist fleets. The location is in one of Irelands busiest tourist locations, known for its natural surroundings and picturesque amenities. Dredged material could not be moved directly inland due to its liquidity making it unsafe to transport. Because of the location, this material could not be treated on land prior to transport as it would have caused too great a visual impact.

Status of the project

The treatment of the harbour sediments demonstrated that:

- Working with a third party marine dredging specialist, Clogrennane implemented a programme of treatment which meant that dredged material could be stabilised while still on the extraction barges. This was done using a fine, medium reactivity quicklime which was injected into the sludge (see picture). The deep injection of quicklime served to stabilise the material prior to transport. Dust, noise and visual impacts were kept to a minimum. Low dust solution to the problem of drying/stabilising harbour sludge so that the material can be transported safely off-site. The concepts of this project were expanded to include larger, commercial ports, with several new locations treated using this method in 2017/2018 [71].

Contribution to

Sustainable sludge treatment – Sediment valorisation – pH control – Low impact treatment of harbour sediments – Avoid visual impact – Avoid dust impact – Avoid noise impacts.

REFERENCES:

[71] clogrennane.ie/environment/sludge-treatment

CLEANER PORT (RENERE HAVN)

Lime fines as harbour cleaning technology

renerehavn.no/english
youtube.com/watch?v=DrFdLgRko08

Scope of work

Trondheim's port was badly affected by years of industrial activity, shipbuilding and the discharge of sewage, not to mention diffuse emissions, including air pollution, which contaminated the harbor with organic environmental toxins and heavy metals. The aim of the project was to ensure that environmental toxins in Trondheim harbor (Kanalen Brattørbassenget, Nyhavna and Ilsvika) would not exceed condition class 3.

Status of the project

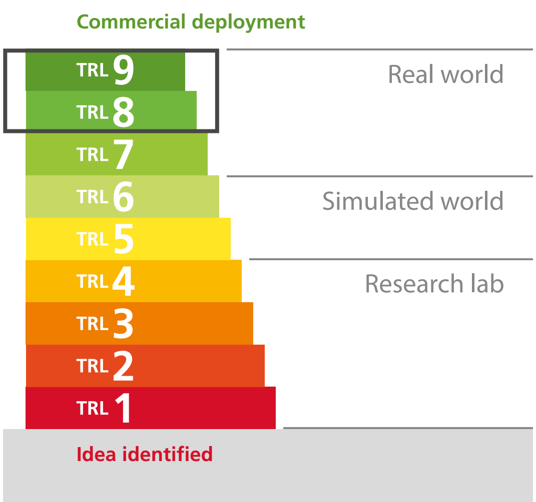
Project finalized in 2016 Key achievements of this project report on:

- The work in Trondheim consisted of dredging, dumping 75,000 m^3 of seabed and capping around 400,000 m^2.
- Over two years the 'zero fractions' for the 'Cleaner Port' project in Trondheim, where the bottom of the harbour basin has been sealed with a layer of limestone in different gradings. Using mobile screening, the supplier supplied a substantial quantity from intermediate stores of fine fractions. In total, around 290,000 tons of limestone was supplied for this purpose.
- Limestone was delivered in 64 shiploads to reduce the carbon footprint and overall environmental impact. Capping was done by spreading clean, crushed limestone through a hatch in the bottom of a barge, with the process being repeated two or three times.
- GPS technology ensured that the stone ends up in the right place, while the thickness of the capping layer on the seabed was checked by means of surveying and visual inspection.
- When the stone is on the seabed, it forms a filter that prevents environmental toxins from leaching out. The capping materials were chosen on what would act as a filter for the sediment on the seabed and it itself be safe for the environment [72].

Contribution to

Avoid leachates – Seabed sealing – pH control – Digital technology.

Type	Innovation action (implemented)
Partners	Port of Trondheim; City council of Trondheim; Lime: Franzefoss Minerals (NO)
Funding	Total project: 221 Mill NOK
Duration	2014 – 2016
TRL	Technology Readiness Level: TRL 8-9



The harbor after capping.

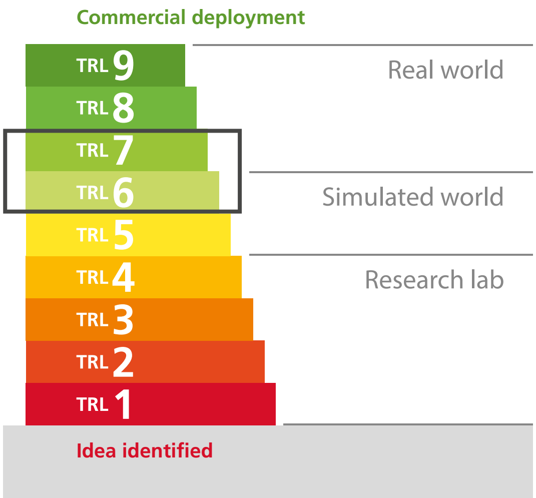
REFERENCES:
[72] Franzefoss Minerals. 2016. Environmental Report 2016. Pp. 31, 51.

P RUNOFF AVOIDANCE

Avoid Phosphorous runoff for healthier Baltic Sea

nordkalk.com/sustainability/community/baltic-sea-action-group

Type	Innovation action (demonstration)
Partners	Stockholm water; BSAG; Swedish University of Agricultural Sciences Lime: Nordkalk (FI, SE)
Funding	Total project: 2.5 Mill EUR
Duration	2012 – 2017
TRL	Technology Readiness Level: TRL 6-7



The Baltic Sea Action Group (BSAG) – officially "Foundation for a Living Baltic Sea" (Finland).

REFERENCES:

[73] Aurola A-M, Wellberg K. et al. 2018. Clay soil structure improvement & lime filters: Engineered solution to control phosphorus leakage. EU Sustainable Phosphorus Conference. 11-13 June 2018 in Helsinki (Finland). Poster presentation.

Scope of work

In agriculture, liming reduces the soil's acidity, which improves the plants' living conditions and allows them to use nutrients more efficiently, resulting in bigger crops and reduced nutrient runoff into watercourses. By liming of fields, the stabilization of sludge, and for lime filters and drains that help to reduce phosphorous runoff leakage and contribute to the recycling of phosphorus. This is extremely important because world's phosphorus reserves are estimated to last only for a few more decades. To address these challenges Nordkalk developed few projects for the soil and sea.

Status of the project

The following achievements can be reported from the multiple projects:

- In Finland, Structural liming has been tested in smaller scale in laboratories and on the fields. These tests help optimizing the correct spreading amounts for the Finnish soil types. Structure lime has been tested on the Finnish market since 2015.
- Another Nordkalk's many phosphorus-related research projects is also under way in Sweden. It involves structure liming and field testing in the fields surrounding lake Bornsjön near Stockholm. The project is being carried out in co-operation with Stockholm Water and the Swedish University of Agricultural Sciences.
- In 2012, Nordkalk joined the Baltic Sea Action Group (BSAG) in preserving the Baltic Sea with a 5-year-long commitment with the goal of reducing the phosphorus burden on the Baltic Sea.
- Nordkalk's commitment is ending, but work to reduce the phosphorus burden on the Baltic Sea and other water courses will continue.
- Increase the awareness of the environmental and crop benefits of liming in these areas is beneficial for the society [73].

Contribution to

P recovery – Sewage sludge stabilization – Phosphorus run-off avoidance.

LIME IN AGRI 1

Lime as a soil improver in Agriculture

carmeuse.com/improved-agricultural-soils

Scope of work

The qualities of lime in agriculture application have been known extensively. Lime adjusts the soil pH from acid to basic to optimize the level of the crop growth, resulting in an increase of the production potential. This paper summarizes the benefits of using lime for farmers.

Status of the project

Project finalized in 2012 Key achievements of this project report on:

- It consolidates the soil structure and improves the air and water flows. This allows a better roots development and a better crop resistance to lack of water in draught periods.
- It optimizes the soil capacity, namely to retain fertilizers and make them available when needed by the crop.
- The effects of the fertilizers are enhanced. If the pH is close to neutral (pH 7), fertilizers are better absorbed by the plants. This avoids wasting fertilizers that can be harmful to the environment by leaching into underground water and rivers. A higher pH offers better conditions of aeration and humidity fostering the biological activity.
- With an acid soil (pH 4,5) only 30% of the Nitrogen (N), 23% of the Phosphorus (P) and 33% of the Potassium (K) spread on the field are absorbed.
- Plants growing on an acid soil absorb toxic elements (such as Aluminum, Cadmium) more easily. This limits the production potential and the crop quality [74, 75].

Contribution to

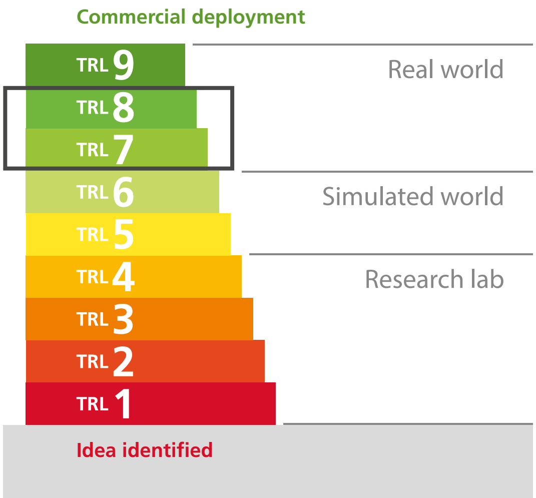
Agriculture – Crop growth improvements – pH control.

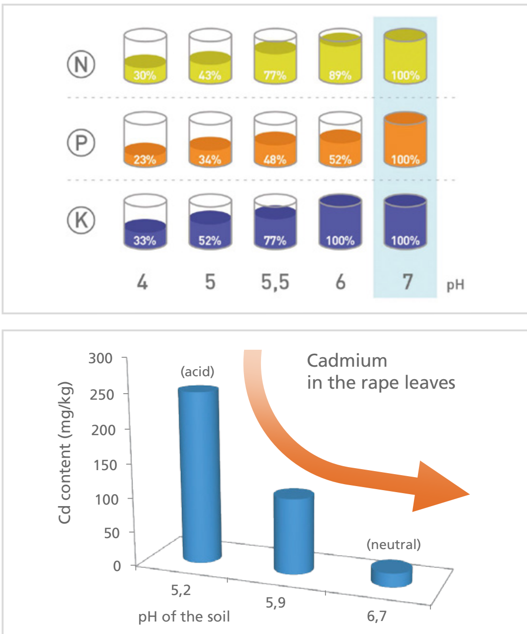
REFERENCES:

[74] Ponchon F. 2016. La chaux aerienne et ses applications. Mines & Carrièrs. Pp. 47-56. In French.

[75] Ponchon F. 2014. La chaux aérienne et ses applications. 64th Congress-Exibition Societe de l'industrie Minérale (SIM 2015), 20-23 October 2015, Mons (Belgium).

Type	Innovation action (demonstration)
Partners	Leader/Lime: Carmeuse (FR)
Funding	Own company initiative Total project: not reported
Duration	1995 – 2012
TRL	Technology Readiness Level: TRL 7-8





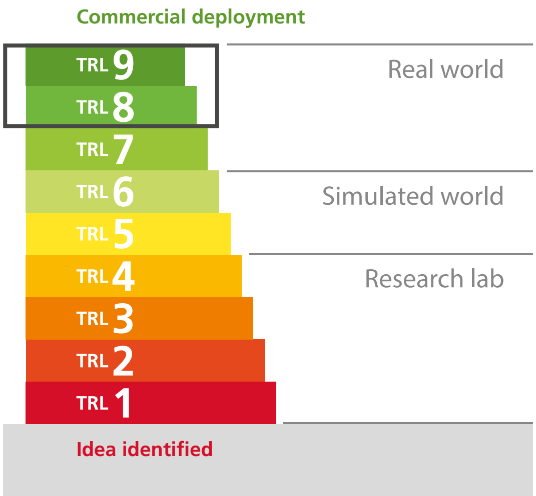
The soil improvement with pH increase.

LIME IN AGRI 2

Natural solutions for sustainable agriculture

carmeuse-agriculture.com/your-applications/soil-amendment

Type	Innovation action (demonstration)
Partners	Leader/Lime: Carmeuse (RO, HU)
Funding	Own company initiative Total project: not reported
Duration	2015 – 2017
TRL	Technology Readiness Level: TRL 8-9



Distinct growth rate on same acid soil upon liming.

