LIME
NATIONAL LIME ASSOCIATION

A ROADMAP TO CARBON NEUTRALITY FOR THE U.S. LIME INDUSTRY

FOREWORD

Lime is a vital product used in all aspects of our society, including purifying the air we breathe and the water we drink, as well as extensive use in manufacturing, construction, environmental protection, agriculture, and many other applications. The lime industry is committed to making the manufacturing and use of lime more sustainable, and to reduce the carbon footprint of the industry.

This document will explain what lime is, how it is made, and how it is important to the public and to the economy, and will set out the industry's plan of action for achieving carbon neutrality by 2050. It sets out the opportunities and challenges ahead for this effort and the need for cooperation of the industry, government entities, and other stakeholders, if the goals are to be achieved.

The National Lime Association is the trade association representing U.S. commercial manufacturers of high calcium quicklime, dolomitic quicklime, and hydrated lime (collectively referred to as "lime"). This document was prepared with the assistance of NLA's Sustainability Committee, with representatives from across the industry.

CONTENTS

1 WHAT'S IN THE ROADMAP?

The energy intensive nature of lime production and the chemical reactions that occur when the raw limestone materials are heated at high temperature produce emissions of carbon dioxide (CO_2) to the atmosphere. The lime industry is committed to reducing these emissions in response to the challenge of climate change. This Carbon Neutrality Roadmap shows the steps that the U.S. lime industry intends to take to achieve significant carbon reductions by 2050.

The roadmap highlights actions and investments to date that have resulted in reduction in CO_2 emissions and describes key approaches that can be used to decarbonize emissions from lime and dolomitic lime production in the U.S., including process optimization for improved energy efficiency, moving to less carbon-intensive fuels (such as natural gas or biofuels), reduction of indirect emissions (such as electricity use and transportation), carbon capture, utilization and storage (CCUS), use of nature-based solutions that will support carbon credits, and the recognition of the role of recarbonization through the use of lime products. Reaching decarbonization goals will require decisive steps by the industry as well as cooperation from government entities and others. These steps and the partnerships required are further explained in this roadmap.

2

WHAT IS THE U.S. LIME INDUSTRY?

In 2023 lime was produced at 45 active commercial lime plants in 21 states and Puerto Rico. Typically, lime plants are located near sources of the high-quality limestone required to produce lime products. The industry includes small businesses as well as large multinational corporations. In 2023, an estimated 17 million tons of quicklime and hydrated lime was produced, valued at approximately $2.3 billion. Lime production is currently rebounding from a pandemic-related decline, as the industries that use lime are also rebounding.

3

WHAT IS LIME AND HOW IS IT MADE?

Lime is a general term for several different lime products, including quicklime, dolomitic lime, and hydrated lime, which are produced by heating and calcining ***limestone***.

Limestone is a naturally occurring and abundant sedimentary rock consisting of calcium carbonate. Some forms of limestone also contain magnesium carbonate, which produces dolomitic lime. Lime production begins by mining limestone from surface quarries or underground mines.

After mining, limestone is fed into a crusher to break the rock into smaller, more manageable sizes. These smaller pieces of stone are the feed that is introduced into the ***lime kiln*** for heating.

