EuLA
European
Lime
Association

A PATHWAY TO NEGATIVE CO_2 EMISSIONS BY 2050

The contribution of the lime industry to a carbon-neutral Europe

A multi-annual way forward to achieve the 2050 carbon-negative vision of the European lime sector.

EuLA
European Lime Association

A About EuLA

24 national associations and companies **are EuLA members,** across **24 European countries.**

EuLA's 2050 climate vision is to deliver **negative CO_2 emissions by 2050.**

18,2 million tons **total sales volumes** (all lime products, 2019.)

EuLA was established in 1990 to provide sector-based representation for the European lime industry. Based in Brussels, EuLA is the decisive voice of lime producers in Europe and aims to promote the safe and sustainable production of lime. The association is also a part of the European Industrial Minerals Association and an active member in the International Lime Association. As a European based product that is essential for many industrial value chains, the lime industry envisions a path to net zero, in line with the targets set out in the European Green Deal. This roadmap presents a pathway to achieving the future of a decarbonised lime sector in Europe.

About Lime

Lime is a strategic mineral for a sustainable European society

Lime is a calcium oxide derived from the decarbonisation of limestone:

$$CaCO_3 + heat = CaO + CO_2$$

It is used for a wide range of processes and in various products that are **essential to our quality of life and to a sustainable European economy.**

Lime kilns are highly energy efficient

The vast majority of lime is produced by kilns with a thermal efficiency above 88%.

69%

of CO_2 emissions are unavoidable process emissions

due to the chemical process of decarbonising limestone.

33% of process emissions are removed from the atmosphere

through the process of carbonation of lime during its use phase.

Lime is an essential mineral for key European value chains. Although it is often an unseen ingredient, it possesses many functionalities used in downstream industries. As a strong enabler, lime is used in various applications and delivers a multitude of benefits.

Lime applications		Positive impact
Iron and steel		*Sustainable mobility, construction & energy*
Air pollution control		*Toxic-free environment*
Civil engineering		*Sustainable transportation infrastructure*
Construction materials		*Low-carbon insulation and building materials*
Agriculture and farming		*Sustainable food system, from farm to fork*
Water sanitation		*Clean, healthy environments*

Foreword

This roadmap presents **a reference pathway for the European lime sector to achieve negative CO_2 emissions by 2050.** It also explores decarbonisation potential towards 2030 as milestone year.

This pathway is a result of a compilation and analysis of data at the European level, in addition to a variety of inputs from companies, national associations, technological experts and existing literature.

The consolidated European decarbonisation pathway cannot be transposed to a particular company, region or country. The actual pathway for companies, regions and countries varies as the local context around each of the production sites strongly influences both the emission mitigation potential and its modalities: applicable regulations, availability and access to specific energies, carriers' access to enabling infrastructure, costs/benefits of a pathway to negative emissions by 2050 and the various decarbonisation technologies.

This roadmap assumes that total European sales volumes remain stable over the period 2019-2050, relying on a preserved competitiveness of European downstream sectors, as lime is an indispensable material in its key applications.

In this document, both quicklime (CaO) and dolime (CaO.MgO) are referred to as "lime."

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Executive summary

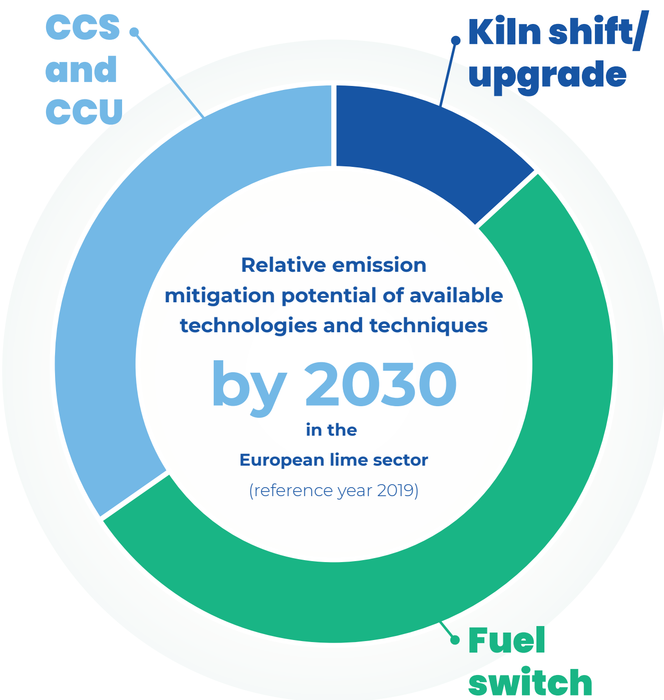
Towards 2030, the European lime sector will activate available levers to mitigate its CO_2 emissions and further invest in research and innovation for decarbonisation

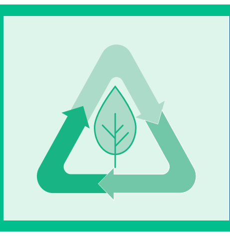
The European lime sector is striving to reduce its direct CO_2 emissions by approximately 20% compared to 2019 levels by 2030. The achievement of these emission reductions are dependent on the realisation of five prerequisites, including:

1. Access to zero-rated biomass, green hydrogen and waste derived fuels;
2. Access to multi-modal CO_2 transportation infrastructure;
3. Access to and sufficient availability of decarbonised electricity;
4. Access to permanent CO_2 storage and utilisation capacities (CCUS);
5. In parallel, lime will work to achieve the recognition of CO_2 removal by lime carbonation.

Between 2023 and 2030, the emission reduction efforts will primarily be achieved through fuel switches and kiln upgrades, followed by the deployment of the first CCUS-ready kiln technologies.

The 2023-2030 period will be crucial for bringing the enabling technologies to the highest technological readiness levels. The lime sector will enhance its related research and innovation efforts and advocate for the policies required for delivering its full potential.





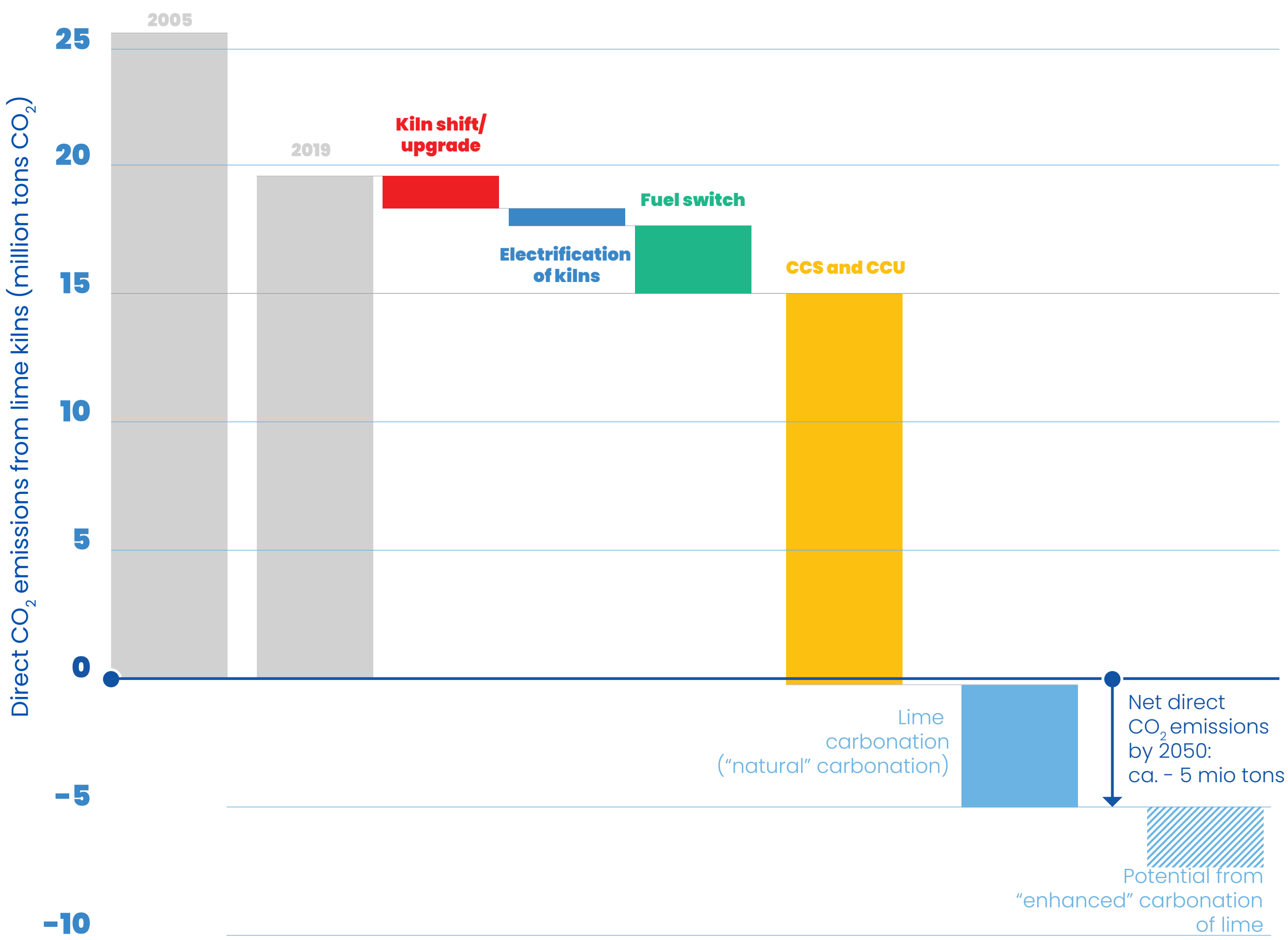
Access to zero-rated biomass, green hydrogen and waste-derived fuels

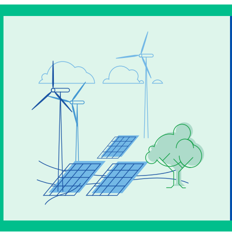
Multi-modal CO_2 transportation infrastructure

Towards 2050, the European lime sector will fully deploy CCUS technologies. Thanks to natural and enhanced carbonation and bioenergy with carbon capture and storage (BECCS), the global footprint of the sector should be considered negative.

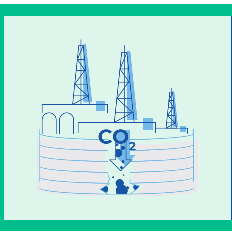
EuLA predicts that the sector will permanently remove approximately 5 million tons of CO_2 a year from the atmosphere. Negative emissions can be achieved through the deployment of decarbonisation technologies and techniques. It is crucial to switch to decarbonised/low carbon energy vectors, energy-efficient/electrified kiln technologies, and CCUS. Considering carbon removal from the atmosphere through lime carbonation during its use phase and combining BECCS is imperative.