- Product has a long term lasting action requiring one application every 3 to 5 years depending on soil type.

This innovative product won the 2016 Product Award for Hungarian Crops Growing [77].

Contribution to

Agriculture – Crop growth improvements – pH control.

REFERENCES:
[76] B. Costea. 2017. Calcium oxide, a solution for soil improvement. Lumea satului magazine. 02.10.2017. Bucharest (Romania).
[77] B. Costea. 2017. Romanian Agriculture Leadership Forum (RALF). 9.11.2017. Bucharest (Rumania).

Scope of work

The challenge for the future is to produce more food in an efficient and sustainable way. Agriculture needs then to follow what is called agroecology which is to focus on the interaction between elements of the ecosystem and productivity. Soil management is obviously a major part of this principles including efficiency, balance, diversity, co-creation of knowledge, recycling, synergies, human and social values, circular economies, cultural and food traditions, land and natural resource governance. Soil acidity is one of the limiting factor to allow to maximize yield and to preserve its reserves. A low pH will lead low fertility due to chemical toxicity, low fertilizer efficiency, compacted soil structure and limited biological life.
Interest in correcting the soil pH and bring calcium is growing and it was needed to develop specific lime-based products allowing both an easy application and proven efficiency.
Trials have been driven in the field during few years both in Romania and Hungary demonstrating the positive effect of this lime product application.

Status of the project

Project finalized in 2017:

- Aim of the project was to demonstrate the effect of new lime-based product to improve chemical, physical and microbiological properties of agricultural soils and to show both its effectiveness in a very short time and easiness to apply. Due to its granulated structure and high neutralizing value, the product could be applied directly with agricultural spreaders, using accurate doses (0.5 to 2 tons) per hectare. The first effects can be seen in just one to two months after the application. Moreover, in contact with water it dissolves and acts extremely rapidly [76, 77].
- Effect on soil structure was visible becoming lighter and more aerated thanks to increase of Calcium and flocculating effect.
- Optimum pH and structure allow good biological life and improved root development.
- Better nitrogen mineralization and nutrient availability like phosphorus and potassium has led to very significant yield improvement.

SOIL-WATER USE EFFICIENCY

Increasing water use efficiency in crop production through optimized liming – Development of an application model for agricultural implementation

fg-kalk-moertel.de/wasserhaushalt-boeden

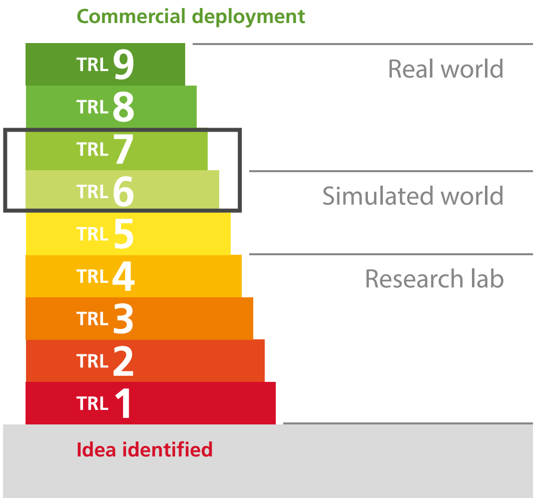
Scope of work

Liming positively influences the soil structure by creating new connections between soil particles that are particularly stable and long-lasting. In addition, the biological activity in the soil is promoted, which in turn leads to the formation of continuous pore systems.
A well-developed soil structure improves the storage capacity for plant-available water and thus the site characteristics for crop production. Crop yield is stabilized, secured or improved, even against the background of the predicted climate change. The optimal lime supply is determined not only by the compensation of the annual land use-dependent soil acidification but also under the aspect of soil protection and optimal water absorption and storage, especially in clayey soils.
The project aims at developing an application model for the agricultural implementation of an optimized lime supply with respect to the soil structure, which helps to protect the soil from erosion and compaction, optimizes the storage capacity for plant-available soil water and thus secures or even increases yields in the long term.
To achieve the research objectives, extensive physicochemical and structural soil investigations are planned not only on disturbed, but also on undisturbed samples of different soils, which are characterized by different calcification intensities.
By developing recommendations that can be applied directly for liming on different soils, increased sales of lime fertilizers are expected.

Status of the project

- First field campaign results already show improvements concerning soil structure and porosity.
- Six month after application best results were achieved with utilization of 1.5x lime amount. in comparison to LUFA recommendations
- The higher the amounts of clay in the soil the higher the liming effect is expected.

Type	Innovation action (demonstration)
Partners	Leader: Kiel University (D) Lime: BVK & DHG/Naturkalk
Funding	National: 0.25 Mill EUR
Duration	06.2016 – 11.2018
TRL	Technology Readiness Level: TRL 6-7



Extremely dried farmland gives not enough water for high yields.

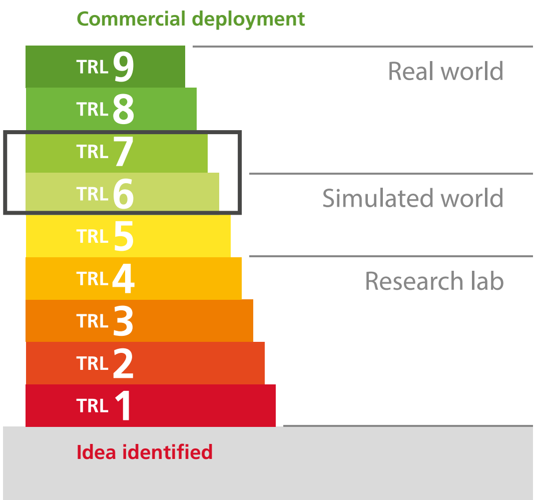
Contribution to

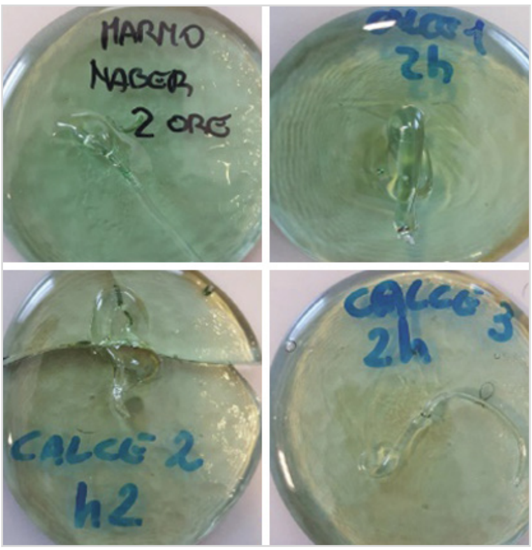
Agriculture – Crop growth – pH control – Soil improvement – Soil structure – Agricultural lime.

LIME IN GLASS MAKING
Use of lime in Glass making

carmeuse.eu/news/carmeuse-value-fiberglass-icg-istanbul

Type	Innovation action (demonstration)
Partners	Leader: Stazione Sperimentale del Vetro (IT) Lime: Carmeuse (TR)
Funding	Own funding
Duration	04.2017 – 11.2017
TRL	Technology Readiness Level: TRL 6-7





The Glass making with lime.

Scope of work

Glass making is an energy intensive process. As part of providing technology and environmental improvements down the value chain to multiple applications, lime producers have made an assessment for the use of pre-calcined lime in glass making and ensure the same functionality of the glass end-product. The tests performed so far at lab scale have indicated some encouraging results on quality and have allowed to evaluate the positive impact on energy and CO_2 balance.

Status of the project

Lab study demonstrates that:

- Quality of glass is not negatively impacted by the conversion to oxides. After 2 hours of melting, similar glass quality; No significant impact on viscosity is observed.
- Lime use leads to better stability of properties.
- Use of burnt products has a positive impact on energy consumption and global CO_2 emissions: CO_2 savings up to 350 kg/ton of glass thanks to 99% savings on calcination and reduced CO_2 on melting thanks to 40% energy savings; transport CO_2 savings; concentration of CO_2 in 1 place (lime production plant) [78].

Contribution to

Glass application – Energy efficiency – Lower carbon footprint.

REFERENCES:

[78] Somerhausen B., Di Marino E., Hunturk T., Tiozzo S., Ceola S. 2017. Benefits for fiber glass producers to use calcium oxide in their raw material. Platform presentation at ICG Annual Meeting in November 2017 in Istanbul (Turkey).

RETAKE

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

Scope of work

The application aims for funding within the research cluster "MARINE CARBON SINKS IN DE-CARBONIZATION PATHWAYS" a DAM Research Mission by the Federal Ministry of Education and Research (BMBF) in Germany. 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 CO_2 from the atmosphere. Increased ocean alkalinity reduces the activity of CO_2 in seawater, and prompts an enhanced flux of CO_2 from the atmosphere into the ocean, thereby reducing the atmospheric CO_2 concentrations. A range of mineral alkalinity sources (limestone and olivine) will be examined with respect to dissolution kinetics, CO_2 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.

BVK/FG will focus on work package: "Enhanced benthic weathering of carbonate and olivine in the Baltic Sea".

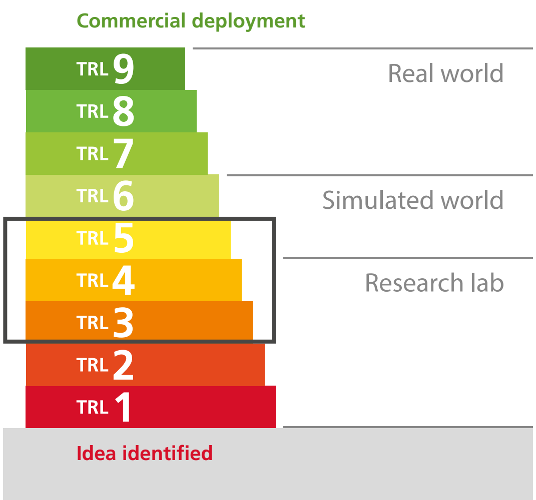
Status of the project

The application has passed successfully the evaluation by the BMBF.

Type	Research & innovation
Partners	Leader: GEOMAR Helmholz-Centre for Ocean Research Kiel (D) Lime: BVK

Partners: Alfred-Wegener-Institute Helmholtz-Centre for Polar and Ocean Research (AWI), Forschungsgemeinschaft Kalk und Mörtel (BVK/FG), Helmoltz-Zentrum Geesthacht (HZG), Kiel Institute for World Economy (IfW), Potsdam Institute for Climate Impact Research (PIK), etc.

Funding	Federal Ministry of Education and Research (BMBF) Total Project: 5 Mill EUR
Duration	08.2021 – 07.2023
TRL	Technology Readiness Level: TRL 3-5



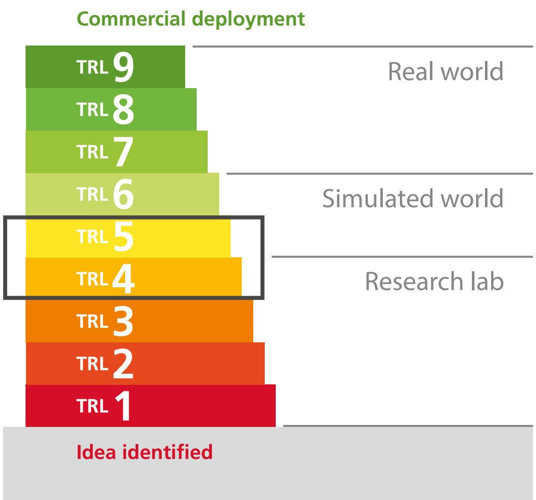
Contribution to

Climate change – Carbon dioxide removal – Alkalinity enhancement.

LCC

Ocean alkalinisation through Lime for Carbon Capture

Type	Research & innovation
Partners	Leader: Politechnico di Milano (IT) & CONISMA – 35 Associated Universities (IT) Lime: EuLA (EU)
Funding	EuLA EU contribution: not applicable
Duration	01.2021 – 06.2022
TRL	Technology Readiness Level: TRL 4-5



• The project findings will be published in peer-review journals.

Status of the project

Ongoing [79].