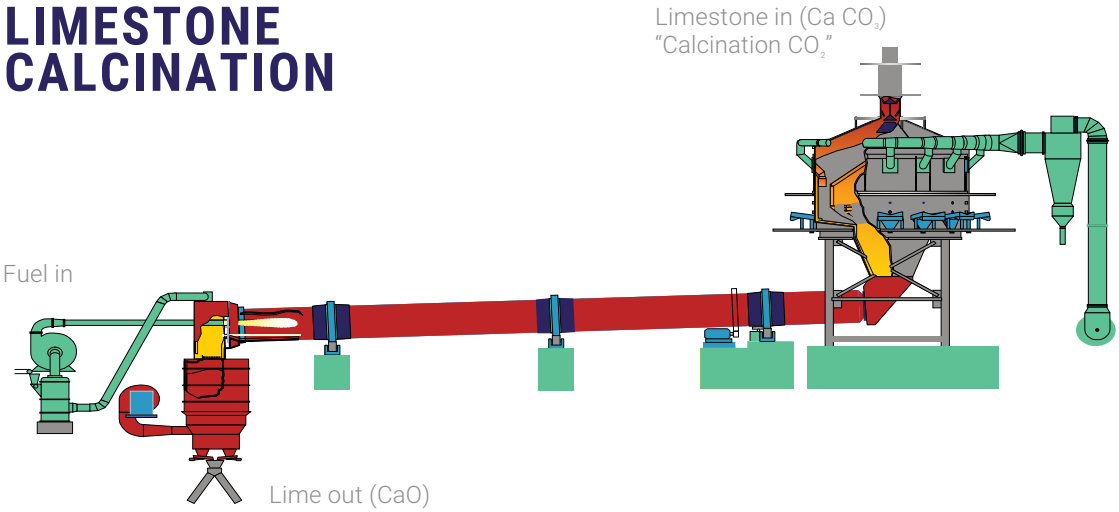
A lime kiln is a large, industrial furnace, and is typically either a rotating horizontal (or rotary) kiln, or an upright vertical kiln. The rotary kiln is the most common type of kiln found in the U.S. These kilns use fossil fuels with high heat content.

To convert limestone to lime, limestone must be heated to a temperature of approximately 1,600 degrees Fahrenheit in the kiln, which begins to convert the limestone (calcium carbonate or $CaCO_3$) into lime (calcium oxide or CaO), while releasing carbon dioxide (CO_2).

This process is called ***calcination***.

$$CaCO_3 + energy => CaO + CO_2$$

LIMESTONE CALCINATION



The lime that comes out of the kiln is typically in the form of "pebbles," which can be ground or milled into smaller pieces or a powder. When lime is made from limestone that contains a high proportion of magnesium carbonate in addition to calcium carbonate, the resulting product is known as ***dolomitic*** lime.

Lime can then either be delivered to the end user or transferred to a hydrating plant, where lime is reacted with water to produce ***hydrated*** or slaked lime.