Pathway to negative emissions by 2050 (baseline 2019)

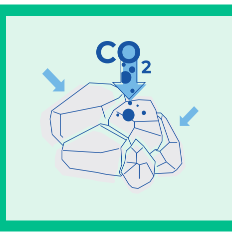




Access to decarbonised electricity



CO_2 permanent storage capacity



Recognition of CO_2 removal by lime carbonation

1 Lime for a sustainable Europe

An essential mineral for key European value chains

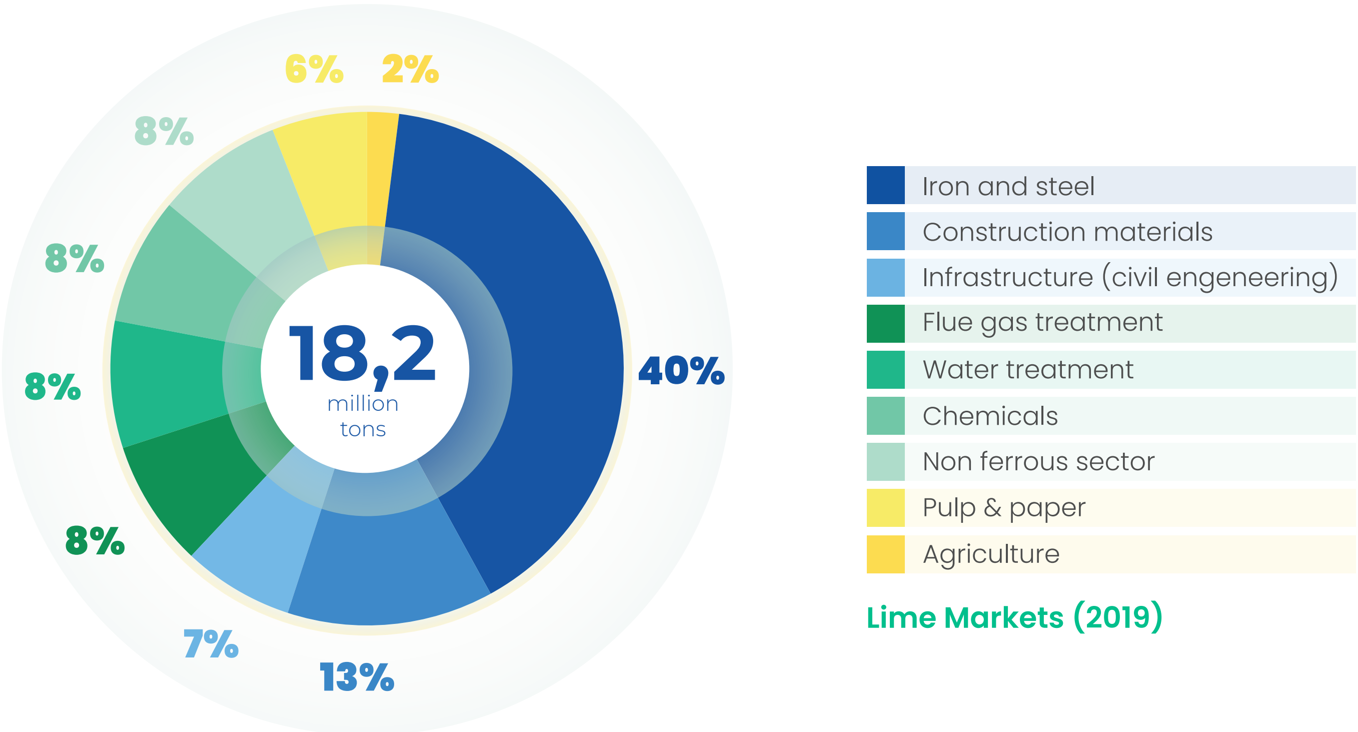
Lime is commonly thought of as an unseen product that profoundly affects our daily lives. Lime is used for a wide range of processes in various applications and products, all of which are essential to sustaining a thriving economy and our quality of life.

Lime is a crucial mineral resource for key European value chains and its occurrence on European territory guarantees access to essential products and services to European citizens.

The absorption and neutralisation properties of lime play an important role **in environmental protection, treatment of industrial flue gases, drinking water purification and polluted soils and wastewater treatment.**

Lime in agriculture increases fertiliser efficiency and is an invaluable ingredient in animal feed and hygienisation processes.

Lime is also an important mineral resource for many manufacturing industries: it helps produce **high strength steel, high performing construction materials for sustainable housing and infrastructure, and provides solutions to civil engineering**, notably for the stabilisation of riverbanks and soils.



Lime Markets (2019)

1 Lime for a sustainable Europe

The contribution of lime to a sustainable Europe through its various value chains

Lime helps to meet the demand for materials required by the technologies and infrastructures that are **crucial to delivering a climate neutral society.**

Through its diverse applications, continuous innovation efforts in products and processes, and enhanced collaboration within and across value chains, **the European lime sector is committed to bringing its full contribution to achieving both the EU Green Deal and United Nation sustainable development objectives.**

This roadmap is developed through the analysis of key scientific research on lime across the EU. It demonstrates and quantifies the potential of the European lime sector to deliver net negative emissions by 2050, hereby contributing to the overall carbon neutrality of European society.

1 Lime for a sustainable Europe

The contribution of lime to a sustainable Europe through its various value chains

Lime, an essential mineral for a sustainable European society: 6 illustrative examples

Iron and steel	→	***Sustainable mobility, construction & energy***

There is no steel without lime. Calcium-, magnesium-based products and minerals from the lime industry are used throughout the iron- & steel-making process, including for secondary metallurgy. Steel is classified by the European Commission as a critical raw material for clean energy transitions, (notably for the production of electric vehicles, windpower, solar PV, electricity networks, hydrogen, bio-energy, hydro and geothermal).

Flue gas cleaning/ Environmental protection	→	***Toxic-free environment***

Lime is a reliable and cost-efficient flue gas cleaning solution for pollutants such as sulphur oxides, hydrochloric acid, hydrofluoric acid, heavy metals, PCB's, dioxins, and furans. Lime therefore plays an important role for a toxic free environment. It contributes to an increased fuel flexibility of industrial processes, as it can be used to clean flue gases both from fossil fuels combustion and from the combustion of waste-derived and biomass-derived fuels.

Water sanitation	→	***Clean, healthy environments***

Lime is critical for water sanitation, as it neutralises the effluent in sewage plants by adjusting the acid capacity and pH value to stabilise the biological sewage treatment process. Process water from industry can be purified with lime or milk of lime and returned to the water circulation. The quality of rivers and lakes as a habitat for micro-organisms can also be improved with a lime-based buffer against acids and alkalis. Furthermore, lime can be used for the remediation of contaminated sites as it neutralises acids, binds heavy metals, and supports the degradation of pollutants.

Civil engineering → **Sustainable transportation infrastructure**

Soil treatment with lime is a technique where fine soils are mixed, in-situ, with lime in order to obtain flexible, permanent structural embankment layers for all types of roads, highways and railways construction. Adding lime into fine soils leads to a rapid decrease in soil moisture content, as it reduces the soils capacity to swell and shrink and improves strength and stability after compaction.

Construction materials → **Low-carbon insulation materials and biomass-based building materials**

Sand lime brick construction presents a reduced embodied CO_2 versus common alternatives, in addition to good acoustic insulation and excellent fire resistance. Lime is also used in autoclaved aerated concrete and in mortars with superior sustainability performance. Plus, lime is increasingly used in biomass-based innovative building materials (such as hemp-based materials) with enhanced humidity regulation, acoustic properties and reduced carbon footprint.

Agriculture and farming → **Sustainable food system, from farm to fork**

In agriculture, lime is used to correct soil acidity, to improve its physical structure and to add nutrients (magnesium and calcium). This results in a better plant uptake of fertilizing compounds (avoiding pollution of ground water), healthy plant growth and enhanced yields. In farming, limestone helps meet cattle's calcium needs and enhances the absorption of nutrients. Lime also naturally disinfects barns, enhances cattle hygiene and health. It can be used in organic farms.