Contribution to

Carbon dioxide removal (CDR) – Lime carbon capture (LCC) – Negative CO_2 emission technologies – Carbonation.

REFERENCES:
[79] IPCC 2021. Climate Change 2021. The Physical Science Basis. Working Group contribution to the Sixth Assessment Report. Pp. 3949.

Scope of work

Carbon mitigation through Carbon Dioxide Removal (CDR): IPCC 2021 report describes some of the carbon dioxide removal (CDR) techniques for land and sea-waters. These CDR's list some possible paths such as afforestation, soil carbon sequestration, bioenergy with carbon capture and storage, wet land restoration, ocean fertilization, ocean alkalinisation, enhanced terrestrial weathering and direct air capture and storage.

The potential of different CDR options in terms of the amount of CO_2 removed per year from the atmosphere, costs, benefits and side effects of the CDR approaches are assessed and key findings are available and in several review papers. In the literature, CDR options are also referred to as "negative CO_2 emission technologies".

The IPCC 2021 report recognises the lack of knowledge in some CDR such as ocean alkalinisation.

Carbonation process: to generate technically relevant information and assess the CDR potential of ocean alkalinisation thanks to the use of lime, EuLA is working with CONISMA consortium, led by Politechnico di Milano. CONISMA coordinates multidisciplinary research and scientific activities and applicability in the field of marine sciences for 35 associated Universities from Italy. The scope of the project between CONISMA and EuLA consist in assessing:

• The kinetics of slaked lime in seawater from literature. So far 170 publications have been assessed and the information has been assessed on quality and technology maturity.
• Laboratory scale experiments and modelling of dissolution of slaked lime in seawater.
• Macroscopic and single particle kinetics.
• Literature review and experimental study setup.
• Ecological implications of ocean liming by performing experimental study on plankton.
• The project is planned to be finalized in January 2022.

7. Innovation in Sustainability Tools

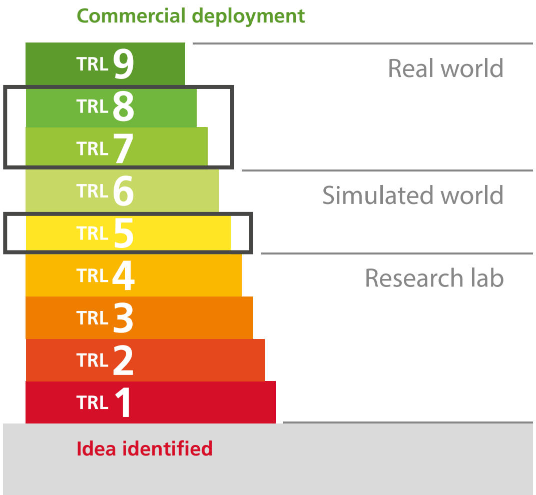
- STYLE
- LCI of Lime
- Lime audits

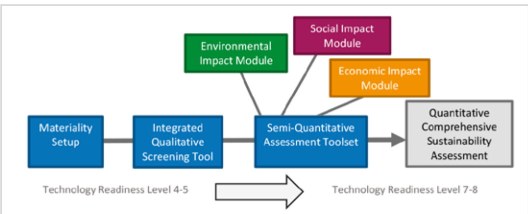
STYLE

Sustainability Toolkit for easY Life-cycle Evaluation

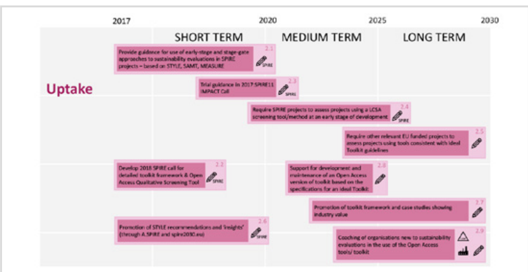
spire2030.eu/style

Type	Coordination support action (sustainability)
Partners	Leader: Brittest (UK) Lime: Carmeuse
Funding	EU / H2020 / SPIRE Total project: 0.5 Mill EUR EU contribution: 0.5 Mill EUR Horizon 2020
Duration	01.2015 – 12.2016
CSA	Coordination Support Action (Sustainability): TRL 5 to 7-8 (expert judgment)





Ideal Toolkit Framework [76].



Recommendations Roadmap [77].

Scope of work

The Sustainable Processing for Resource and Energy efficiency (SPIRE) Roadmap calls for an industry-focused study of current sustainability assessment approaches across the process industries, with the aim of identifying and promoting a suitable 'toolkit'.

Project STYLE has three key objectives:

- Identify best practice in sustainability evaluation, across sectors and through value chains via inventory and classification of established approaches.
- Test and deliver a practical toolkit for sustainability evaluation of processes and products, spanning multiple sectors and easily usable by non-practitioners of LCA.
- Determine gaps, through critical assessment and validation, and identify future research needs to improve the toolkit and ensure broad applicability across sectors.

Status of the project

Project finalized in December 2016. Key deliverables of STYLE consist of:

- Inventory of known tools, methodologies and approaches for sustainability evaluation.
- Characterisation and assessment of a tools suitability & selection of tool(s) to be tested on industrial processes across multiple sectors.
- Critiques of the tools' effectiveness, applicability and barriers to use via Toolkit framework.
- Critical analysis and identification of future research needs and steps required to increase uptake of tools across industry sectors and value chains via the STYLE Roadmap [80, 81].

Contribution to

Sustainability tools – Cross sectoral – Sustainability assessment.

REFERENCES:

[80] SPIRE. 2016. STYLE Toolkit Framework. 2016. spire2030.eu/sites/default/files/users/user221/STYLE/STYLE--IdealToolkitFramework.pdf.

[81] SPIRE. 2016. STYLE Roadmap. 2016. spire2030.eu/sites/default/files/users/user221/STYLE/STYLE-Roadmap.pdf.

LCI OF LIME

Assessment of lime extraction and production in Europe through a Life Cycle Inventory approach

eula.eu/topics/environmental-impact-assessment-lca-life-cycle-assessment; eplca.jrc.ec.europa.eu/ELCD3/processSearch.xhtml

Scope of work

European Lime Association (EuLA) covers 95% of the European lime production in Europe. Lime is a versatile material which is used in many different applications, such as in steel, agriculture, environment, chemical industry and so on. Due to increasing demand about the environmental impacts of products placed on the market, EuLA has used a scientific and quantitative approach (i.e. Life Cycle standard series ISO 14040-14044) to answer the requests for the environmental footprint of lime products at the use phase but also to define management strategy at quarry/processing facility.

Status of the project

Project was finalized in 2011 and the following can be reported:

• Life cycle inventory (LCI) from cradle (limestone extraction) to gate (lime plant) in is based on data for the reference year 2007, which were provided from the different lime manufacturers across Europe.

• The outcome of the EuLA LCI study is the most comprehensive and representative set of European data provided from the lime manufacturers for the production of quicklime and hydrated lime, which covers up to 73% of the total European lime production.

• In accordance with the ISO requirements, the outcome of the study was validated by an external critical reviewer.

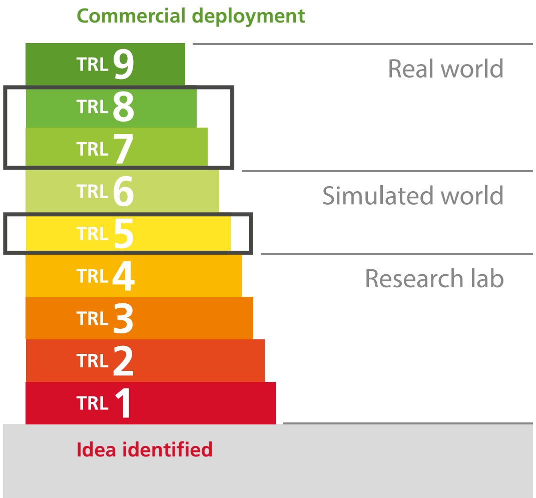
• This inventory provides valuable and reliable data also to downstream users intending to carry out their own LCA to cover their products. In the period 2011-2016 around 63 requests were responded at EuLA level.

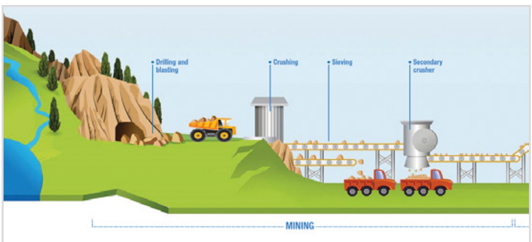
• To assess the most recent environmental footprint of lime products., a revision of the EuLA LCI is ongoing during 2017 [82, 83].

Contribution to

Life Cycle Assessment – Value chain sustainable management – Innovation – Improve performance – Communication.

Type	Coordination support action (sustainability)
Partners	Leader/Lime: EuLA (EU)
Funding	Own industry initiative
Duration	2007-2011, 2014-2016
CSA	Coordination Support Action (CSA): TRL 5 to 7-8 (expert judgment)





The three main process steps consisting of mining, calcination and hydration.

REFERENCES:

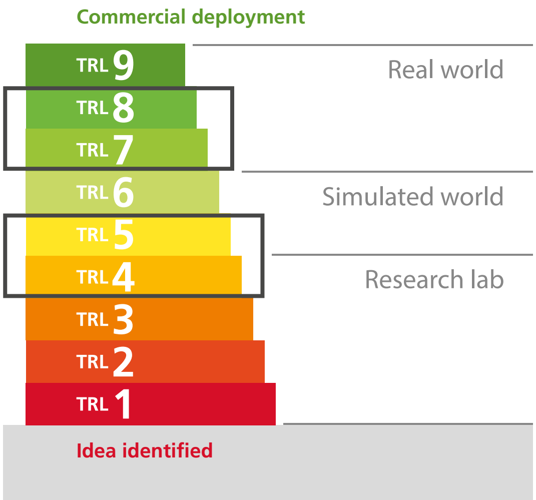
[82] Shtiza A., Danvers J., E. Despotou E., 2014. The value of LCI data in sustainability and market development: case of the lime data. 8th International Conference of Society & Materials (SAM 8), Liège, (Belgium). 20-21 May 2014. Poster presentation.

[83] Shtiza A., Verhelst F., 2014. The value of EuLA life cycle inventory (LCI) data to conduct LCA studies & their applicability. Science-Industry Roundtable: The use of lime in mortars. Guimarães (Portugal). 10 July 2014. Platform presentation.

LIME AUDITS

eula.eu

Type	Innovation action
Partners	Leader/Lime: EuLA (EU)
Funding	Company initiatives Total project: not reported EU contribution: not applicable
Duration	1980 – ongoing
TRL	Technology Readiness Level: TRL 4-5 to 7-8 (expert judgment)



Contribution to

Resource optimization – Waste minimization – Value chain management – Sustainability integrated actions.

REFERENCES:

[84] 2014. Xella: Sustainability report 2014. Ecoloop project.

Scope of work

The access of raw materials and their sustainable management are a challenge that lime extraction and manufacturing companies have incorporated in their management practices through the practice of auditing of the operations on-site and off-site in cooperation with multiple value chain stakeholders. The audits assist in the monitoring of the handling of the extraction, processing, transport and storage of lime products.

The key objectives of these audits are:

- Optimize the raw material recovery at the quarry site.
- Minimize the amount of waste.
- Determine gaps and corrective actions to ensure that handling, transport and storage conditions assist in meeting these objectives.

Status of the project

The audits are an ongoing practice and key deliverables consist in:

- Established of multi competence expert teams within their Application & Development teams.
- Perform performance audits on-site, by internal and external inspectors (energy efficiency, health & safety; handling, environmental, …).
- Perform "Lime Audit" at customers sites. The goal is to locate potential shortcomings in Lime handling and day to day operational use by the local operators.
- The scope of the Surveys include transportation to the site, storage facilities, conveying, charging, discharging and weighing equipment.
- These audits, have shown that better handling (i.e. Lime exposure to humidity and Lime ending up as hydrate in the dedusting facilities, or, the generation of fines in lump Lime handling) can result in improved resource optimization and cost reduction for the user.
- The audit result help to monitor developments an assess whether corrective measures are delivering and improve handling and the product performance no-site and of-site [84].