LIMESTONE

HYDRATED LIME

PEBBLE QUICKLIME

DOLOMITIC LIME

4 HOW IS LIME USED?

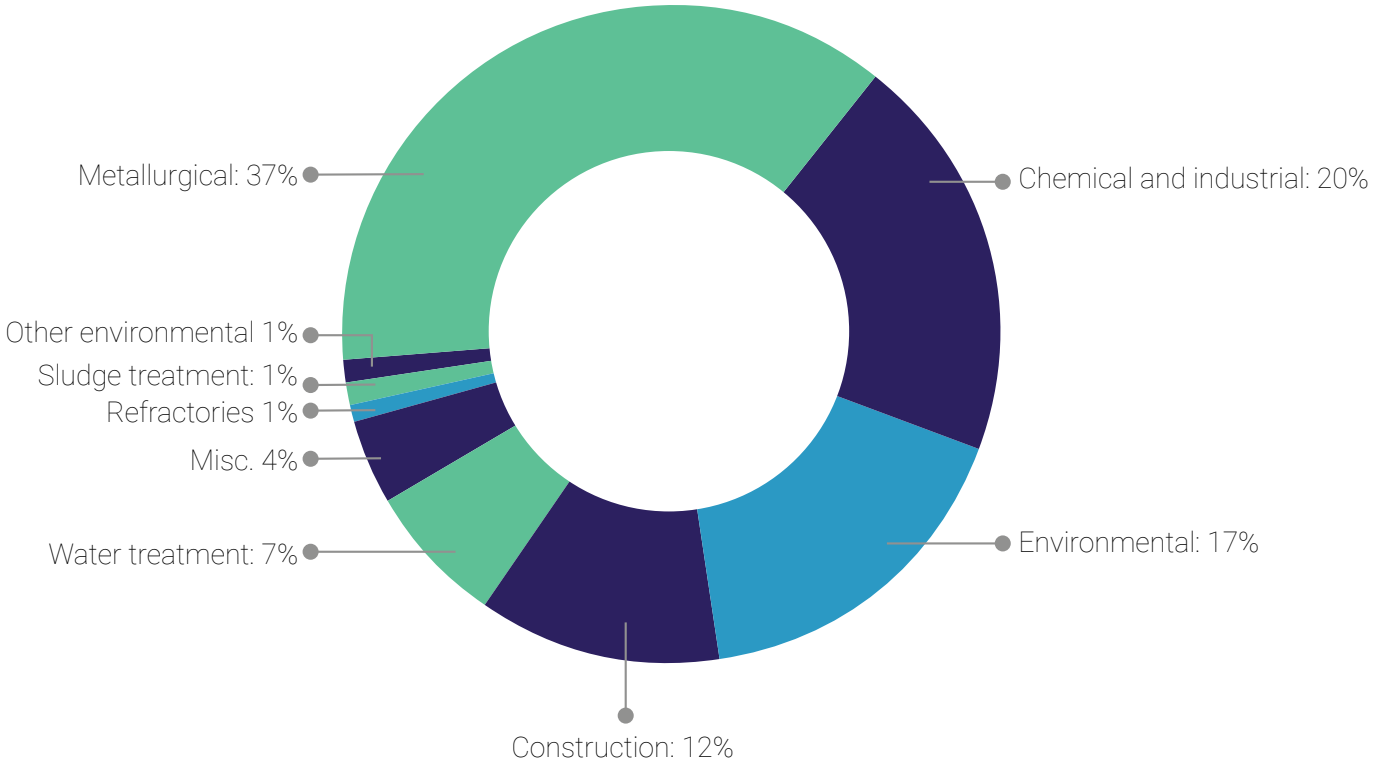
Lime is broadly used in modern society. Various forms of lime are used in environmental, metallurgical, construction, and chemical/ industrial applications, and more. The fastest growing use of lime is in environmental applications, where lime is used to purify air and water, and to comply with air, drinking water, wastewater, and solid waste regulations.

The largest single use of lime is in steel manufacturing, where it is used to remove impurities during the steelmaking process. In construction, the dominant use of lime is in soil stabilization for roads, earthen dams, airfields, and building foundations. Lime can be combined with certain additives to produce other materials and is also a key ingredient in mortar and plaster in lime slurry form. When added to asphalt, lime improves cohesion, reduces stripping, and improves paving longevity. There are numerous additional chemical

and industrial uses of lime, such as manufacturing chemicals and production of precipitated calcium carbonate (PCC) , as well as use in food production and agriculture. Many of the uses of lime will be essential to the transition to a greener economy, such as lime's role in treating contaminants at metal mines and neutralization of hazardous wastes.

Many of the applications of lime products cause them to be exposed to the atmosphere either immediately, or over a more extended period. When exposure to air occurs, the lime chemically reacts with CO_2 present in the atmosphere, permanently capturing it as the lime returns to a form of limestone.

Recent research indicates that across major lime product applications, as much as 29% of the total process CO_2 emitted during production is reabsorbed.



WHAT IS THE LIME INDUSTRY'S CARBON FOOTPRINT?

The lime industry faces a particular challenge in addressing greenhouse gas emissions, because of emissions of CO_2 (a greenhouse gas) from lime manufacturing processes. Lime is produced in large kilns that are primarily powered by fossil fuels, which produce CO_2 when combusted. The lime industry has long been working to increase energy efficiency, and while progress has been made in this area, efforts to do even more are continuing.

In addition to fuel-based emissions, however, the lime industry also generates CO_2 from the basic chemistry of its manufacturing process. When limestone (calcium carbonate) is heated in a kiln, the result is quicklime (calcium oxide) and CO_2. These "process emissions" or "calcination emissions" are inherent to the production of lime and cannot be altered through efficiency measures. As a result, these emissions cannot be addressed in the same manner as energy-related emissions but can be addressed by carbon capture, carbon utilization, carbon credits, or reabsorption.

6

WHAT IS THE LIME INDUSTRY'S COMMITMENT TO CARBON NEUTRALITY?