2 How lime is produced

Overview of the lime production process

Raw materials extraction and preparation

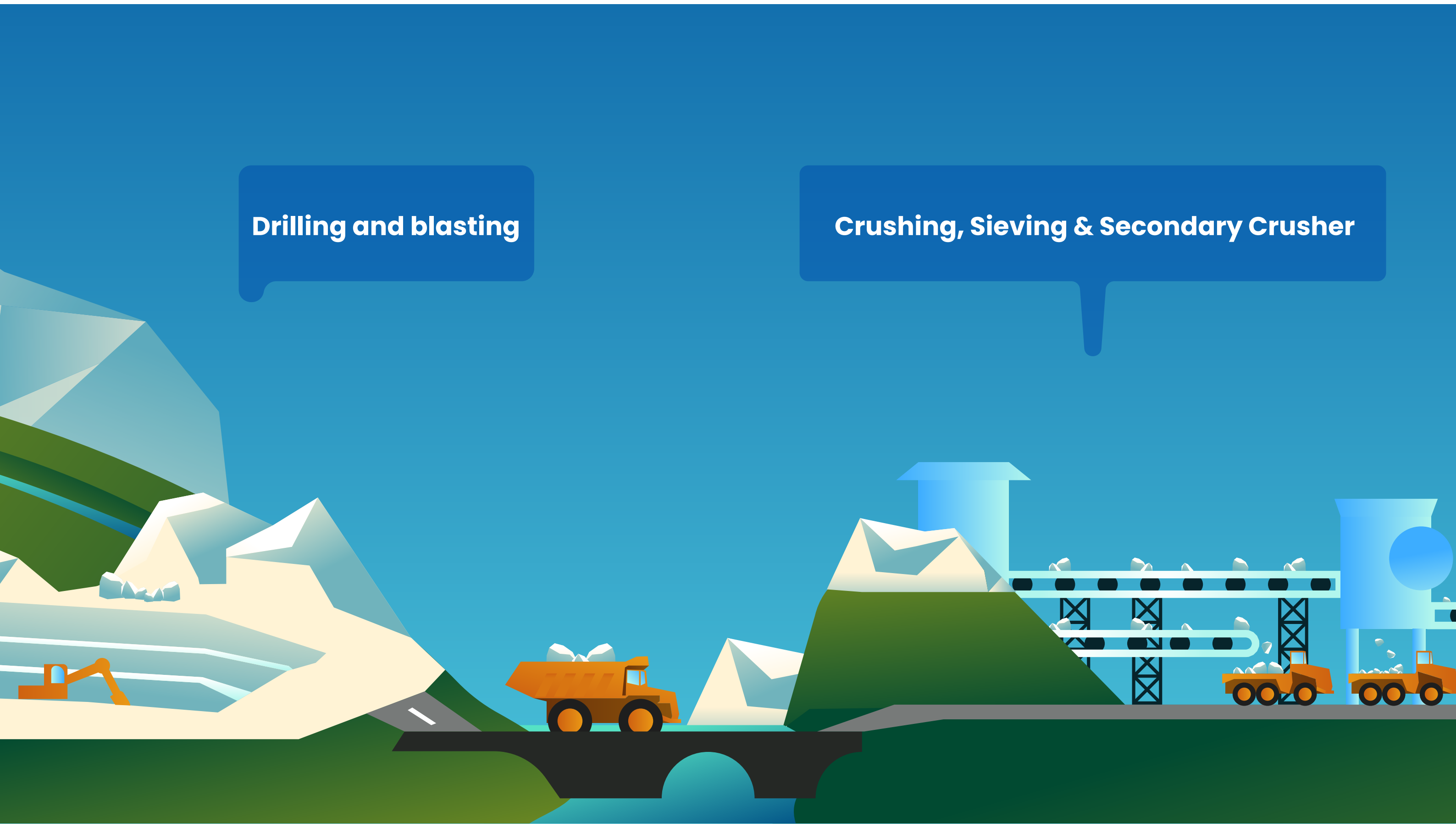
Limestone quarrying

Most limestones (and/or dolomitic limestone) are extracted in quarries through modern blasting technologies minimizing vibrations. The dislodged rocks are then picked up at the quarry 'face' by excavators, loading the rocks into dumpers to transport them to the primary crusher.

Limestone preparation

After the primary crusher, depending on the size of the feed stone required and the kiln type, the stone can go through a second and even a tertiary crusher.

The stone is then screened into a wide range of different sizes.



Schematic flow-chart of the lime production process

2 How lime is produced

Overview of the lime production process

Calcination

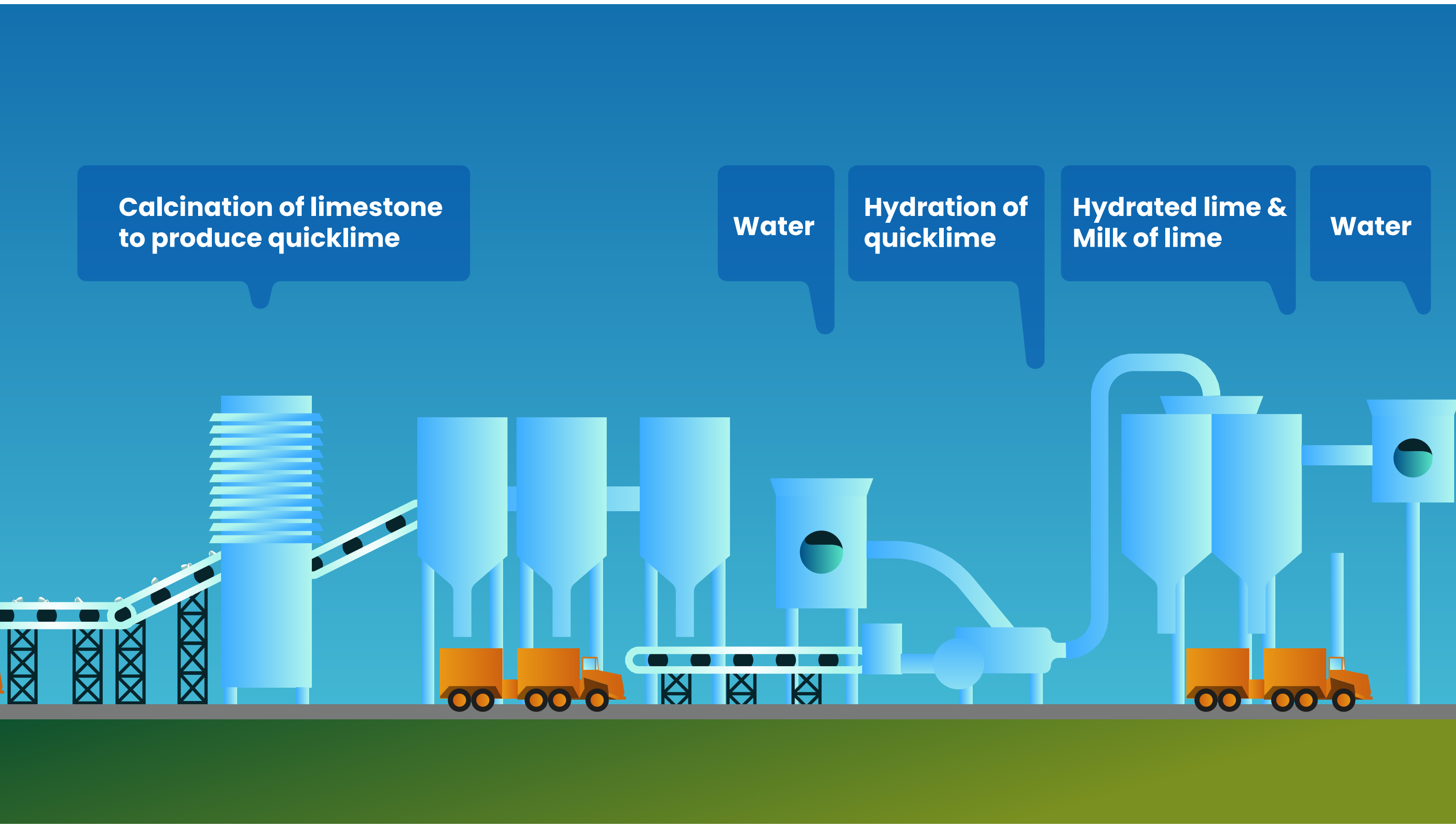
The lime-burning process within the kiln requires enough heat to be transferred to the limestone to allow the decomposition of limestone into lime. Above 900°C the decarbonation reaction turns limestone into quicklime and liberates process CO_2.

$$CaCO_3 + heat = CaO + CO_2$$

The theoretical heat of dissociation of calcium limestone amounts to 3.2 GJ/ton of lime *(see next page for more information).*

Milling/Hydration

The burned lime is either delivered to the end user for use in the form of quicklime or transferred to a hydrating plant, where it reacts with water to produce hydrated or slaked lime. The product can be submitted to crushing/milling/screening steps to adjust granulometry.



2 How lime is produced

Digging into the technology and chemistry

There are six general categories of kilns used for lime manufacturing: rotary kilns with preheater (PRK), long rotary kilns, parallel flow regenerative kilns, annular shaft kilns, mixed feed shaft kilns and other kilns.

Today, the average thermal efficiency of lime production in Europe is 88%.

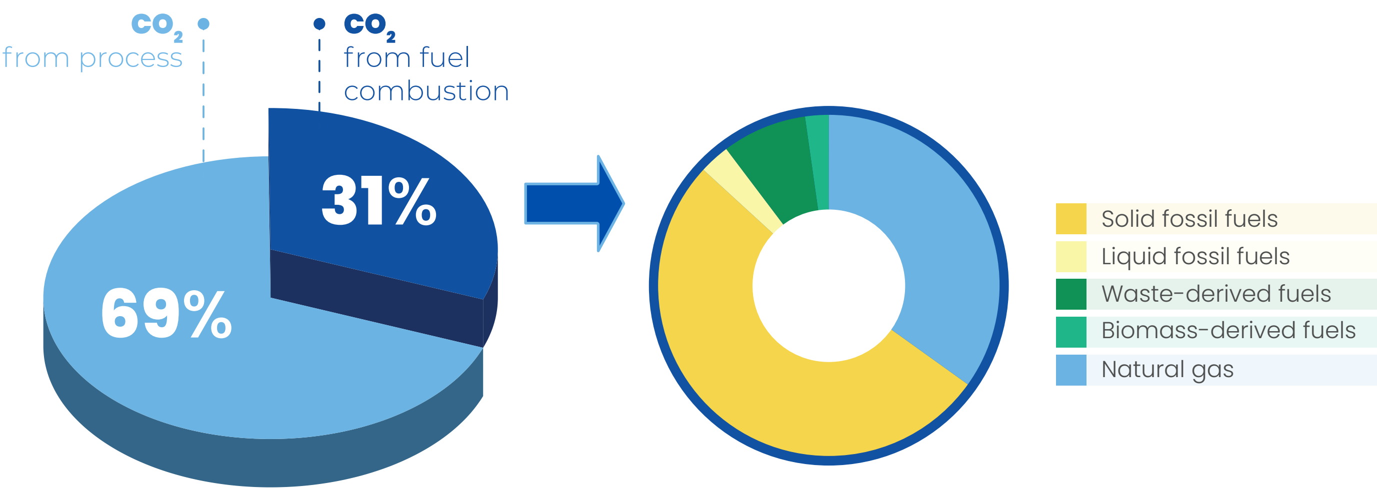
The average fuel mix of the European lime industry in 2019 is presented below. The substitution of solid fossil fuels for natural gas reduces the CO_2 intensity of the combustion. Over the past few decades, the sector has been increasing its use of waste-derived fuels and climate-neutral biomass-derived fuels*.

Waste-derived fuels represent an environmentally and economically attractive option: they help to reduce the consumption of primary fossil fuels, contribute to the competitiveness of the European lime sector and provide solutions to local communities for sustainable waste management.

In 2019, process CO_2 emissions (from the decarbonation of limestone) represented on average 69% of the direct CO_2 emissions from lime kilns. The total direct CO_2 emissions from European lime kilns amounted to 19,5 million tons CO_2 in 2019 (EuLA membership).