8. Innovation in Carbonation

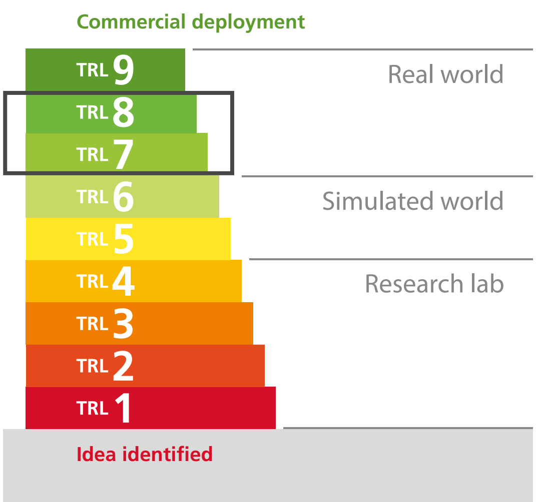
- Carbonation
- Steel
- Construction: Pure airlime mortars
- Construction: Mixed airlime mortars
- Construction: Hemp lime
- Environment: Drinking water
- Environment: Flue gas cleaning
- Pulp and paper: PCC
- Non-Ferrous: Aluminum
- Civil Engineering: Soil Stabilization

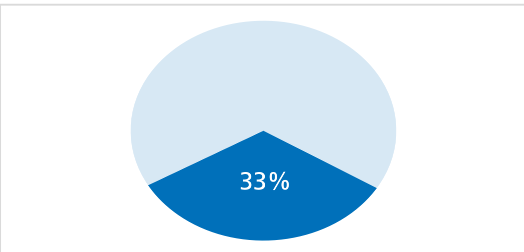
CARBONATION

Carbonation of lime (summary)

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

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





Total CO_2 captured by natural carbonation.

Contribution to

Carbon removal – Carbon sink – Carbonation – CCU.

REFERENCES:

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

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

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

The findings from PoliMI study show that:

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

Status of the project

Finalized [85].

STEEL

Carbonation in steel (study)

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

Scope of work

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

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

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

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

Status of the project

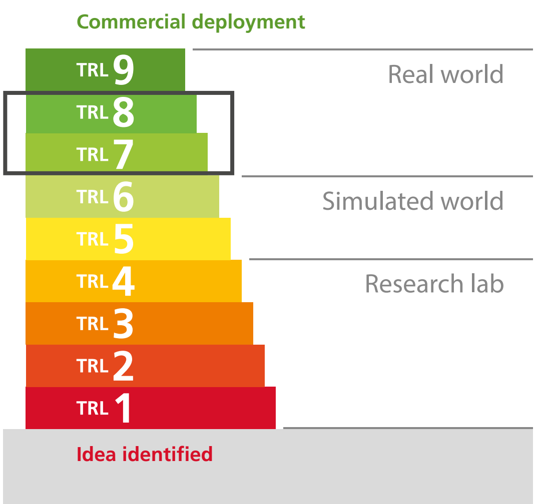
Finalized [86].

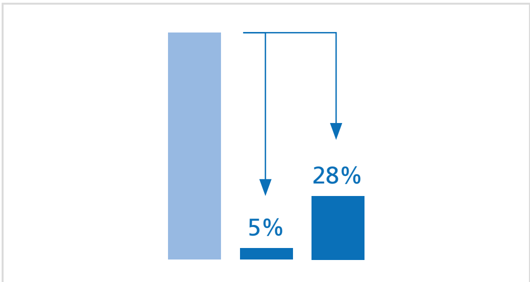
Contribution to

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

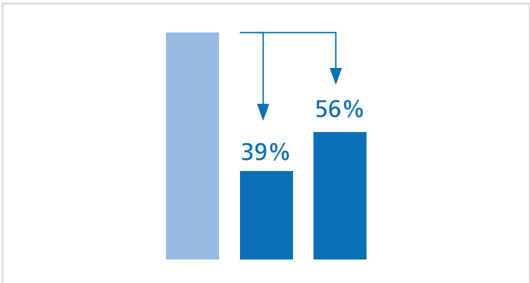
REFERENCES:
[86] Campo F. P., Tua C., Biganzoli L., Pantini S., & Grosso M. 2021. Natural and enhanced carbonation of lime in its different applications: a review. Environmental Technology Reviewss. 10:1. Pp. 224-237. https://doi.org/10.1080/21622515.2021.1982023

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





Natural carbonation rate (gradual increase over time).

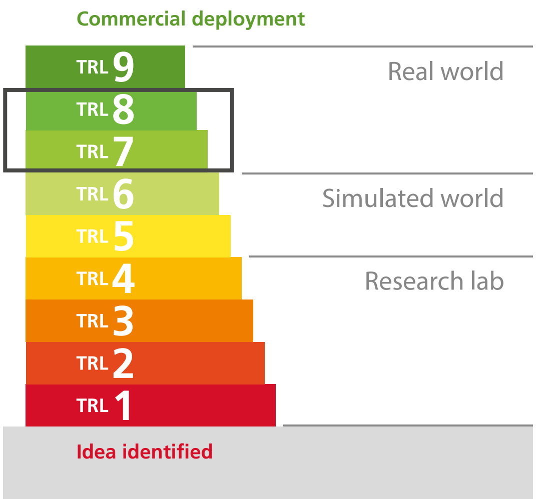


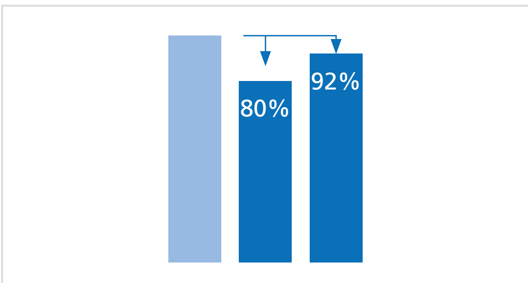
Enhanced carbonation rate (gradual increase over time).

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

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

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

Status of the project

Project finalized in 2012. The following can be reported:

- A carbonation front moves progressively from mortar surface exposed to the atmosphere to depth of the mortar.
- Carbonation levels in ancient and new air lime mortars is: 80 to 92% generally [87, 88, 89].
- The carbonation front progresses around 190 mm for 100 years. Fastest carbonation rate is within the first years (i.e. 20 mm end of first 400d).
- The LCA results show that, the impact of the carbonation is the highest for the mortars or renders with the highest lime content. CO_2 footprint is reduced by 3% (cement based mortars) to 17% (lime based mortars).
- Considering carbonation, will change the overall carbon footprint for the lifetime of mortars/plasters [88, 89].

Contribution to

Lime carbonation – Lower carbon footprint – Intelligent building skins.

REFERENCES:

[87] 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.

[88] 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.

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

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

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

Scope of work

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

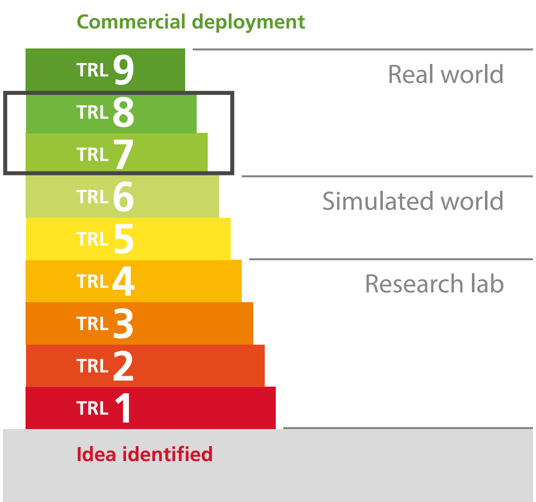
Status of the project

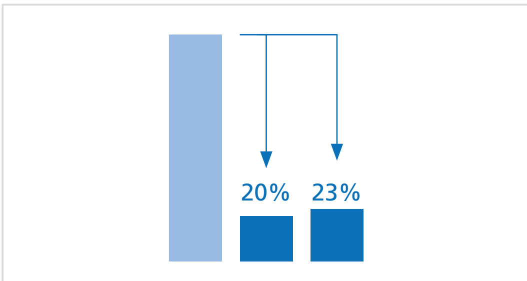
Finalized [85, 86, 89].

Contribution to

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

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





Mixed air lime mortar (gradual increase over time).

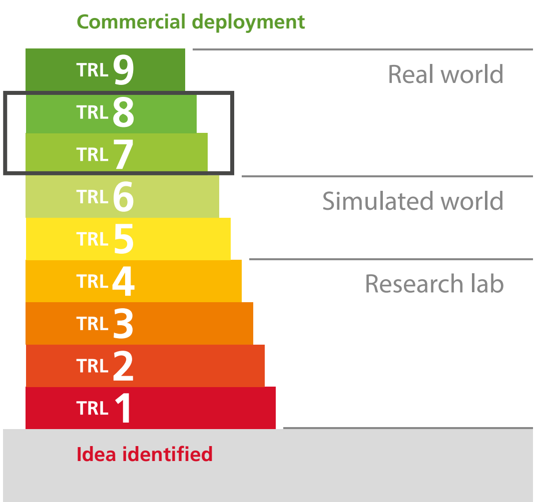
REFERENCES:
[85] Grosso M., Biganzoli L., Campo F. P., Pantini S., Tua C. 2020. Literature review on the assessment of the carbonation potential of lime in different markets and beyond. Report prepared by Assessment on Waste and Resources (AWARE) Research Group at Politecnico di Milano (PoliMI), for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

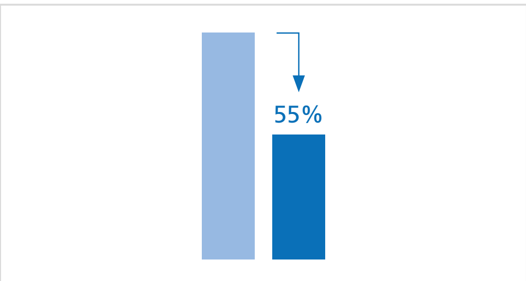
HEMP LIME

Carbonation in hemp lime (study)

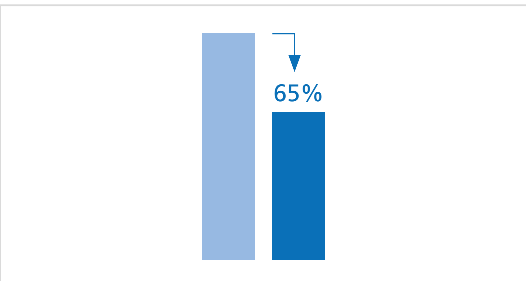
eula.eu/politecnico-di-milano-literature-review-on-the--assessment-of-the-carbonation-potential-of-lime-in-different-markets-and-beyond/

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





Natural carbonation rate (gradual increase over time).



Enhanced carbonation rate (gradual increase over time).

Scope of work

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

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

The literature review shows that for hemp lime:

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

Status of the project

Finalized [85, 86, 89].

Contribution to

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

REFERENCES:

[85] 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.

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

[89] 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

Carbonation in treating drinking water (study)

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

Scope of work

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

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

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

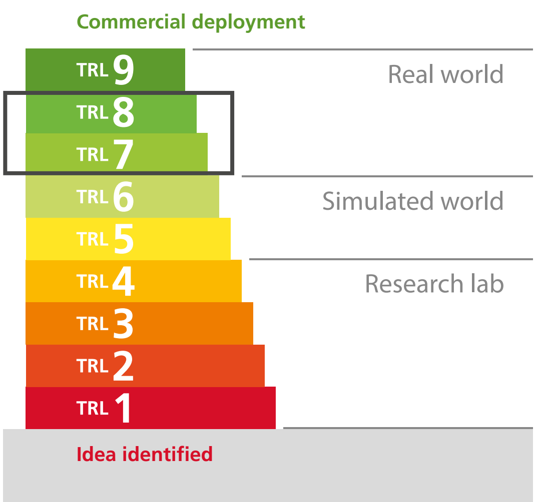
Status of the project

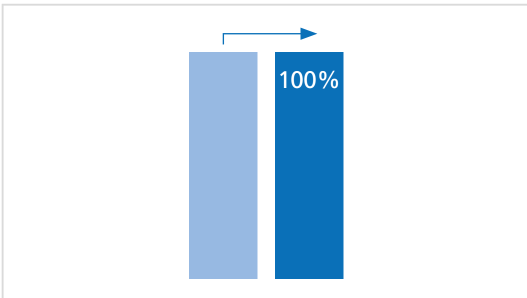
Finalized [85, 86].