The lime industry has been working to reduce its carbon footprint for many years, including such early efforts as voluntary participation in the Department of Energy's Climate Vision program more than 20 years ago. These efforts have increased in recent years, with the formation of NLA's Sustainability Committee, and most recently in the summer of 2023, with the decision of NLA's Board of Directors to adopt a Carbon Neutrality Commitment and to develop this Roadmap. The Commitment is:

> The members of the lime industry represented by NLA commit to take actions to achieve carbon neutrality across the lime product value chain when technologically and economically feasible. The actions taken (including those listed elsewhere in this document) may vary across the industry, based on size of company, location of operations, product mix, and other factors, but all members pledge to use reasonable efforts to identify measures to reduce their carbon footprint. The industry believes that if the actions identified in this Roadmap are pursued, and if needed actions by federal and state government entities and other economic actors are taken, lime industry carbon neutrality can be achieved by 2050.

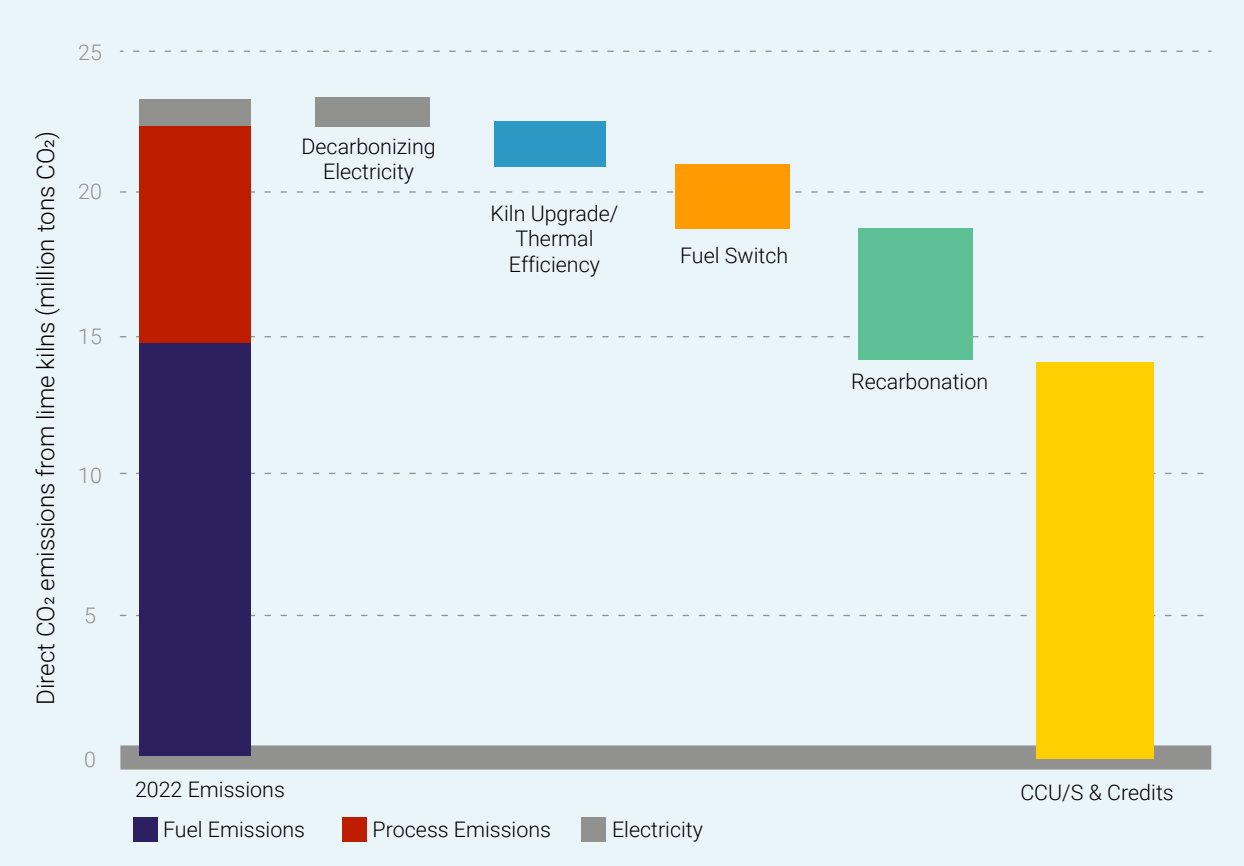
7

WHAT WILL THE LIME INDUSTRY DO TO FULFILL ITS COMMITMENT?