LIME KILNS ARE HIGHLY ENERGY EFFICIENT

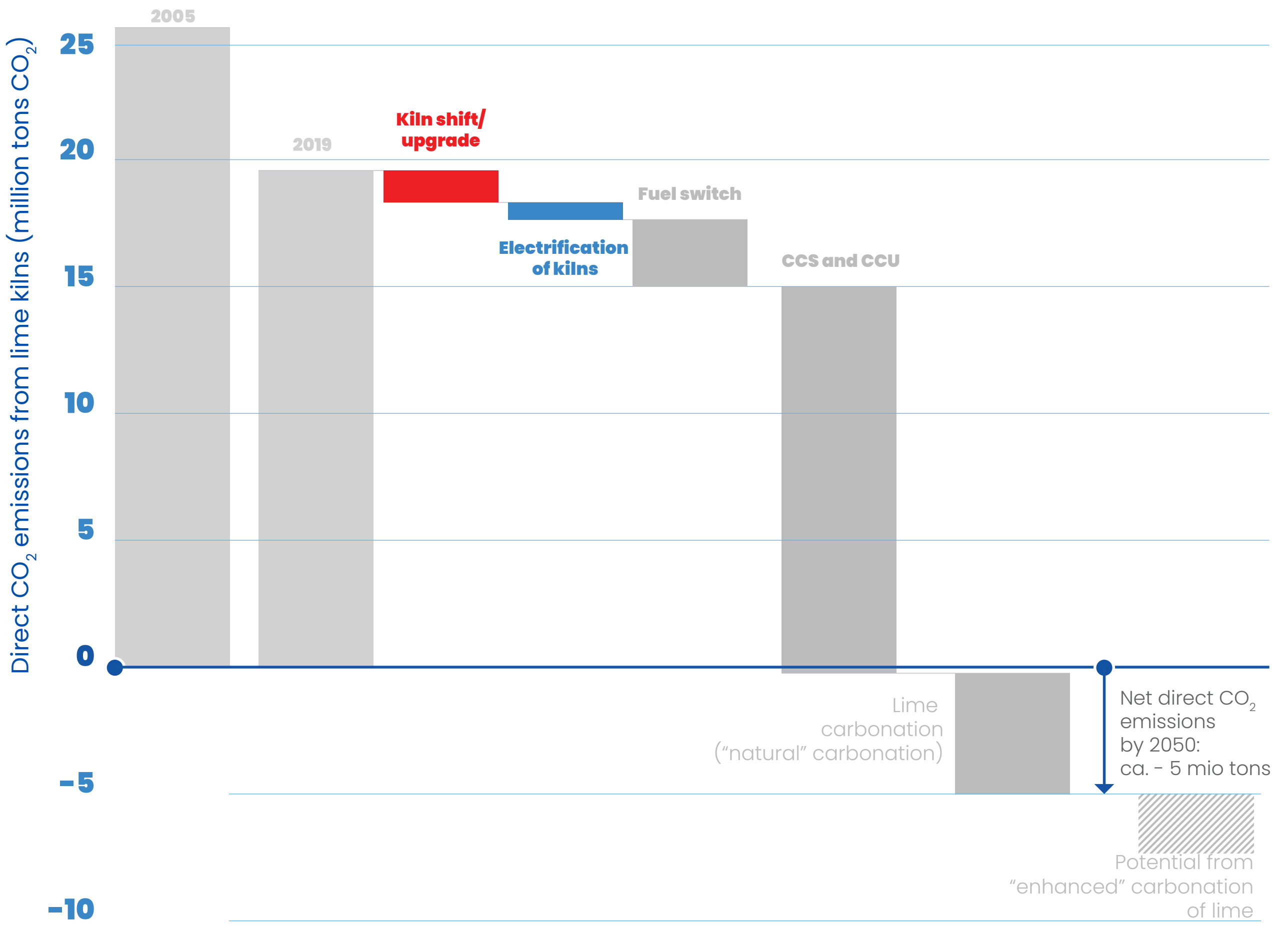
The vast majority of plants in Europe are equipped with modern, energy efficient kilns. The energy efficiency of lime kilns are well above that of many other thermal industrial processes.



** The wording "biomass-derived fuels" is used in this roadmap for renewable fuels of biological origin (biofuels, bioliquids, biogas).*

3 Emission mitigation technologies and techniques

3.1 Kiln shift, kiln upgrade, electrification of thermal processes



Emission mitigation potential

Among the six general types of kilns used for manufacture of lime, the biggest energy efficiency potential lies in replacing horizontal kilns by vertical ones. Vertical lime kilns, such as the PFRK, are highly efficient technologies and perform close to the thermodynamic minimum energy use. Long term, towards 2050, the least energy efficient manufacturing technologies should only be used for specialty products – such as dead burned dolime production in long rotary kilns, or small-scale batch production as part of integrated manufacturing processes. The deployment of digital technologies offers additional opportunities to enhance energy efficiency, notably through the reduction of degraded kiln modes, kiln stops and out-of-spec production.

3 Emission mitigation technologies and techniques

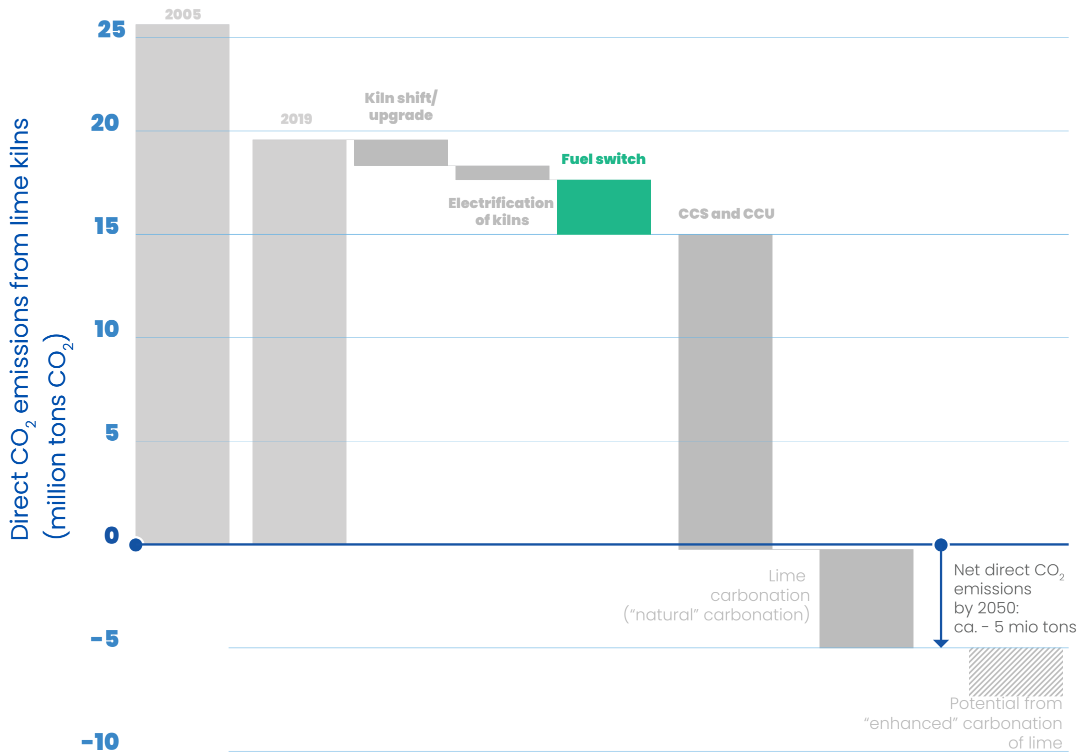
3.1 Kiln shift, kiln upgrade, electrification of thermal processes

The total remaining potential for CO_2 emission mitigation through kiln shift/upgrade is estimated to be ca. 4,5% of total direct CO_2 emissions (reference year 2019), including the impact of digital technologies.

By 2030	***The European lime industry is working to deliver a 2,5% reduction of total direct CO_2 emissions by kiln shift/upgrade*** *(including impact of digital technologies), representing ca. 50% of the total remaining potential (see here above) of ca. CO_2 reduction/year by 2030 (vs 2019). Delivering 50% of the remaining potential related to kiln shift/upgrade by 2030 represents a consequent effort of the European lime industry, considering the related investment costs and the long investment cycles in the sector.*
By 2050	***The full remaining emission mitigation potential related to kiln shift/upgrade will be delivered.*** ***5 to 10% of total lime production will be switched to fully electrified kilns.***

3 Emission mitigation technologies and techniques

3.2 Fuel switch



Emission mitigation potential

The switch to more renewable fuels of biological origin ("biomass-derived fuels" from primary biomass or biomass residues, including biogas) and to fuels derived from non-recyclable waste can be achieved through available technologies and techniques and helps mitigate CO_2 emissions of lime kilns. Fuel switch requires initial investments (for handling, storage and injection into the kiln), process adaptations (maintenance, quality and environmental assurance systems) and special attention for lime quality specifications.

The use of green hydrogen/e-fuels as energy vectors is currently being experimented on lime kilns, and early applications might emerge by the very end of this decade.

The access to affordable low-carbon/climate neutral fuel resources strongly varies from one region to another. In general, while waste-derived fuels are typically more easily available in densely populated European regions (where competition for alternative fuels is also higher), climate-neutral biomass resources can be more easily sourced in remote areas.

PREREQUISITES (see section 7)

Access to carbon-neutral biomass, hydrogen and waste-derived fuels

It is estimated that alternative fuels will deliver almost 10 TWh by 2030 and over 22 TWh to lime kilns by 2050.

3 Emission mitigation technologies and techniques

3.2 Fuel switch

By 2030

Fuel mix **2030**

The European lime sector envisions to cover half of its kiln energy needs through alternative fuels, *including one third of biomass-derived fuels, 15% of waste-derived fuels (continuation of the current trajectory) and first steps in the deployment of green hydrogen/e-fuels.*