Contribution to

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

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





Natural carbonation rate (instantaneous).

REFERENCES:

[85] 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.

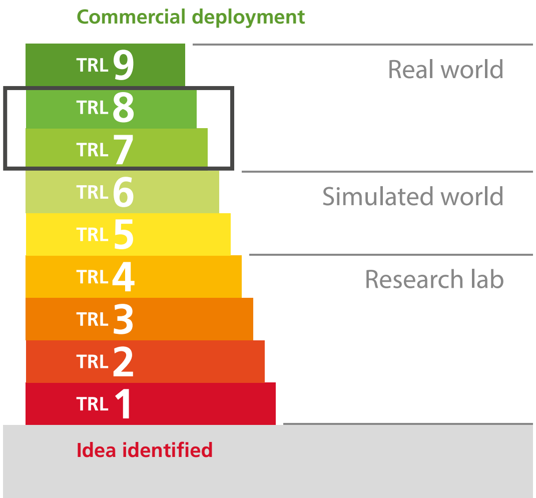
[86] Campo F. P., Tua C., Biganzoli L., Pantini S., & Grosso M. 2021. Natural and enhanced carbonation of lime in its different applications: a review. Environmental Technology Reviewss. 10:1. Pp. 224-237. https://doi.org/10.1080/21622515.2021.1982023

FLUE GAS CLEANING

Carbonation in flue gas cleaning (FGC) (study)

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

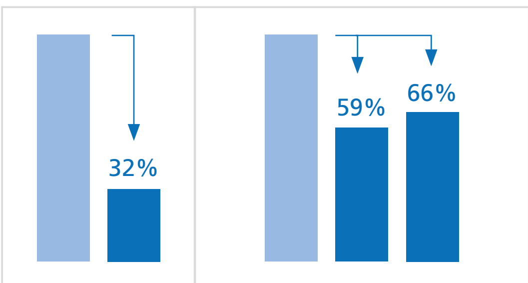
Type	Innovation action (demonstration)
Partners	Leader: Politecnico di Milano (PoliMI-IT) Lime: EuLA (EU)
Funding	EuLA EU contribution: not applicable
Duration	12.2018 – 03.2021
TRL	Technology Readiness Level: TRL 7-8



REFERENCES:

[85] 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.

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



Natural carbonation rate (instantaneous).

Enhanced carbonation rate (instantaneous).

Scope of work

Use of lime in treating FGC: lime is used for removing the acid gases (HCl, SOx, HF) contained in flue gases generated from combustion plants: fossil fuel power plants, biomass combustion and waste in-cineration facilities. A flue gas treatment process can be semi-dry or dry, depending on the form of lime used. In (semi-)wet processes, lime is supplied as an aqueous solution or 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).

Carbonation process: during the flue gas treatment, lime reacts with HCl, HF and SOx but also with CO_2, 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 carbonation. 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 CO_2 sequestration directly at a CO_2 point source emission where these residues are generated.

Status of the project

Finalized [85, 86].

Contribution to

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

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

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

Scope of work

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

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

The literature review shows that for PCC:

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

Status of the project

Finalized [85, 86].

Contribution to

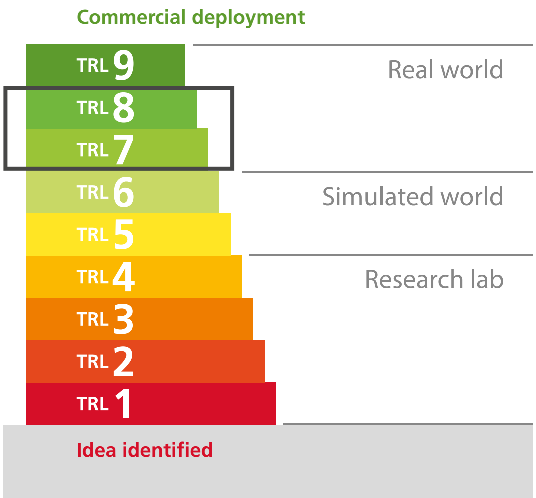
Carbon removal in PCC – Carbon sink – Carbonation – CCU.

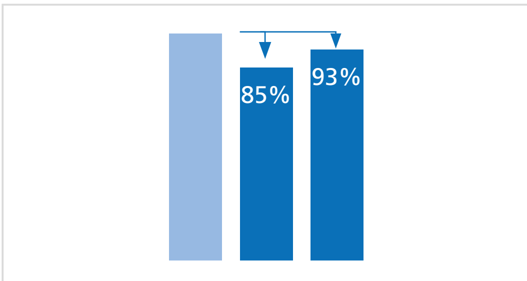
REFERENCES:

[85] 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.

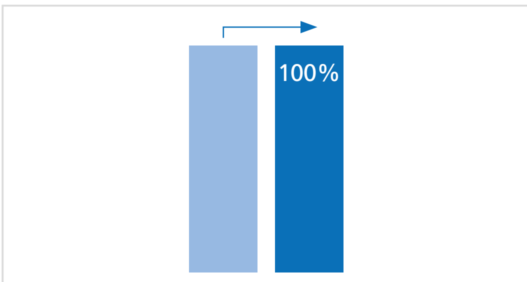
[86] Campo F. P., Tua C., Biganzoli L., Pantini S., & Grosso M. 2021. Natural and enhanced carbonation of lime in its different applications: a review. Environmental Technology Reviewss. 10:1. Pp. 224-237. https://doi.org/10.1080/21622515.2021.1982023

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





Natural carbonation rate (instantaneous).



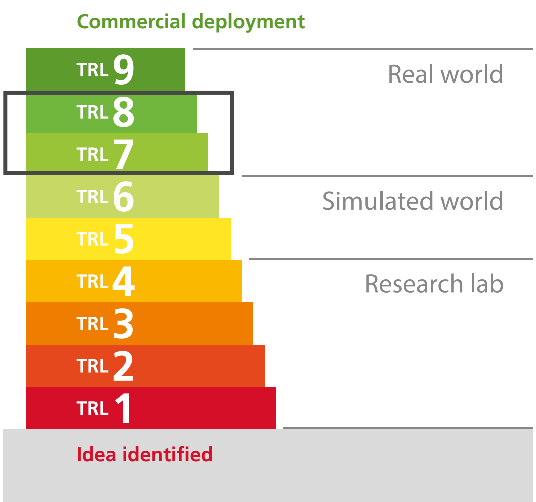
Enhanced carbonation rate (instantaneous).

ALUMINUM

Carbonation in aluminum (study)

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

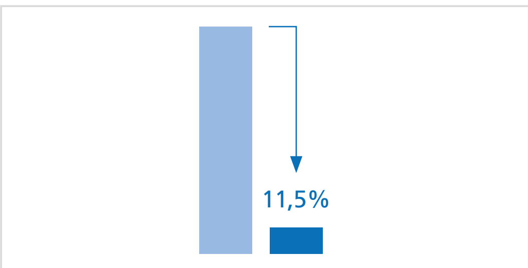
Type	Innovation action (demonstration)
Partners	Leader: Politecnico di Milano (PoliMI-IT) Lime: EuLA (EU)
Funding	EuLA EU contribution: not applicable
Duration	12.2018 – 03.2021
TRL	Technology Readiness Level: TRL 7-8



REFERENCES:

[85] 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.

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



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

Scope of work

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

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

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

The literature review shows that for aluminum:

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

Status of the project

Finalized [85, 86].

Contribution to

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

SOIL STABILIZATION
Carbonation 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 carbonation reaction although known, has not been quantified. The main objectives of this project were:

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

Status of the project

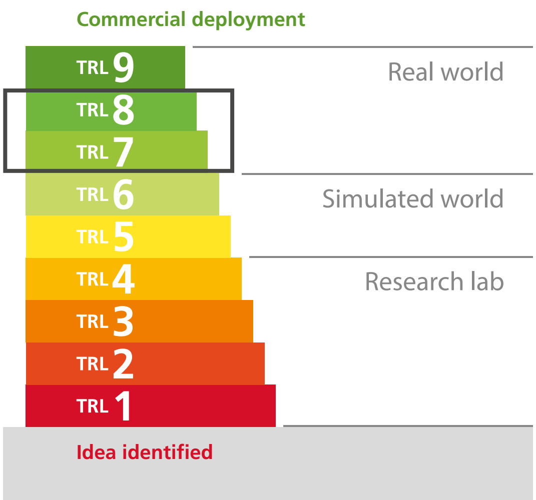
Project finalized in 2014. The following findings can be reported:

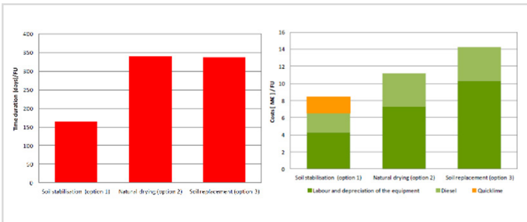
- The case study in a road in Germany, where the soil stabilization with lime was carried out 25 years ago indicated that carbonation rate is ranging between 35-40%. 10-15%: still available as free CaO and 50% is used for puzzolanic reactions. These results were obtained from the application of various techniques, such as X Ray Diffraction, Phenolphthalein as well as geochemistry modelling [90].
- When comparing: 1. Soil stabilisation with quicklime for the re-use of wet soils. 2. Natural drying of wet soils before re-use and 3. Replacement of wet soils by external suitable soils, the time to complete the works is shorter for option 1 and the cost savings by using lime soil treatment for the soil stabilization are in the range of 22% and 42% if compared to the natural drying (option 2) or Soil replacement (option 3) [91, 92].

Contribution to

Lime carbonation – Lower carbon footprint – Soil stabilization.

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





Timeline to complete the works and cost savings.

REFERENCES:

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

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

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

9. Innovation at End of Life

- LODOCAL
- P recovery
- P recovery from Digestate
- PLASMETREC
- PLD
- Re-BioP-Cycle
- Mineral LOOP

LODOCAL • Lime
to sanitize sludge from waste water for use in agriculture

cordis.europa.eu/news/rcn/128630_en.html

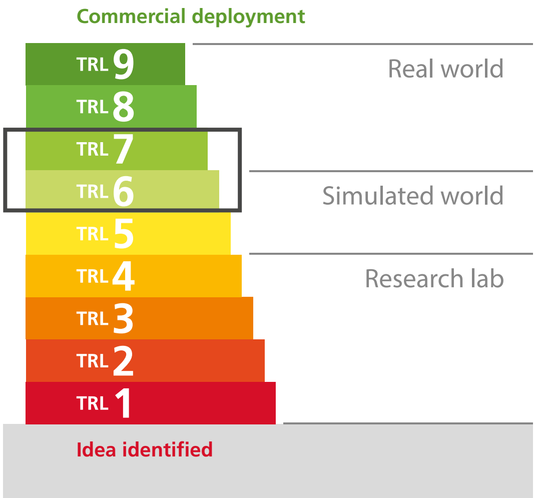
Scope of work

The sludge originated by wastewater treatment plants are governed by very tight requirements through legislations/EU directives. However, they can be purified and later reused in the field as mulch or for composting. Faced with stronger requirements, the industry looks for viable alternatives to current uses, which enable them to sell this by-product.
Several studies have shown that adding lime to the sludge can eliminate pathogens. Specifically, lime can help to create physicochemical conditions which can stop the biological degradation of organic matter they contain, avoiding thus the production of odors.
The scope of the project was to demonstrate that the application of lime enables sludge sanitation, either for reuse for soil improvement as a sanitized agricultural amendment, or for regeneration of degraded environments without risk to plant, animal or human health.

Status of the project

Project finalized in 2011. The following results can be reported:
- The WWTP sludge treatment with lime, sanitizes, reduces the concentration of bacteria below the detection limits.
- Stabilizes the sludge in the long term by avoiding the decomposition of organic matter and reduces its moisture, thereby facilitating handling.
- Thus, the results obtained to date suggest that this study will provide a solution to sanitize the wastewater treatment plant sludge and that they may continue to apply with full guarantees of safety in agriculture.
- Propose a scheme of the facility needed to move the application to an industrial level, the size of which depend on both the type of sludge treatment plant and the volume to be processed [93, 94, 95].
- Sludge legislation must be agreed inside and between the countries.