There are substantial differences among lime producers – some are small businesses that are family-owned operations with a single lime plant, and others are large multinational corporations with multiple lime plants in the U.S. and overseas. Some are located in very remote areas, and others are located in areas with more infrastructure and energy resources nearby (such as natural gas or CO_2 pipelines). These and other differences mean that not all lime plants will be able to use the same strategies to reduce their carbon footprints. As a result, the approaches described below must be considered as options available to lime plants, and not requirements prescribed for all lime plants.

There are four essential methods lime plants will use to reduce carbon footprint: (1) reducing carbon emissions from fuel consumption, by means of improved energy efficiency and/or use of lower carbon fuels (including innovative fuels such as hydrogen), (2) carbon capture, utilization and storage (CCUS), which in many cases will require new technology to generate CO_2 streams pure enough for capture and storage, (3) use of nature-based solutions resulting in high-quality certified carbon credits, such as protecting forests or planting trees or other plants to capture carbon, and (4) recognition of the role of recarbonization. These approaches are the tools that will lead the industry to carbon neutrality. The projected relative contributions to overall emissions reduction of each technology or technique are shown below.

EMISSION MITIGATION TECHNOLOGIES AND TECHNIQUES



8

HOW CAN CARBON EMISSIONS FROM FUEL CONSUMPTION BE REDUCED?

As noted above, lime manufacturing requires high energy in the form of heat, and today that heat is primarily provided by the combustion of fossil fuels, such as coal, petroleum coke, and natural gas. There are several approaches that lime producers are taking, and will take in the future, to reduce the carbon emissions from these fuels.

USE OF LESS CARBON-INTENSIVE FUELS

One option is to reduce carbon emissions by shifting from higher-carbon to lower-carbon fuels. Moving to different fuels generally requires substantial capital investments, such as new handling and storage facilities, and alterations to the manufacturing process.

Many lime plants can reduce fuel-related carbon emissions by switching from solid fuels (such as coal) to natural gas, but there can be significant obstacles to such a change, such as the availability of a natural gas pipeline in the area of the lime plant, and the need to make costly process changes. In addition, some lime plants, such as those making dolomitic lime, may not be able to achieve the necessary temperatures using natural gas.

Another potential fuel for use in lime kilns is biomass, composed of natural materials or byproducts. These fuels can produce carbon emissions, but because they are renewable (and absorb carbon when they are created), their use can be considered carbon-neutral. Because

of the variability of these materials, there can be significant technical challenges in using them as kiln fuels. Consistent sourcing of such materials can also be a challenge. Nevertheless, this is an option lime plants are pursuing.

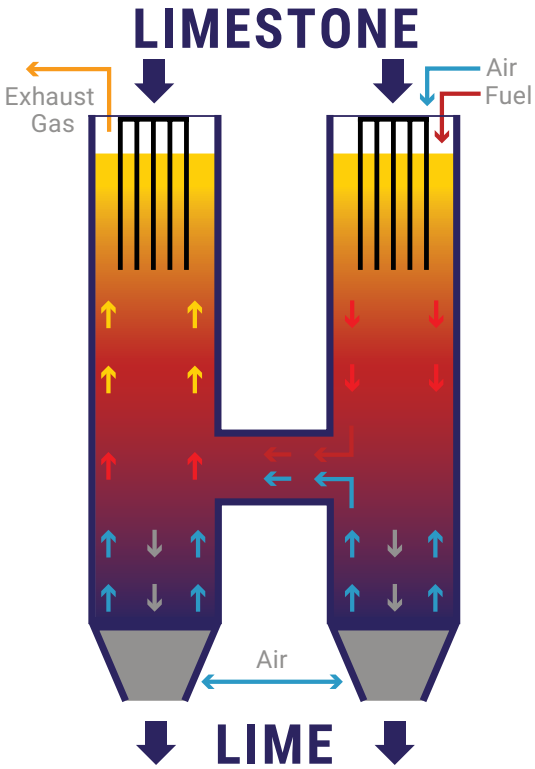
Lime companies are also investigating other potential fuels, such as hydrogen, biomethane, oxyfuels, waste fuels, and others. Some of these options will require entirely new kiln designs, meaning that significant investment will be needed if these methods are to be instrumental in achieving carbon neutrality.