By 2050

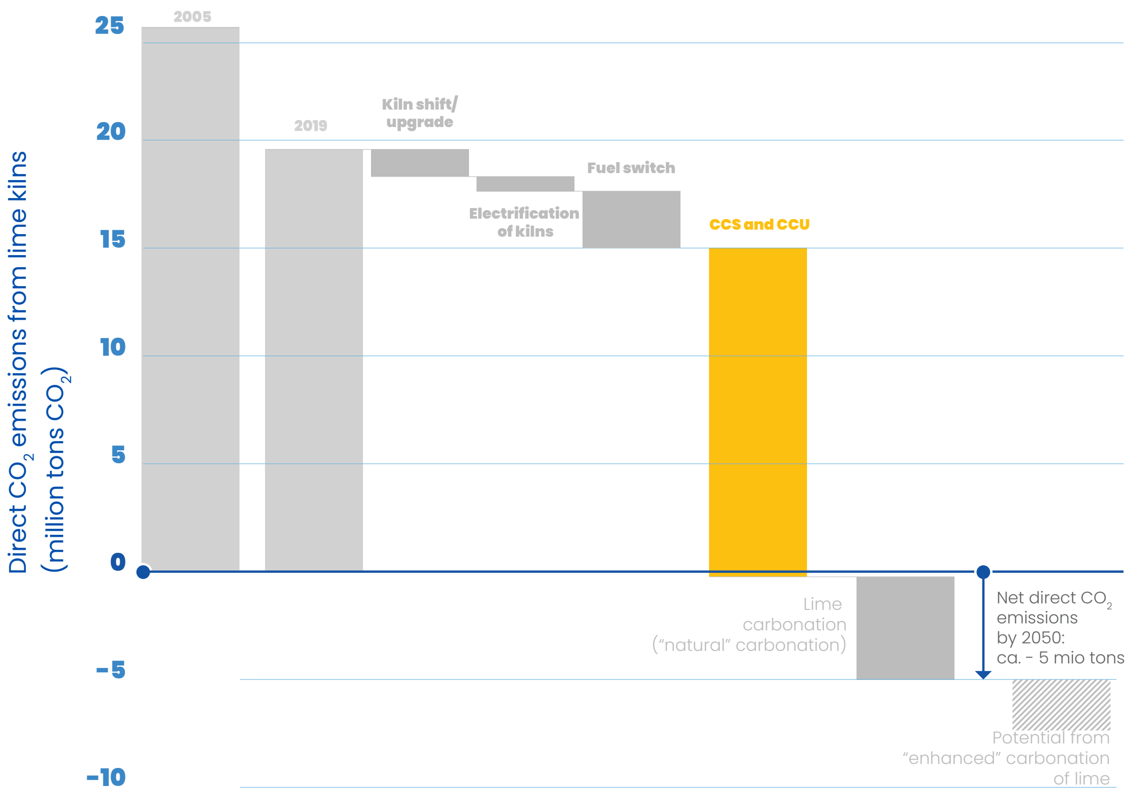
Fuel mix **2050**

The European lime sector aims to cover 100% of its kiln energy needs through alternative fuels. *This roadmap assumes a balanced fuel mix between biomass-derived fuels, hydrogen/ e-fuels and waste-derived fuels (non biomass).*

- Solid fossil fuels
- Natural gas
- Waste-derived fuels
- Biomass-derived fuels
- Green Hydrogen/ e-fuels

3 Emission mitigation technologies and techniques

3.3 Carbon Capture and Use or Storage (CCUS)



Emission mitigation potential

CCUS technologies offer an indispensable tool to mitigate CO_2 emissions from the lime sector, where ca. 69% of emitted CO_2 is unavoidably released by the chemical process (limestone decarbonation). Capture technologies on lime kilns should be available for industrial-scale deployment by the second half of the 2020's (estimated year of availability: 2025-2028). Their deployment will significantly enhance the total electricity consumption of the lime production process.

A technological capture rate of 90% of kiln CO_2 emissions is considered in the roadmap.

CO_2 utilisation is expected to represent a complement, not an alternative, to CO_2 storage as it is not expected to deliver emissions reductions on the same scale. Industrial clusters ('hubs for circularity') can provide local opportunities for CCU, where industrial CO_2 emitters, low-cost raw materials, affordable decarbonised electricity and market demand for generated products are all present.

3 Emission mitigation technologies and techniques

3.3 Carbon Capture and Use or Storage (CCUS)

Once captured and concentrated, the pure CO_2 can then be transported to an underground sequestration site (CCS) or used in other industrial process (CCU).

In the case of CCS, CO_2 is injected in deep underground layers of depleted oil and gas reservoirs or saline aquifers and safely stored, so that it does not contribute to climate change.

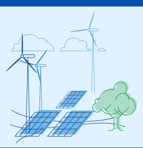
By 2030

The European lime sector envisages deploying carbon capture technologies for 5 to 10% of its direct kiln-related CO_2 emissions and to deliver these volumes for sequestration or utilisation.

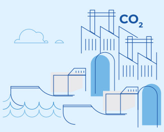
By 2050

As energy efficiency measures and cleaner energy only reduce CO_2 emissions from combustion, unavoidable process emissions from the decarbonation of limestone will be captured for use or storage by 2050.

PREREQUISITES (see section 7)



Access to decarbonised electricity



CO_2 transportation infrastructure

CO_2 permanent storage capacitiy

It is estimated that the total volume of captured CO_2 emissions from the lime sector will reach ca. 1,3 mio tons by 2030 and ca. 15,5 mio tons by 2050.

BECCS LIME KILNS AS ***CARBON REMOVAL BOOSTERS***

A lime kiln operating-partly or totally- with biomass fuels, from which CO_2 emissions are captured and permanently sequestrated or used, acts as an extremely effective 'carbon removal pump', drawing down historical CO_2 concentration from the atmosphere.

3 Emission mitigation technologies and techniques

3.4 Indirect emissions generated by electricity consumption (scope 2)

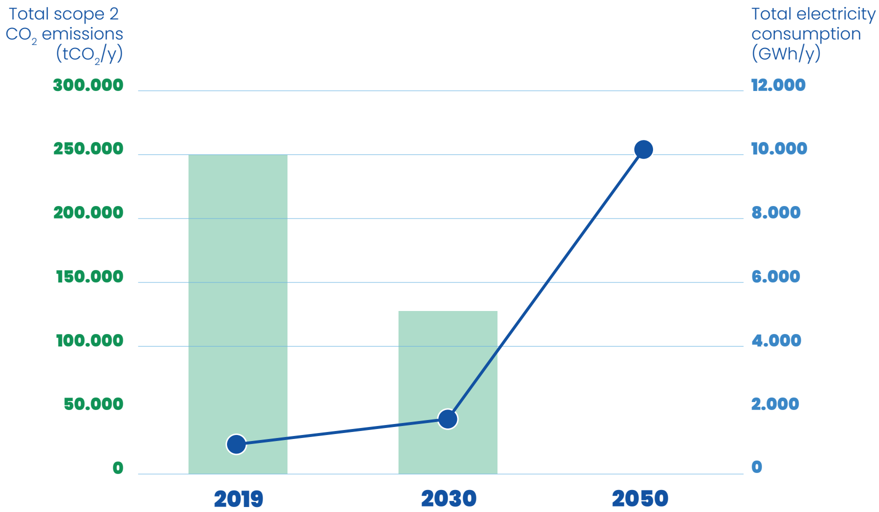
The relevant scope 2 emissions for the lime sector are **indirect emissions from the generation of purchased electricity, from utility providers.** The total electricity consumption of the lime sector in 2019 amounted to ca. 900 GWh, representing ca. 250.000 t of scope 2 CO_2 emissions.

Due to the progressive deployment of carbon capture technologies and – at a later stage – of electrified lime kiln technologies in the sector (according to the assumptions adopted in the present study), **the total electricity consumption is expected to increase by 80% by 2030 and to be multiplied by a factor 10 by 2050.**

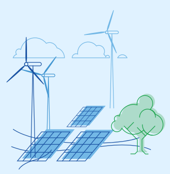
The impact on scope 2 CO_2 emissions is represented hereby, using EURELECTRIC emission factors related to average European electricity mix *(275g CO_2/kWh in 2019, 77g CO_2/kWh in 2030 and 0g CO_2/kWh in 2050).*

It is estimated that the deployment of carbon capture technologies in the lime industry will increase the total electricity consumption per ton of lime by a factor of around 10.

Given the European ambitions to have a 100% non-fossil energy mix in the EU, we assume that the scope 2 emissions of the lime sector will be 0% CO_2 by 2050. Lime operators continue to invest in auto production and renewable electricity sourcing (PPA).



PREREQUISITES (see section 7)



Access to decarbonised electricity

It is estimated that the total electricity consumption of the European lime sector will reach ca. 10 TeraWh (10^9 kWh) by 2050.

3 Emission mitigation technologies and techniques

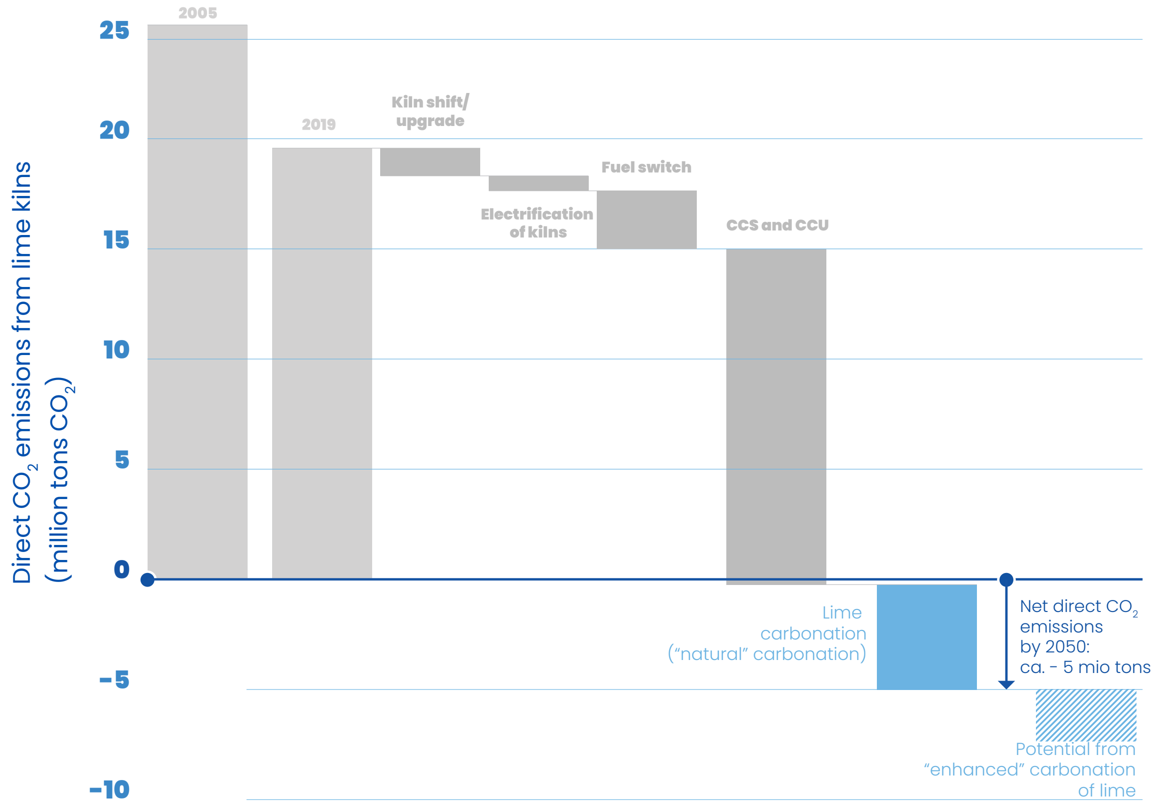
3.5 Material efficiency: optimisation of the use of lime products

1. Innovative specialty products	**Development of innovative specialty products enabling the reduction of specific dosage while delivering the same performance, notably:** • **High porous hydrated lime in flue gas cleaning:** use of high specific surface and high porous volume hydrated lime in dry treatment of flue gases allowing to significantly reduce both the consumption of lime and the associated residues after treatment compared to standard hydrated lime. • **Use of secondary raw material (vs. pure quicklime) in soil stabilization:** use of lime blended with recycled industrial byproducts containing lime and/or hydraulic or pozzolanic materials, reducing product carbon footprint as well as the overall environmental and technology footprint for earthworks.
2. Dosage optimisation through engagement with customers	**Engaging individually with customers to reduce specific lime dosage at customer's site, through tailored product specifications, optimised product handling and injection:** • **For lime usage in customer's core-business activity (e.g. steel industry):** significant specific dosage reduction rates were demonstrated. • **For lime usage in non-core business activities (e.g. flue gas cleaning):** higher potential for specific dosage reduction.