Type	Innovation action (product)
Partners	Leader/Lime: Calcinor (ES)
Funding	National INTEK-BERRI (ES)
Duration	02.2009 – 12.2011
TRL	Technology Readiness Level: TRL 6-7



Contribution to

Environmental protection – Materials technology – End of life treatment.

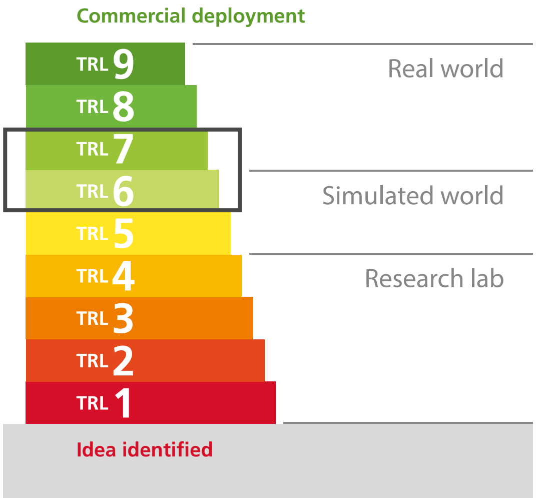
REFERENCES:
[93] La cal como tratamiento avanzado para lodos de EDAR. INFOENVIRO Issue 56. July 2010. In Spanish.
[94] Utilización de la cal en tratamiento de aguas lodos. Aspectos téchnico-comerciales y estrategia de desarrollo del Mercado. CONCAL 2012 event. Platform presentation. In Spanish. an-fa-cal.org/media/Eventos/PRESENTACIONES_DEL_EVENTO_CONACAL_2012/Utilizacion_de_la_cal_en_tratamiento_de_aguas.pdf.
[95] Usos de la cal en tratamiento de agua potable. 2012. ANFACAL. Pp. 7. In Spanish.

P RECOVERY

Development of a crystallization process for re-covering P fertilizers from ww purification with complete recovery of the remaining phases in the cement industry

fg-kalk-moertel.de/forschungsberichte

Type	Innovation action (pilot)
Partners	Leader/Lime: BVK (DE)
Funding	National: 0.45 Mill EUR
Duration	11.2013 – 04.2016
TRL	Technology Readiness Level: TRL 6-7



Pilot plant for the recovery of Phosphate from sewage sludge and planting tests performed by University of Bonn (DE).

Scope of work

In Germany, the current use of phosphate fertilizer is around 110,000 t/year. Average phosphate content in sludge is 4% to 6% (approx. 25,000 t phosphate p.a.) in Germany. Phosphate recovery from sewage water for utilization as fertilizer and usage of residual phases within the cement industry was tested. Through process optimization, the recovery of phosphate-containing phases with lime products, the use of metal salts can be minimized to maintain the run-off parameters.

Status of the project

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

- Development of a crystallization process for recovering phosphate fertilizers from the waste water purification process with complete recovery of the remaining phases for use in the cement industry.
- Trials at the Giessen sewage treatment plant completed: Successful P recovery and fertilizer production
- Plant tests at the University of Bonn, have demonstrated and validated the effectiveness and plant availability of P within the crystallization product [96].

Contribution to

P recovery – Sewage sludge treatment & management – Fertilizer industry – Agriculture – Co-incineration processes.

REFERENCES:

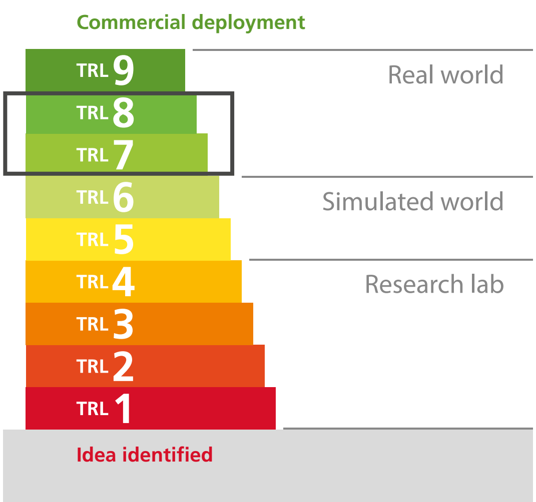
[96] Ehbrecht A., Ritter H.-J., Schmidt S.-O., Schönauer S., Schuhmann R., Weber N. 2016. Entwicklung eines kombinierten Kristallisationsverfahrens zur Gewinnung von Phosphatdünger aus dem Abwasserreinigungsprozess mit vollständiger Verwertung der Restphasen in der Zementindustrie. Final report. Pp. 75.

P RECOVERY FROM DIGESTATE

Phosphorous recovery from Digestate

byosis.com/wp-content/uploads/2017/03/Artikel-Boerderij-2017-Feb.pdf

Type	Innovation action (demonstration)
Partners	Leader/Lime: Lhoist (NL)
Funding	Own initiative Total project: not reported
Duration	2012 – 2017
TRL	Technology Readiness Level: TRL 7-8



Scope of work

The abolition of the milk quota on 1st April 2015 led to a growing dairy cattle stock in the Netherlands. The consequence is that the animal manure puts an increasing pressure on the environment.

Phosphate and nitrogen are needed as fertilizer, but when these minerals are not absorbed by the crops they leach in the soil and pollute the ground water. For this reason, farmers are strictly regulated in the period and amount of phosphate and nitrogen they may use on their land. Also, the need for e.g. nitrogen and phosphorous varies in the growth season depending on the crop availability and the soil type. Many farms struggle to stay within these limits and have to balance the demand for nitrogen and phosphorous with the supply. The project has been carried out at a farm with approximately 500 dairy cattle. The animal manure is digested together with co-products in an anaerobic digestion plant. At the end of this process around 25000 ton digestate is produced each year, high in nitrogen and phosphate.

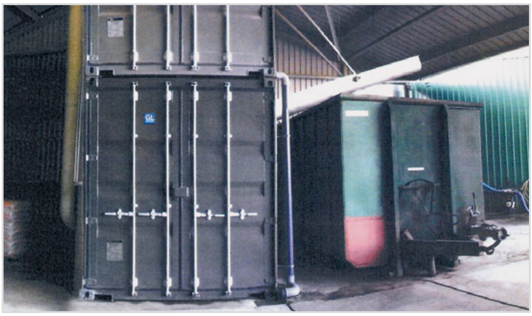
Status of the project

Together with technology partner Lhoist has developed a process to recover and concentrate nitrogen and phosphate from digestate in separate fractions by a physico-chemical treatment with a specially developed lime--based product.

By this, 18.00 tons of a thin fraction can be produced, which contains less than 20% of the initial nitrogen and phosphor. The nutrients are concentrated in a stream of ammonium sulfate and a phosphate fertilizer and can be valorized where needed [97].

Contribution to

P recovery – P & N runoff avoidance – Transport reduction – Fertilizer valorization.



Usable fertilizers stripped from digestate.

REFERENCES:

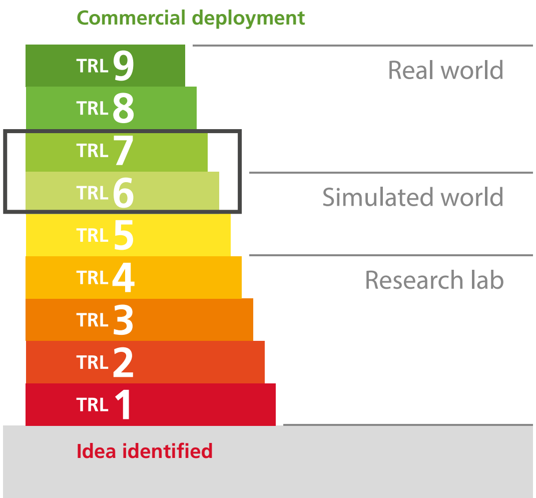
[97] Poelsma, Bouke. Bruikbare meststoffen gestript uit digestaat. Boerderij 102, no. 22. Pp. 20-21. In Dutch.

PLASMETREC

Reverse Metallurgy: Plasma Metal Recovery

reversemetallurgy.be/fr/axes.html?ID=83

Type	Innovation action (demonstration)
Partners	Leader: Hydrometal (BE) Lime: Carmeuse
Funding	National PPP (BE, Wallonia) NEXT programme + industry partners (9 Mill EUR)
Duration	01.2016 – 12.2021
TRL	Technology Readiness Level: TRL 6-7



Timeline to complete the works and cost savings.

Scope of work

The circular economy objective is to valorize the industrial waste through the recycling and ensure that secondary raw materials (especially non-ferrous metals and critical raw materials) become part of the value chain. Reverse Metallurgy Public Private Partnership (PPP) responds to these strategic objectives of Wallonia region in Belgium, which objective is to become a center of excellence for the recycling and recovery of non-ferrous and critical raw materials.
The objective of Reverse metallurgy lies in the technology development for plasma oven to process a multitude of secondary raw materials and valorize non-ferrous materials, some of them being critical, for the European industry. Hydrometallurgical treatments are carried out upstream of the oven to improve the quality of end products.

Status of the project

Project ongoing until 2021. The following objectives can be reported:
• Commission a pilot facility consisting of oven, gas treatment and metal feed and concentration units on the Hydrometal site in Engis.
• Investigate multiple non-ferrous waste flows at CRM and assess technical and economic feasibility at the pilot facility.
• Carmeuse will contribute with the expertise on flue gas treatment to minimize the polluted emissions.
• Univeristy of Liege will contribute with the expertise on mineral characterization.
• The ultimate objective will be to adapt and optimize the functioning of the pilot facility that’s to the tests and identify the raw materials to feed the industrial facility in the future [98, 99, 100].

Contribution to

Recycling – Circular economy – Non-ferrous metal recovery – Materials technology – Raw material optimization – Critical raw materials.

REFERENCES:
[98] Bechet M., La siderurgie Wallone n’es pas morte. La Derniere Heure. Pp. 16-17. In French.
[99] ULg lance les robot trieurs de dechets. La Meuse. Pp. 8-9. In French.
[100] Recycling Valley: Innovative Reverse Metallurgy in Wallonia and in Europe. Conference 21 November 2016. Liege (Belgium).

PLD
Paul Wurth – Lhoist Deoiling process

pld-life.eu

Scope of work

The main objectives of the PLD project are:

- De-oiling of oily material by means of an innovative low-temperature and auto-thermal process using lime and testing at full industrial scale.
- Recycle of PLD end-product in sinter plant as substitute of raw material (iron ore) and reduce steelmaking waste amount.
- Improving energy consumption in comparison with existing processes.
- Reduce soil and water pollution related to waste landfilling.
- Application to worldwide iron and steelmaking industry.
- 100% of PLD end-product into sinter plant as substitute of iron ore.
- Adapt PLD process to other oily waste.

Status of the project

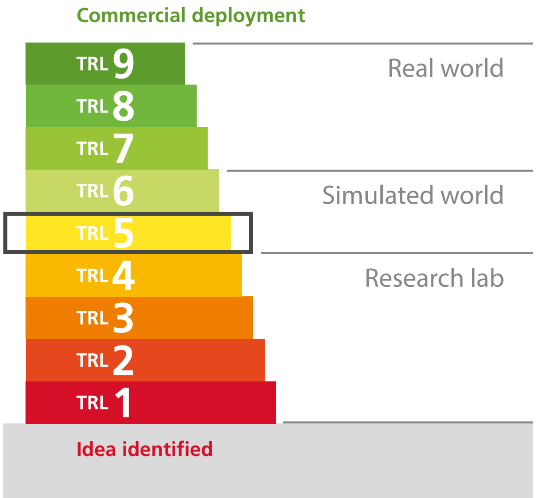
Project finalized in 2015. The following achievements can be reported:

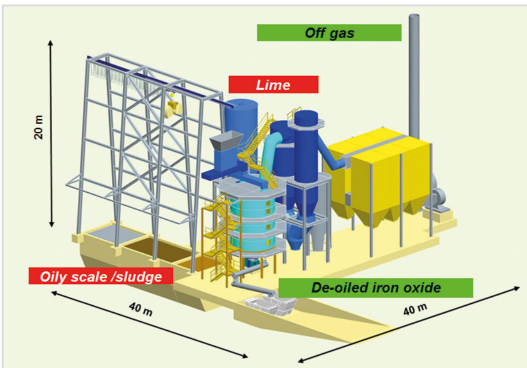
- By means of the pilot test, efficiency of PLD process efficiency was proven at Paul Wurth lab and efficient de-oiling rate was achieved to recover pure iron ore fines.
- Market analysis, focusing on securing sufficient oily sludge supply from different industrial sites to operate the PLD pilot plant.
- Identification of the site to construct the PLD plant has been selected and local authorities have been approached to start construction permit application.
- Due to the long delay compared to the initial LIFE project time schedule, the low amount of oily by-products available and the refusal of the local authorities to issue a construction permit due to urban reasons, the partners were forced to end the project in May 2015 [101, 102].