KILN EFFICIENCY IMPROVEMENTS

Lime producers have long pursued efforts to make the manufacturing of lime more efficient, and many strides have been made in this area. These include improved operational controls, better control of the flame within the lime kiln, reduction of waste materials, improved insulation of the kiln to reduce heat loss, minimization of kiln downtime, and many more. These efforts will continue and efficiency will continue to improve.

In many plants, greater efficiency improvements have been obtained by replacement of current kilns with

new, more efficient kilns. Thus, for example, replacement of rotary kilns with vertical kilns improves efficiency, and the industry is also working with consultants and kiln manufactures to develop improved vertical kilns, such as parallel flow regenerative kilns (PFRK) that are even more efficient. However, replacement of a kiln is a multimillion-dollar project, and many less-efficient kilns still have many years of useful life before a replacement would be required in the normal course of business. Accelerated replacement will require assistance from government entities in the form or grants or loans in order to be practicable.



INDIRECT AND TRANSPORT EMISSIONS

Additional improvements in energy efficiency will be possible for the lime industry, but only with cooperation from other sectors of the economy. For example, the lime industry uses electricity in its operations (in addition to the fuel use described above). If the power grid is partially decarbonized, such as by moving to renewable energy sources, the energy used by the lime industry is correspondingly decarbonized. Similarly, the industry currently uses large fossil fuel-fired quarry vehicles and over-the-road trucks in making and distributing its products. To the extent those vehicles can be replaced by electric or other low-carbon emitting alternatives, the lime industry's carbon footprint may be further reduced. However,

appropriate alternatives will have to be readily available at a practicable cost, and government assistance will likely be needed in order to develop the appropriate technology and infrastructure and make it widely available.

OTHER EFFICIENCY MEASURES

Lime producers will continue to seek other creative methods of increasing the efficiency of lime plants. One possibility is to reuse excess heat from lime kilns for other purposes, such as heating buildings at the lime plant. Another approach is to increase the commercial use of lime kiln dust (LKD), which is a byproduct of lime manufacturing. LKD has multiple beneficial uses, such as use as a soil stabilizing agent. However, not all LKD is sold back into commerce, and a significant amount is landfilled each year. Further increasing use of LKD will lower the overall energy intensity of the lime industry.