In all those initiatives, the objective of the lime supplier is to achieve a win-win solution with the end-user, considering the total cost of ownership for the lime functionality.

4 Lime as a carbon sink

4.1 Carbonation during industrial applications



Carbon removal potential

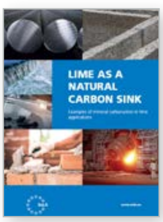
During the lifetime of products in which lime is applied, CO_2 from the atmosphere is captured, basically reversing the reaction in which lime is produced from limestone.

$$CaO + CO_2 = CaCO_3$$

Atmospheric CO_2 can undergo reactions with the lime itself or its derived compounds, ending up again in the formation of calcium carbonate $CaCO_3$.

The rate of carbonation in each specific application of lime and its permanence were recently assessed by a study of the Politecnico di Milano, which shows **that on average, 33% of the amount of process CO_2 emitted during lime production is permanently captured back in the use stage** (based on sales volumes per application in year 2018). 95% of the carbonation reactions occur within the first year.

The present roadmap deducts CO_2 volumes captured through natural (or "spontaneous") carbonation of lime from direct CO_2 emission volumes to assess **the net direct CO_2 footprint of the sector**.



Find out more about how lime is a natural carbon sink in the EuLA carbonation brochure.

4 Lime as a carbon sink

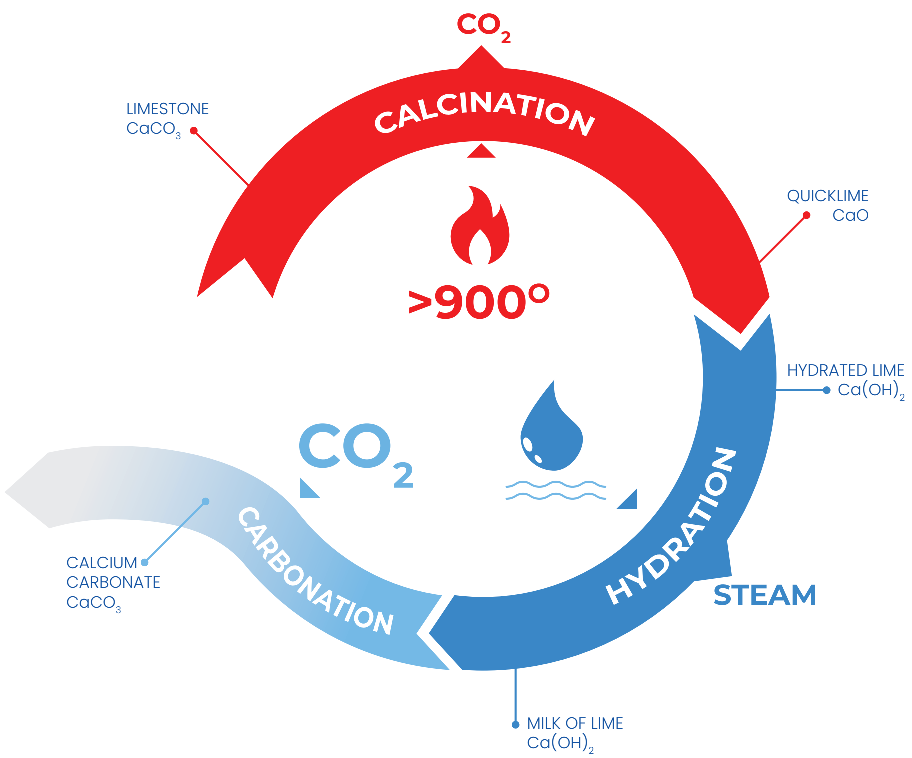
4.1 Carbonation during industrial applications

ENHANCED LIME CARBONATION: *COLLABORATION ALONG VALUE CHAINS*

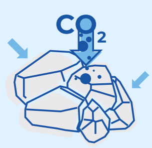
In some cases, it is possible to adjust how lime is used to maximise the carbonation rate. This is often best achieved by maximising the contact between lime and CO_2, in terms of surface area, CO_2 concentration, pressure and time.

This additional atmospheric carbon removal through 'enhanced lime carbonation' was estimated at 12% of process CO_2 emissions. Lime companies and associations are exploring these opportunities.

Through enhanced collaboration with lime users, this additional carbon removal potential can be fully unlocked by 2050. This potential is represented by a dotted area on our 'Pathway to negative emissions'.



PREREQUISITES (see section 7)



Recognition of CO_2 removal by lime carbonation.

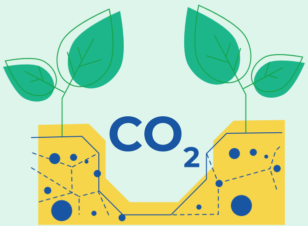
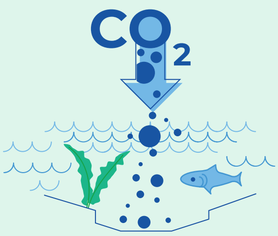
4 Lime as a carbon sink

4.2 Using lime for additional carbonation in nature

Description

Large-scale removal of CO_2 from the atmosphere will be needed to reach overall carbon neutrality, both to offset residual emissions and to address any climate 'overshoot'.

The expansion of nature-based carbon sinks (forests, oceans, soils) can play an important role as short-cycle removals, which can be rapidly scaled up in the near term. Thanks to its pH adjustment properties, lime can help enhance carbon removal by nature-based sinks, both for soils and oceans.

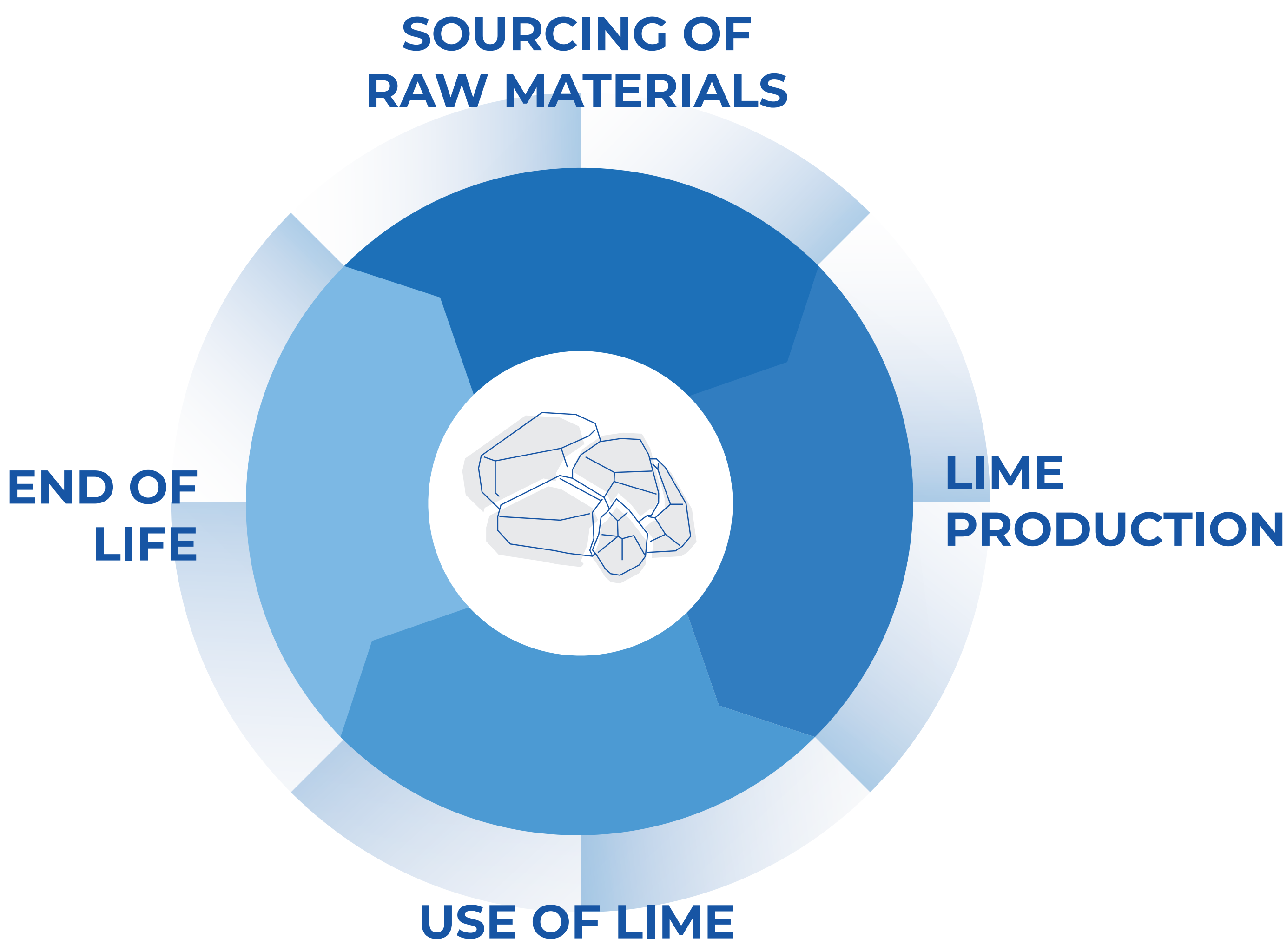
1. Soils: enhanced weathering	 **Spreading lime (as well as other minerals) on land** can result in the accelerated formation of stable carbonate from atmospheric CO_2. On agricultural lands, it also results in enhanced yields. This pathway is still at an early-stage of development and carbon removal estimates, as well as related costs, are still largely missing.
2. Oceans: alkalinisation	 **Ocean alkalinization involves adding alkaline substances to seawater** to enhance the ocean natural carbon sink. It removes CO_2 from the atmosphere through reactions converting dissolved CO_2 into stable bicarbonate/carbonate molecules, which in turn causes the ocean to absorb more CO_2 from the air. **Benefits and concerns:** on the one hand, ocean alkalinization would directly counteract ocean acidification, protecting marine ecosystems but, on the other hand, effects on ocean chemistry and marine ecosystems (especially local effects) remain uncertain and most approaches require large amounts of energy.