Contribution to

Lime technology – Steel making – Circular economy – Waste valorization.

Type	Innovation action (process)
Partners	Leader: Paul Wurth (LU) Lime: Lhoist
Funding	EU / LIFE+ Total project: 13 Mill EUR EU contribution: 4.9 Mill EUR
Duration	09.2012 – 09.2015
TRL	Technology Readiness Level: TRL 5





Simplified process flow sheet of the PLD process [92, 93].

REFERENCES:

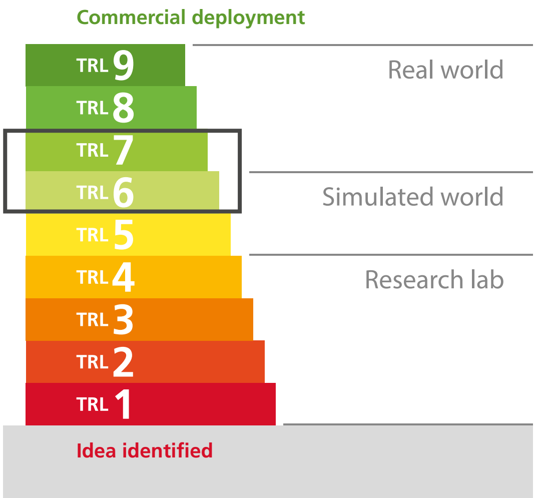
[101] Rodriguez D., Pelletier M., Houbart M., 2013. De--oiling of oily mill sludge and scales. Associação Brasileira de Metalurgia, Materials e Mineração (ABM) – 50th Rolling seminar in Ouro Preto (Brazil) on 19 November 2013. Pp. 1-9.

[102] Pelletier M., Rodriguez D., Houbart M., 2014. De--oiling of oily mill sludge and scales. European Steel Technology & Application Days (ESTAD) at Paris (France) on April 2014. Pp. 2.

RE-BIOP-CYCLE • Recycling Phosphate from communal sewage treatment plants by Bio-P re-dissolution and crystallisation in a fluidised bed reactor

fg-kalk-moertel.de/re-biop-cycle

Type	Innovation action (plant)
Partners	Leader/Lime: BVK (DE) Partner: THM
Funding	National: 0.5 Mill EUR
Duration	01.2018 – 06.2020
TRL	Technology Readiness Level: TRL 6-7



Aerial view of the Sewage Treatment Plant in Gießen (DE).

Scope of work

In agriculture, the application of mineral fertilizer becomes necessary as the soil loses its nutrients over time. Among the most important is Phosphor (P), which is mainly recovered from P mines. One common problem using these resources is the increasing contamination with radiogenic Uranium and Cadmium, both of which end up in fertilizer in concentrations that violate national and international regulations.

Therefore, secondary, uncontaminated P-resources like sewage sludge are gaining more and more attention. The Re-BioP-Cycle project aims at recovery of P from activated and excess sludge by optimising the Bio-P process at a sewage treatment plant in Gießen, Germany. The phosphates are recovered without any endocrinic active substances or organic contaminants. In a fluidized bed reactor, the extracted phosphates will react with (dolo-) limestone to calcium phosphate and struvite, which can be readily used as fertilizers in agriculture.

With a P recovery rate of > 50%, the Re-BioP-Cycle project will adhere to the new sewage sludge regulations in D from 2025 onwards while providing a sustainable, cross-industry solution for economic recycling and reuse of secondary P. The end-product will allow a controlled agricultural use of P, thus helping to reduce costs and to avoid overfertilization.

Status of the project

Project started in January 2018:

- At the moment, laboratory scale pilot tests are taking place which focus on optimising the fluidized bed reactor and the Bio-P process.
- First pilot scale experiments will be carried out in the end of 2019.

Contribution to

Environmental protection – Materials technology – End of life treatment.

MINERAL LOOP • Capture and sequestration of industrial CO_2 by carbonation of mineral waste

carmeuse.com/eu-en/mineral-loop

Scope of work

The challenge to be addressed (regulatory / societal / national / Global). Mineral waste, which constitute by far the most important mass of waste, are currently very little recycled and mainly put in landfills. Their recycling is currently economically difficult, notably because of the low value of the by-products and the cost of transport.

To overcome this problem, the Mineral LOOP project aims to design, develop, install, and operate a pilot plant for the transformation of mineral wastes / by-products into higher value-added products. To achieve this, the Mineral LOOP project will develop innovative solutions in mineral waste pre-conditioning techniques, carbonation reaction processes and post-treatment processes.

Status of the project

Project started in December 2021 and is still in its early stages. The project in a step wise approach will address:

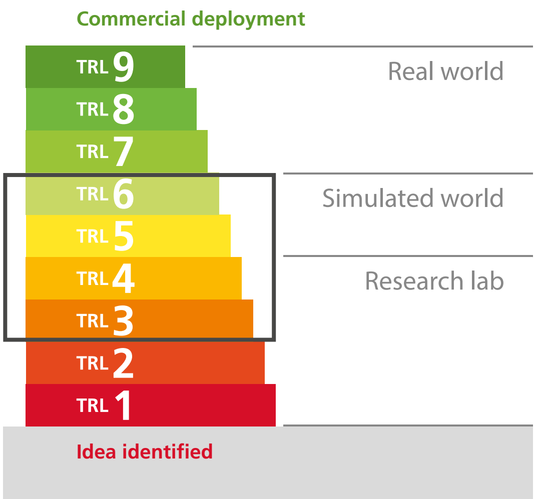
- A first stage will identify, characterize, and select the potential mineral waste / by--product streams. This stage will also evaluate the need and develop pre-conditioning treatments to optimize the carbonation process. Development and optimization of the carbonation processes and post-treatments to meet higher added-value products are also part of this first stage.

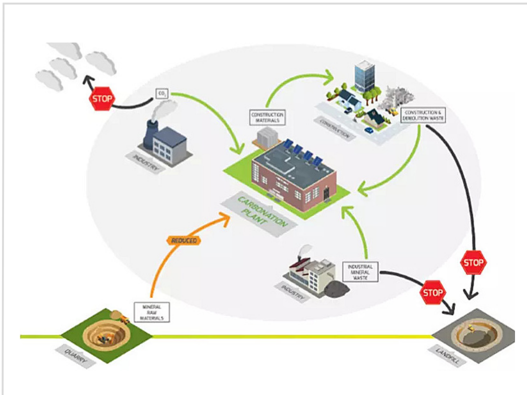
A second stage will scale-up the results from the previous stage into a first demonstration plant that will process mineral waste / by--product streams and valorize higher added--value products. These products will be used in, among others, construction applications. Throughout the project, LCA analyses will validate the options chosen to demonstrate positive results in terms of environmental impact reduction of the processed mineral waste / by-product streams.

Contribution to

Circular Economy – Green Deal – Decarbonation – Carbon Sequestration – Waste reduction – Carbonation – CCU.

Type	Innovation action (mineral valorisation)
Partners	Leader/Lime: Carmeuse (B)
Funding	Total project: 4.7 Mill EUR National contribution: 3.0 Mill EUR
Duration	12.2021 – 12.2025
TRL	Technology Readiness Level: TRL 3-6





Mineral LOOP graph.

10. Projects in Pipeline

- CO_2 solid bed reactor
- CO_2ncrEAT
- Réty CCS
- AGRI liming

CO_2 SOLID BED REACTOR

Separation combined with a Bio-Methanation (CCU)

Scope of work

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

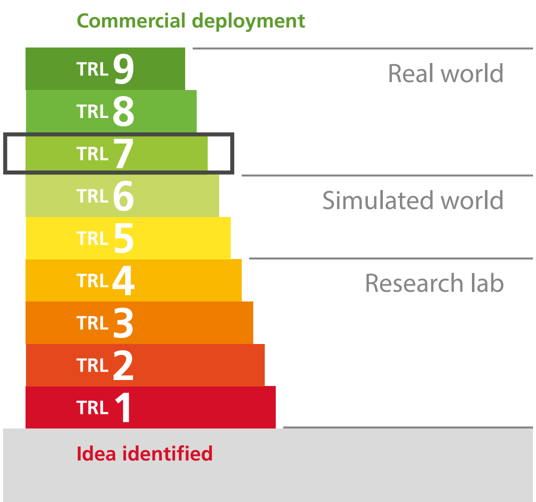
Status of the project

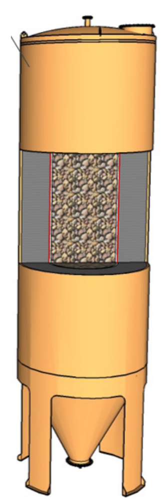
Pilot plant project: Application Phase I was successful within the BMWK-program "Decarbonization of the industry"; Phase II application is submitted in 09.2022. Preceding project (running until 12.2022, Funding 0.75 Mill EUR): Tests at the technical center of the University of Magdeburg are finished, modelling is ongoing [103].

Contribution to

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

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



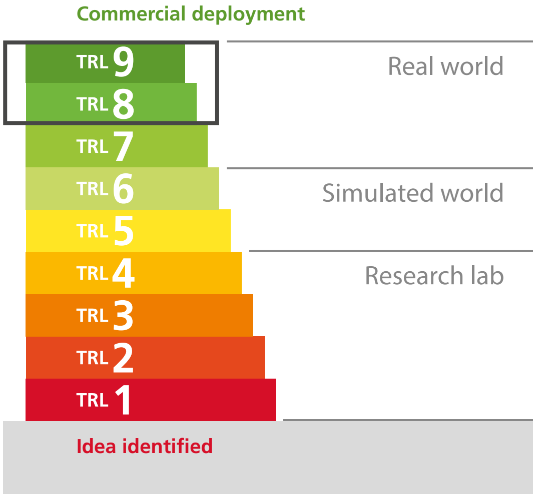


Sketch of a CO_2 separation reactor.

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

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

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



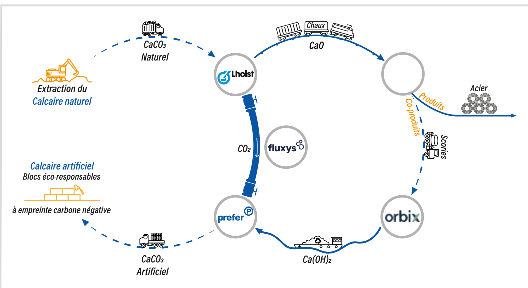


Illustration of the double circularity of the project.

Scope of work

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

Status of the project

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

Contribution to

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

RÉTY CCS

Decarbonizing lime manufacturing with Carbon Capture & Storage using cryogenic technology

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

Scope of work

Lime manufacturing CO_2 emissions are from two sources:

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

Lhoist and Air Liquide have signed a memorandum of understanding with the aim of decarbonizing the Lhoist lime production plant located in Réty, in the Hauts-de-France region, using the Air Liquide cryogenic carbon capture technology. This technology aims to capture and purify 95% of the CO_2 emitted from Lhoist's existing lime production site in Réty, marking the first instance of its use to decarbonise lime production in France.
Once captured, the CO_2 gas will be transported to a multimodal CO_2 export hub currently under development in the area, before being permanently stored in the North Sea as part of the D'Artagnan EU project.
Thanks to this project proposal, Lhoist could reduce its CO_2 emissions from the Réty plant by more than 600,000 tonnes per year as from 2028. This is equivalent to the annual emissions of around 55,000 households in France.