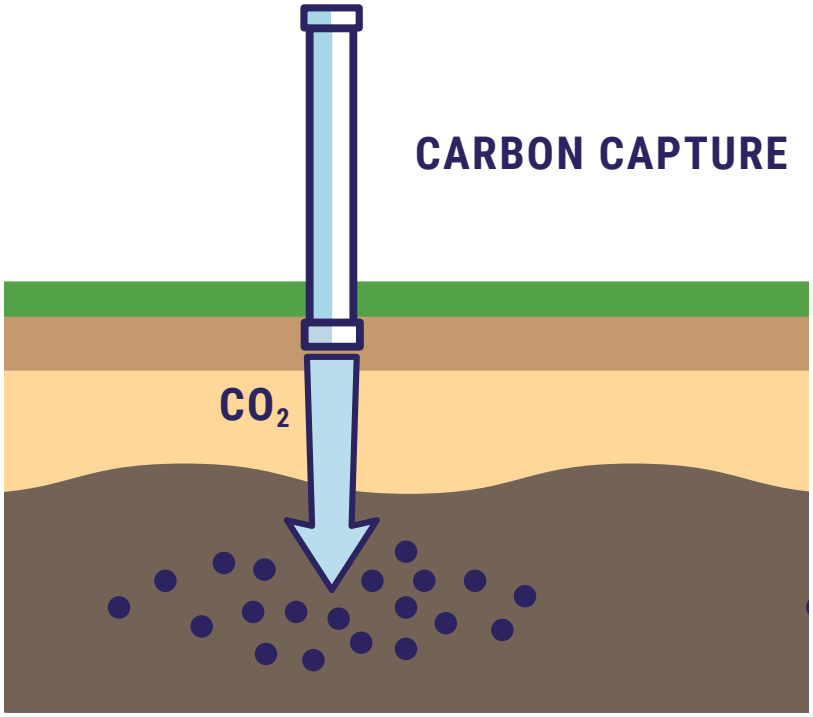
9

HOW CAN THE LIME INDUSTRY USE CARBON CAPTURE, UTILIZATION, AND STORAGE?

Carbon capture, utilization, and storage (CCUS) refers to methods of capturing carbon that is emitted from industrial operations, and either using it as a product, or permanently storing it, usually by injecting it into underground geological formations, such as deep underground layers of depleted oil and gas reservoirs or saline aquifers. Depending on plant locations in relation to suitable geologic formations and transport infrastructure, CCUS could provide an opportunity for lime producers to reduce carbon emissions, but many challenges must be addressed before this approach can be widely used.

The CO_2 emissions from lime plants typically include impurities at levels which do not allow the gas to be transported by pipeline, to be injected into geological formations, or to be used as a product. To address this issue, technology will be needed to purify the emissions after they leave the kiln, or new kiln designs will be needed to provide for more concentrated CO_2 emissions from the kiln itself. Kiln designs to achieve this goal are currently being studied by lime companies, in conjunction with consultants and kiln design and manufacturing firms. However, as noted above, construction of an entirely new lime kiln is a multimillion-dollar project, and it would require substantial investment from lime companies, with assistance from government, before such new construction could significantly impact the carbon footprint of the industry as a whole.

Even if CO_2 from a lime plant can be rendered sufficiently pure to allow it to be stored or used, difficult logistical challenges remain. First, there is the matter of scale—effective carbon storage will require substantial infrastructure investment, including pipeline systems and dedicated injection sites with associated monitoring and environmental controls. This will involve many more (and larger) industries than just the lime industry, with important roles to be played by government entities, including permitting, regulations, and grants. The success of CCUS for the lime industry also depends on the suitability and characteristics of geologic formations available to the lime plant.



Despite these challenges, NLA believes that carbon capture and storage will become more widely available in the coming years, as more of industry focuses on the issue and pools resources to solve the challenges involved. Carbon utilization will also play a role, but as a lesser component, because of limitations on the market for CO_2 in the economy.

Lime companies will pursue the potential of CCUS through research and investment. However, cooperation with government and wider industry will be needed if these techniques are to be effective in helping to achieve carbon neutrality.

10

HOW CAN THE LIME INDUSTRY USE CARBON CREDITS?

Another method of reducing the carbon footprint of an industry is to use high quality certified carbon credits derived from nature-based solutions. These solutions are investments in measures that reduce carbon emissions or absorb carbon outside the industrial process. For example, these investments could include reforestation, wilderness protection, some forms of agriculture, and assistance to other industries in which decarbonization might be achieved at a lesser cost.

Some NLA members have already invested in such projects, and more are planned.

For the use of carbon credits to be effective, it is essential that a program be in place to measure, certify, and account for the credits in connection with the regulation of greenhouse gas emissions from the industry. Thus, any program of regulation of greenhouse gases by the federal government or by the states must include a robust carbon credit program giving full recognition of nature-based and related solutions.

11

WHAT IS REABSORPTION AND HOW DOES IT AFFECT THE LIME CARBON FOOTPRINT?