Carbon removal potential

The benefits and concerns related to both techniques are being explored. Enhanced weathering and ocean alkalinisation are still at their early stages of development. The European lime industry is following these developments and is committed to providing its contribution to the enhancement of nature-based carbon removal.

5 How lime enables a circular economy

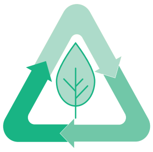
Key principles of circular economy are to maintain the value of products and materials for as long as possible, to minimise waste and to use products that reached their end of life to create further value. Moving towards a more circular economy contributes to mitigating CO_2 emissions. Following examples illustrate how lime enables a more circular use of resources, throughout its life-cycle.



MATERIAL EFFICIENCY AT EVERY STEP OF THE LIFE-CYCLE	The European lime industry maximizes the use of every ton of primary raw materials extracted from quarries. Material efficiency is being enhanced through innovative specialty products and through engagement with industrial customers resulting in lime dosage optimisation.
USE OF WASTE-DERIVED ENERGY RESOURCES	In lime kilns, the use of non-recyclable waste provides sustainable waste treatment solutions to local communities. It helps to reduce primary fuels consumption, as well as the average CO_2 emission factor per unit of energy. The switch to waste-derived fuels is a significant contributor to the decarbonisation of the lime industry.
USE OF WASTE-DERIVED MATERIAL RESOURCES	In soil stabilisation, the use of lime blended with recycled industrial byproducts reduces the product carbon footprint, as well as the overall environmental and technology footprint for earthworks.
USE OF LIME IN CIVIL ENGINEERING: TREATMENT AND REUSE OF POLLUTED SOILS	Soil treatment with lime is a technique where fine soils are mixed, in-situ, with lime in order to obtain flexible, permanent structural embankment layers for all types of road, highway and railway construction. The treatment of polluted soils by lime (avoiding leaching of contaminants) enables the reuse of local materials in infrastructure projects.
CIRCULARITY OF CARBON: CARBON CAPTURE AND USE	CO_2 captured from exhaust gases of lime kilns can be used as a valuable resource for the production of e-fuels, chemicals or building materials. In particular, the use of captured CO_2 for the carbonation of mineral waste (e.g. demolition waste, industrial residues) enhances their mechanical and durability properties for recycling in/as building materials.

6 Our policy recommendations

Five prerequisites to be met to allow the full contribution of the lime sector to a carbon neutral society



1. ACCESS TO ZERO-RATED BIOMASS, GREEN HYDROGEN AND WASTE DERIVED FUELS

Ensure availability and access to carbon neutral/low carbon energy vectors

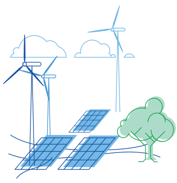
Affordable access to biomass-derived fuels, to hydrogen and e-fuels as energy vectors, as well as to related transportation infrastructure, must be guaranteed.

A lime kiln operating with biomass-derived fuels, from which CO_2 emissions are captured and permanently stored/used, acts as an effective 'carbon removal booster', drawing down CO_2 concentrations from the atmosphere. Biomass-derived energy resources should consequently be allocated in priority to the lime sector.

Mid to long term, synthetic fuels made from decarbonised electricity have a crucial role to play for the decarbonisation of processes where high energy density is required, notably the lime sector.

It is estimated that alternative fuels (carbon neutral and low carbon energy vectors) will represent 50% of the lime kilns fuel mix by 2030, i.e. 35 PetaJoules (10^{15}J) energy, and 100% of the lime kilns fuel mix by 2050, i.e. 60 PetaJoules.

This roadmap assumes that biomass-derived fuels, hydrogen/e-fuels and waste-derived fuels will each contribute by 2050 for 20 PetaJoules/year of energy input for lime production.



2. ACCESS TO DECARBONISED ELECTRICITY

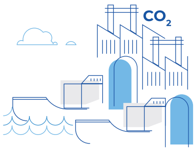
Ensure access to affordable carbon neutral electricity

The supply of large amounts of low carbon/carbon neutral electricity, at affordable prices, must be secured for European energy intensive industries. The transformation of the industry goes hand in hand with the decarbonisation of the power sector.

Many low carbon technological solutions result in large increases of electricity consumption: CCUS, production of hydrogen and e-fuels, electrified industrial thermal processes, electrified transportation, etc.

It is estimated that the total electricity consumption of the European lime sector will be multiplied by 10 between 2019 and 2050, reaching ca. 10 TeraWh (10^9 kWh) by 2050.

6 Our policy recommendations



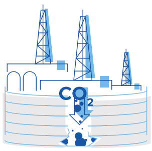
3. MULTI-MODAL CO_2 TRANSPORTATION INFRASTRUCTURE

Make CO_2 transport infrastructure available and accessible to all lime producers

Developing shared infrastructure for the transport (and intermediate storage) of CO_2 before sequestration or use (CCUS) should be a priority for public authorities and network operators.

Carbon capture technologies should be available for implementation in the lime sector from 2025-2028. The access to affordable CO_2 transportation, aggregation and intermediate storage facilities is crucial for in time deployment of carbon capture, also for continental production sites.

It is estimated that the total volume of captured CO_2 emissions from the lime sector will reach ca. 1,3 mio tons by 2030 and ca. 15,5 mio tons by 2050.



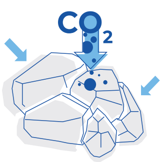
4. CO2 PERMANENT STORAGE AND UTILISATION CAPACITY

Ensure sufficient carbon storage (geological sequestration) capacities in Europe, offshore and onshore

Sufficient carbon storage (geological sequestration) capacities must be made available by the second half of 2020.

EU and Member States have an important role to play in providing an open and fair access to EU CO_2 storage capacities, **ensuring priority is given to unavoidable CO_2 process emissions from 'hard-to-abate' EU-based industrial sectors.**

It is estimated that the total volume of captured CO_2 emissions from the lime sector will reach ca. 1,3 mio tons by 2030 and ca. 15,5 mio tons by 2050.



5. RECOGNITION OF CO2 REMOVAL BY LIME CARBONATION

Account for carbonation of lime in emissions inventories

Lime captures atmospheric CO_2 during its use phase. The rate of carbonation in each specific application of lime and its permanence are important parameters in assessing the environmental benefits from this mechanism.

The overall carbon dioxide removal effect must be fully documented and recognised in CO_2 emissions accounting, emission inventories and carbon footprint methodologies.

Lime carbonation during its use phase, in its various applications, removes from the atmosphere the equivalent of 33% of initial CO_2 process emissions, generated during the lime production process. Through enhanced collaboration with lime users, an additional carbon removal potential of 12% can be fully unlocked by 2050.

7 Landmark CO_2 innovation projects

CO_2 capture and concentration technology is at the heart of our decarbonisation strategy. As an industry, EuLA recognizes that investing in CO_2 research and innovation is imperative to driving both the sector and the European economy forward.

The following pages provide an overview of some of the landmark CO_2 innovation projects ongoing across the European lime sector.

ENERGY MIX **HYDROGEN FUEL ENERGY INNOVATION** British Lime Association	This project aims **to use hydrogen as an alternative fuel** for lime manufacturing. The following challenges related to the conversion of different kiln types are notably addressed: • 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.
CARBON CAPTURE *Oxyfuel technologies* **BUTTERFLY PROJECT** Carmeuse	Butterfly is a collaborative project aiming at capturing and concentrating CO_2 directly in the lime manufacturing process. The construction of a first pilot lime kiln is in progress.

7 Landmark CO_2 innovation projects

CARBON CAPTURE ***Oxyfuel technologies*** **OXYFUEL LIME KILN** Singleton Birch	Oxyfuel Lime Kiln is a collaborative innovation project aiming at developing a new kiln based on oxyfuel calciner technology. The pilot plant started operating in the second half of 2022, progressively scaling up production up to >3000 tons lime/day.
CARBON CAPTURE ***Oxyfuel technologies*** **LEILAC I & II PROJECTS** Lhoist Tarmac	The LEILAC Project aims at developing an indirect heating technology for limestone. Fine limestone is introduced into a closed calciner, externally heated. Since the calcination and combustion gases are not mixed, this technology generates exhaust gases made up of almost 100% CO_2. The aim of the project is to develop in situ CO_2 capture process for lime/dolime and cement manufacturing.
CARBON CAPTURE ***End-of-pipe technologies*** **CO_2-SOLID BED REACTOR** BVK + consortium of lime producers	The project is based on the principle of pressure swing absorption and subsequent biological methanation (CCU) under industrial conditions (10% flue gas of a 200tons/day kiln). High purity CO_2 is separated by using a dolomite-based fixed bed reactor as looping method. CO_2 absorption is carried out at overpressure and calcination at negative pressure. CO_2 will be used in a biotransforming process to generate bio-methane.

7 Landmark CO_2 innovation projects

CARBON CAPTURE

End-of-pipe technologies

CRYOGENIC CARBON CAPTURE

Lhoist

This project targets the implementation of a cryogenic technology, aiming at capturing and purifying 95% of CO_2 emissions arising from a Lhoist production unit. The captured CO_2 would then be transported to a multimodal CO_2 export hub (under development) and sent for sequestration in the North Sea.

600 kt CO_2 emissions avoided/year

CARBON CAPTURE

Modular Membrane

Nordkalk

Each module will be able to capture up to 25% of Nordkalk's kiln process emissions. This is the first industrial scale facility of its type with the first module planned to be installed in 2023. A full roll-out plan will follow. In parallel, Nordkalk is also working on the entire carbon chain that includes not only capture and sequestration, but also uses and commercialisation of the captured CO_2.

Find out more about these projects and many more in the EuLA Innovation brochure.