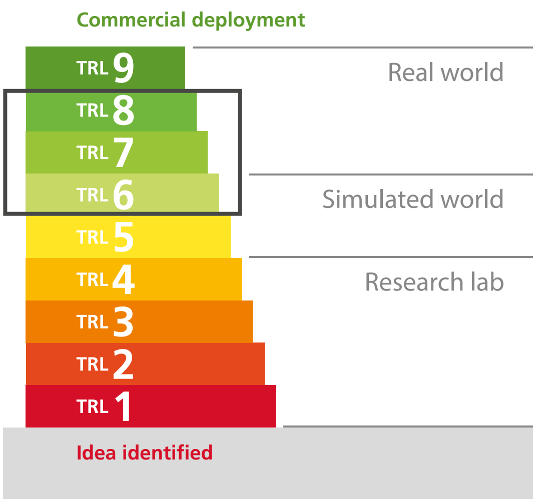
Status of the project

Application submitted in 2022. Industrial operation targeted from 2028.
To kick off this project, Lhoist and Air Liquide have submitted a joint request for funding from the European Innovation Fund support program for large-scale projects. This partnership marks a new stage in the creation of a low-carbon industrial ecosystem in the wider area of Dunkirk.

Contribution to

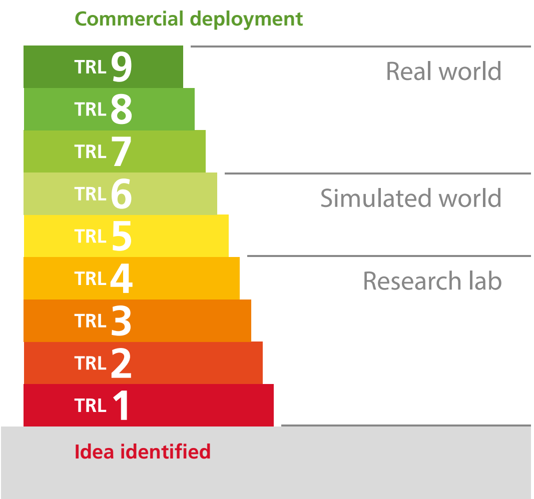
Low carbon intensity lime – Carbon capture – CCS – CO_2 reduction.

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



AGRI LIMING • Agriculture soil liming and mitigation of GHG emission – a literature review

Type	Literature review
Partners	Leader: Politecnico di Milano (PoliMI-IT) CCA/EuLA
Funding	CCA/EuLA EU/national contribution: not applicable
Duration	03.2022 – 10.2022
TRL	Not applicable



• Amount used for each application and application frequency.
• Initial and final soil conditions.
• Balance in greenhouse gases (GHG) emissions, such as CO_2, N_2O and CH_4.
• Soil Organic Carbon increase.
• Soil respiration modifications.
• Increased agronomic productivity.
• Optimization of the use of fertilizers.
• The GHG emissions logistic calculations (liming materials and/or fertilizers production, transport and spreading).

Scope of work

EU has launched a "Carbon Farming" initiative aiming to reward and promote climate-friendly practices via the Common Agriculture Policy (CAP) or other private and public linked to carbon market. This joint IMA/EuLA project aims to assess the scientific knowledge of the potential benefits of agriculture soil liming to mitigate greenhouse gases emissions to support this policy.
Acidity, which can be offset by liming, is often a parameter not considered in soil quality management practices.
Increasing soil pH and calcium intake leads to a globally positive effect on GHG balance in the different pools:
• Uptake of CO_2 during the neutralization of the soil (hydro-carbonate neutralization).
• Increase of carbon sinking in plants and agri-products.
• Optimization of inputs to reach the same yield level.
• Long term increment of Soil Organic Carbon (SOC).
Reduction of N_2O emission thanks to higher pH (N_2O has 300x GHG effect compared to CO_2).
The research will analyze the available scientific literature on the effects of soil liming, focusing on stud-ies in field published from year 2000, with a focus on Europe.

Status of the project

Project started in March 2022.
Expected deliverables, assessments on:
• The characteristics, e.g. composition and size distribution, of liming materials used for the applications on the soil, such as limestone ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), lime (CaO and $Ca(OH)_2$).

11. Future Technological Innovation Priorities for the lime sector

The lime industry sector although small is an important sector due to its enabling nature and embedded in different value chains. Being an energy intensive sector, (70% of its CO_2 emissions are due to the decarbonation of the raw material), the lime industry's first priority is to find ways to mitigate those [104]. As you can see from this brochure extensive work has been done by the sector to address this challenge through multiple innovation actions/projects.

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

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

- Bioethanol.
- Biomass.
- Oxyfuel.

Few ideas for future innovation projects could be:

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

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

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

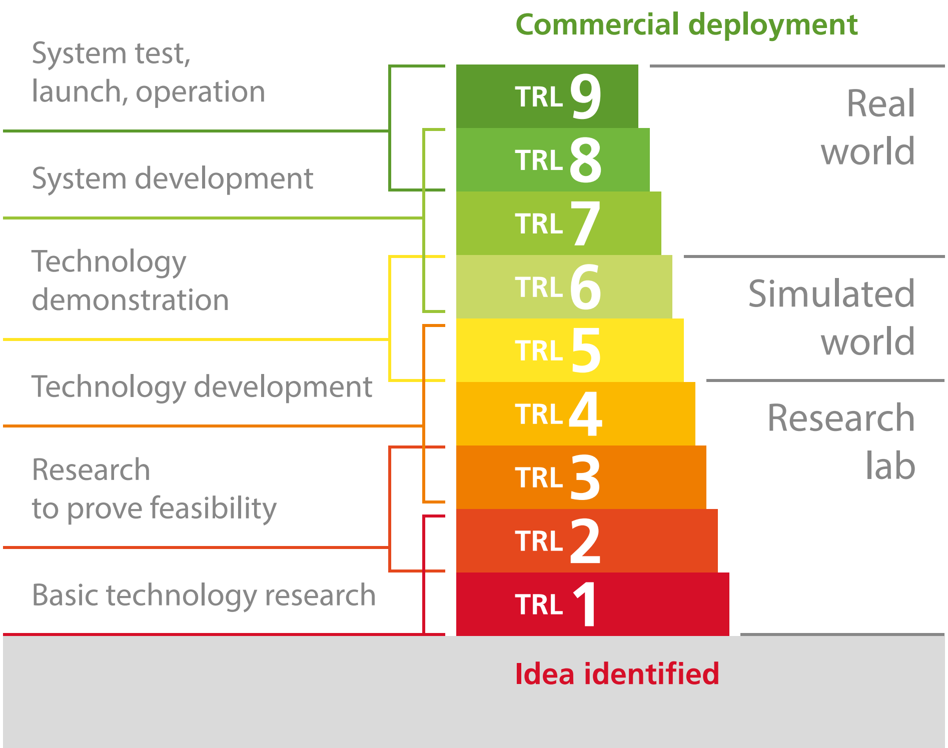
12. Annexes

Annex 1: Technology Readiness Levels (TRL scale)

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

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

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



Annex 2: EuLA Innovation Task Force

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

To refer to this report please use the following reference: © EuLA. 2022. Innovation in the lime sector 3.0. Pp. 1-116.

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

Active Members EuLA Innovation TF

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Alan Ryan (Clogrennane)
Bernardi Lorenzo (Fassabortolo)
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Costea Bogdan (Carmeuse)
Cowling Tim (Tarmac/CRH)
Creveceour Stephane (Carmeuse)
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Degerstedt Erik (Nordkalk)
Foster Steve (Singleton Birch)
Foucart Fabrice (Carmeuse)
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Pettiau Xavier (Lhoist)
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Vels Thomas (Fels)
Verhelst Frederik (Lhoist)
Wangenborn Pernilla (Nordkalk)
Zocco Domenico (Lhoist)

Annex 3: List of projects and duration

Project	Company	Project type
INNOVATION IN QUARRY		
Less fines	Nordkalk	Resource optimisation
Blast-Control	Calcinor & Lhoist	Resource optimisation
Repurpose lime by-products	Nordkalk	Resource optimisation
Noise barriers	Nordkalk	Impact mitigation
Water Management Platform	Carmeuse	Water management
Life in Quarries	Fediex	Biodiversity
Drinking water from quarry	Nordkalk	Water management
Gravity conveyer belt	Baumit	Technology innovation
Resource optimisation	Nordkalk	Resource optimisation
Water Management	Nordkalk	Water management
Community relations	Carmeuse	Community relations
PROCESS EMISSIONS MITIGATION		
AGICAL+	Carmeuse	CO_2 capture
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
CO_2-solid bed reactor	BVK	Innovation action (CO_2 separation)
NECAPoGEN 4Lime	Singleton Birch	Negative CO_2
C4U	Carmeuse	CCU
Columbus	Carmeuse	CCU
$LOWCO_2$	Calcinor	Ongoing pilot plant tests
ZerCaL	Singleton	Pilot plant
DinamX	Lhoist	Innovative application
INNOVATION IN ENERGY		
ADiREN4Lime	Singleton Birch	Anerobic digestion
WHeatRec4PG	Lhoist & Steetley	Heat recovery
Energy optimisation	Nordkalk	Heat recovery
Energy generation	Carmeuse	Energy generation
CHP Generation	Lhoist	Energy generation
Hydrogen Fuel Energy Innovation	BLA	Alernative fuels
FFL	Nordkalk	Innovation action (CO_2 free fuels)
NKL	Lhoist	Innovation action (CCU)
Other company projects/initiatives	EuLA	Energy (varia)

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Project	Company	Project type
INNOVATION IN USE PHASE		
Steel: ULCOS	Lhoist	Low CO_2
Steel: LIMEFLOW Steel	Carmeuse	RM efficiency
Construction: ECO-SEE	Lhoist	Negative CO_2
Construction: ISOBIO	Lhoist	Negative CO_2
Construction: Compact mortar pellets	Fels	Less dust exposure
Construction: Hempcrete	Carmeuse	Negative CO_2
Construction: SUBLime	EuLA & Companies	Sustainabile products
Civil Engineering: HMA LCA study	EuLA	Low CO_2
Environment: Lime pellets for marine SOx reduction	Fels	SO_x Reduction
Environment: Lime in FGT and WTE	Unicalce	SO_x reduction
Environment: Harbour sludge stabilization	Clogrennane	Sediment valorisation
Environment: Cleaner Port (Renere Havn)	Franzefoss Minerals	Sediment valorisation
Agriculture: P runoff avoidance	Nordkalk	P recovery
Agriculture: Lime in AGRI 1	Carmeuse	Soil improver
Agriculture: Lime in AGRI 2	Carmeuse	Soil improver
Agriculture: Soil-water use efficiency	BVK	Soil improver
Glass: Lime in Glass making	Carmeuse	Low CO_2
RETAKE	BVK	Ocean liming
LCC	EuLA	Ocean Liming
INNOVATION IN SUSTAINABILITY TOOLS		
STYLE	Carmeuse	Sustainability
LCI of Lime	EuLA	Sustainability
Lime audits	EuLA	Sustainability
INNOVATION IN CARBONATION		
Carbonation	EuLA	(Re)Carbonation
Steel	EuLA	(Re)Carbonation
Construction: Pure airlime mortars	EuLA	(Re)Carbonation
Construction: Mixed airlime mortars	EuLA	(Re)Carbonation
Construction: Hemp lime	EuLA	(Re)Carbonation
Environment: Drinking water	EuLA	(Re)Carbonation
Environment: Flue gas cleaning	EuLA	(Re)Carbonation
Pulp and paper: PCC	EuLA	(Re)Carbonation
Non-Ferrous: Aluminum	EuLA	(Re)Carbonation
Civil Engineering: Soil Stabilization	EuLA	(Re)Carbonation
INNOVATION AT END OF LIFE		
LODOCAL	Calcinor	Sediment valorisation
P recovery	BVK	P recovery
P recovery from Digestate	Lhoist	P recovery
PLASMETREC	Carmeuse	SO_x reduction
PLD	Lhoist	Sediment valorisation
Re-BioP-Cycle	BVK	P recovery
Mineral LOOP	Carmeuse	Innovation action (mineral valorisation)
PROJECTS IN PIPELINE		
CO_2 solid bed reactor	BVK, Fels, Baumit	Innovation action (pilot)
CO_2ncrEAT	Lhoist	Innovation action (pilot)
Réty CCS	Lhoist	Innovation action (pilot)
AGRI liming	CCA/EuLA	Literature review

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Notes

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