7 Landmark CO_2 innovation projects

CCU ***e-fuels, chemicals, mineralisation*** **LOWCO$_2$** **Calcinor**	The LOWCO$_2$ project will develop and validate technologies of capture and valorisation of industrial CO_2. Several strategic innovations are piloted: new materials and processes for the capture of CO_2, technologies for the carbonation of residues improving their performances as raw materials for construction, 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 reducing operating costs.
CCU ***e-fuels and chemicals*** **POWER TO METHANE COLOMBUS PROJECT** **Carmeuse**	This CCU project will concentrate CO_2 from an innovative type of lime kiln and combine it with green hydrogen to produce synthetic methane that can be injected into the gas grid or used in the transport or industry sectors. The green hydrogen will be produced by a 100 MW electrolysis unit, powered by renewable electricity. **Up to 160 kt CO_2 emissions avoided/year**

7 Landmark CO_2 innovation projects

CCU ***mineralisation*** **MINERAL LOOP** **Carmeuse**	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. Innovative solutions in mineral waste pre-conditioning techniques will be developed together with carbonation reaction processes and post-treatment processes.
CCU ***mineralisation*** **CO_2ncrEAT** **Lhoist**	The CO_2ncrEAT project aims at utilising ca 12.000 tons/y of CO_2 captured from a lime kiln as feedstock for the production of construction blocks, incorporating residues from the stainless-steel industry. CO_2 transportation between the capture and utilization units will be achieved through pipelines. **20 kt CO_2 emissions avoided/year**

8 A pathway to negative emissions

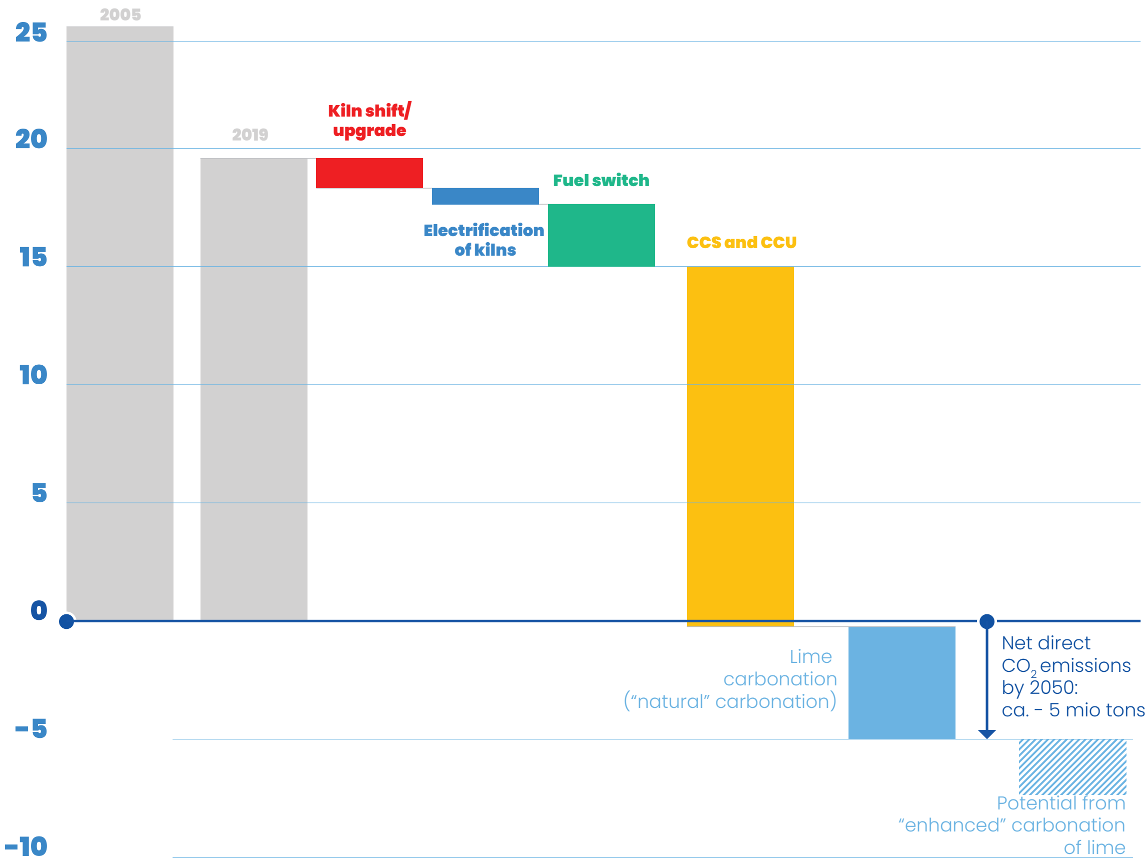
Assuming that the five prerequisites are satisfied, the European lime sector can contribute to a carbon-neutral Europe by delivering negative emissions, effectively removing carbon from the atmosphere.

Considered technologies and techniques are described under section 3 of the present document.

Throughout the coming years, the sector will further focus its innovation efforts on climate-related projects, so that key enabling technologies for further decarbonisation after 2030 are available in due time for industrial-scale deployment. We will also advocate for the policies identified in the roadmap as being essential prerequisites for delivering its full decarbonisation potential.

Between now and 2030, the European lime sector will activate levers which are currently available to mitigate its emissions, resulting in a reduction of scope 1 emissions of ca. 20% CO_2 (by 2030 versus 2019).

By 2050, it is estimated that the European lime sector could permanently remove ca. 5 million tons of CO_2 from the atmosphere per year (net negative emissions).



A pathway to negative CO_2 emissions by 2050

8 A pathway to negative emissions

The contribution of EuLA, its members and key stakeholders to the achievement of the EuLA pathway to negative emissions

As previously mentioned, **the EuLA "pathway to negative emissions" is a reference at European level.** It does not provide detailed instructions or guidance for the transition towards negative emissions, but it presents a clear direction for each company/country to find ways to deliver their contribution.

All EuLA members are committed to collectively delivering net negative emissions but will have to follow different pathways to contributing to this objective. The actual pathway for individual lime producers and countries/regions varies, as the local context around each of the production sites strongly influences both the emission mitigation potential and its modalities: applicable regulations, availability and access to specific energy carriers, access to enabling infrastructure, costs/benefits of the various decarbonisation technologies, etc.

All EuLA members and EuLA are committed to pursuing and - wherever needed - enhancing their Research & Innovation efforts related to decarbonisation technologies and techniques, so that these technologies are available for deployment in due time. Technological breakthrough must be achieved rapidly for successful industrial-scale pilots to be launched before a roll out across Europe's plants can be envisaged,

EuLA and its members call on policymakers, investors, researchers, innovators, equipment suppliers, customers and end-users to join the lime sector in its efforts and to ensure the right set of resources, infrastructure, tools and policies are in place to deliver net negative emissions across the lime life-cycle.

EuLA Climate Vision 2050:
"The European Lime Industry will be carbon negative by 2050"

By 2050, the European Lime Industry will be carbon negative.

This means that the European lime sector will *remove more CO_2 from the atmosphere* (through carbonation of lime during its use phase and through BECCS* deployment on lime kilns), ***than its own residual CO_2 emissions*** (after deployment of emission mitigation technologies and techniques in its production processes and value chains). All this is subject to the realisation of the five key perquisites.

Glossary

Key concepts

Biomass-derived fuels: the wording used in this roadmap for all renewable fuels of biological/biogenic origin (biofuels, bioliquids, biogas), produced from primary biomass resources or secondary (waste-derived) biomass resources.

Carbon Capture and Storage: the process of capturing carbon dioxide (CO_2) emissions from fossil power generation and industrial processes for storage deep underground.

Carbon neutrality: achieving a balance between CO_2 emissions and CO_2 removal from the atmosphere in carbon sinks. Carbon sink is any system that absorbs more carbon than it emits. The main natural carbon sinks are soil, forests and oceans. Lime itself acts as a carbon sink during its use phase, through its carbonation reaction with CO_2 from the atmosphere.

Carbon Capture Utilisation: refers to the process of capturing carbon dioxide to be recycled for further usage, such as building materials.

Lime: Lime, or calcium oxide (CaO), is derived from high quality natural deposits of limestone, or calcium carbonate ($CaCO_3$). Lime is produced when limestone is subjected to extreme heat, changing calcium carbonate to calcium oxide. Dolime is produced by heating (calcining) dolomitic limestone.

Lime carbonation: lime 'naturally' reverts to limestone by capturing ambient CO_2. This is called carbonation (or mineralisation by carbonation) and is essential to many uses of lime. For example, mortars containing lime capture CO_2 from the atmosphere, which reacts with free lime to produce calcium carbonate crystals and is responsible for hardening of lime mortars over time. The carbonation reaction is exothermal and therefore thermodynamically favorable. Lime carbonation can occur in natural conditions (i.e. under ambient carbon dioxide concentrations and under 'traditiona'l process conditions during use) and in enhanced conditions (i.e. under enhanced carbon dioxide concentrations and by optimising other parameters such as the temperature and the relative humidity). The routes for accelerating carbonation can be direct or indirect. In the direct process, carbonation occurs in a single step, while in the indirect one the lime is initially extracted from the mineral matrix and subsequently carbonated.

Material efficiency: products and services are produced and used in a way which minimizes total material inputs while negative environmental impacts are minimized during the life cycle.

Negative emissions (or carbon negativity): a 2050 objective used throughout this document with respect to the lime industry and its products. This objective relates to the mitigation of direct and indirect CO_2 emissions from lime production as well as to the removal of CO_2 from the atmosphere by carbonation of lime during its use phase. Offsetting measures such as planting of trees or other nature-based solutions are not included in the calculations to get to negative emissions.

Rotary kiln: kiln designed to calcine limestone in a rotating tube. It is the most flexible of any lime kilns able to produce a large variety of products but with a relatively high energy consumption.

Scope 1 emissions*: covers the Green House Gas (GHG) emissions that a company makes directly — for example while running its kilns and vehicles.

Scope 2 emissions*: These are the emissions it makes indirectly – like when the electricity or energy it buys for burning lime or cooling buildings, is being produced on its behalf.

Scope 3 emissions*: all the emissions associated that the organisation is indirectly responsible for, up and down its value chain. For example, from buying products from its suppliers, and from its products when customers use them.

Vertical kiln: shaft kiln were limestone is progressively decarbonized when going down the kiln. Very efficient kiln in term of energy consumption.

Waste-derived fuels: all fuels produced from household or industrial waste streams (with or without pretreatment steps) which are not from biogenic origin.

* World Resources Institute, 2001, 'The Greenhouse Gas Protocol.

Abbreviations

ASK: Annular shaft kilns

BECCS: Bioenergy carbon capture and storage

CCS: Carbon capture and storage

CCUS: Carbon capture utilisation and storage

CO_2: Carbon dioxide

E-fuels: Electrofuel

EuLA: European Lime Association

GHG: Greenhouse gas

IMA-Europe: Industrial Minerals Association

ILA: International Lime Association

LRK: Long rotary kilns

MFSK: Mixed feed shaft kilns

OK: Other kilns

PCBs: Polychlorinated biphenyls (industrial products or chemicals)

PFRK: Parallel flow regenerative kilns

PRK: Rotary kilns with preheater

R&I: Research and innovation

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