A substantial amount of the carbon emitted in the manufacture of lime products is reabsorbed by those products when they are used, and afterwards. As noted above, when lime products are exposed to the atmosphere during or after use, lime chemically reacts with CO_2 present in the atmosphere, permanently capturing it as the lime returns to a form of limestone. Recent research indicates that across major lime product applications, as much as 29% of the total process CO_2 emitted during production is reabsorbed.

This means that when calculating the carbon footprint of the lime industry, it is necessary to correct the emissions data by subtracting the amount shown to be reabsorbed. This correction must be a part of any regulatory approach that accounts for lime industry emissions and credits.

12

WHAT ARE LIME COMPANIES DOING TO REDUCE CARBON FOOTPRINT?

Many lime companies have already taken positive steps to reduce their carbon footprints, and many more such steps are planned.

For example, several NLA member companies are actively engaged in kiln upgrade and replacement projects. MLC in 2022 acquired an existing lime operation in Bonne Terre Missouri, where it will install a new state-of-the art lime kiln. The kiln is being designed with sustainability as a priority, and will significantly reduce air emissions and improve efficiency at the location.

Another NLA member, Lhoist North America, is pursuing a long-term project of replacing less efficient lime kilns with Parallel Flow Regenerative Kilns (PFRKs). These highly efficient kilns consist of two vertical shafts that alternate between a burning and a preheating, allowing for energy efficient output and increased productivity. Lhoist is already operating PFRKs in overseas locations, and is pursuing conversions at its North American locations.

Lime companies have also taken measures outside lime plant operations. One NLA member

company, Graymont, has created a community-centered Carbon Reduction Fund (GCRF) which focuses on collaborating with local partners to protect the environment through the responsible use of resources; reduce carbon footprint through increased energy efficiency; and develop and maintain natural, biological 'carbon sinks', such as agricultural land, forests or peat bogs that act as natural offsets for carbon.

During the initial year of the GCRF program in 2022, Graymont awarded funding for various projects proposed by constituent communities across North America, from rejuvenating and improving aging local infrastructure such as fairgrounds and hockey rinks to providing solar power to greenhouses and expanding community gardens - all of which share the underlying goals of protecting the environment and achieving increased energy efficiency.

13

WHAT IS NEEDED FOR SUCCESS?

For the lime industry to successfully meet its neutrality goal, the industry and others will need to take decisive steps, as described below.

FULL COMMITMENT BY THE LIME INDUSTRY

The lime industry recognizes that success will require full commitment by the entire lime industry, and a willingness to do what it takes to meet the goal. The industry has taken the first step by signing on to the carbon neutrality commitment printed above, and by endorsing this Roadmap.

EFFECTIVE ADVOCACY

Success will also require effective advocacy by the lime industry and its partners in other industries on legislation, regulation, government investments, and public-private partnerships, in order to create a legal and regulatory environment in which effective steps are supported.

LEGISLATION AND REGULATION

Federal and state governments will need to work together with industry and other stakeholders to provide clear and stable climate change policies that will allow industry to make long-term investments into the carbon strategies outlined in this Roadmap. This includes ensuring that projects can be permitted in a reasonable amount of time, that fair and reasonable benchmarks are set for lime, that the differences between energy-related and process emissions are understood and reflected in regulations, that proper credit will be given for nature-based solutions and recarbonization, and that carbon capture, utilization and storage is preserved as an

appropriate means of addressing carbon.

Regulations must also ensure that there is a level playing field for industry internationally. The lime industry is "energy-intensive/ trade-exposed," which means that if restrictions imposed on the industry are too costly, it could be subject to unfair competition from lime imports from countries with weaker restrictions. This not only hurts US business but results in higher carbon emissions overall. Legislation and regulations must consider and have provisions for impacts on energy-intensive trade-exposed industries to avoid this so-called carbon "leakage" through imports, such as a Carbon Border Adjustment Mechanism (CBAM). In addition, incentives for carbon reduction can be enhanced if there are opportunities for energy-intensive industries to generate tradeable carbon credits through emissions reductions.

NLA recommends that any greenhouse gas emissions regulatory program include, at a minimum, the following elements:

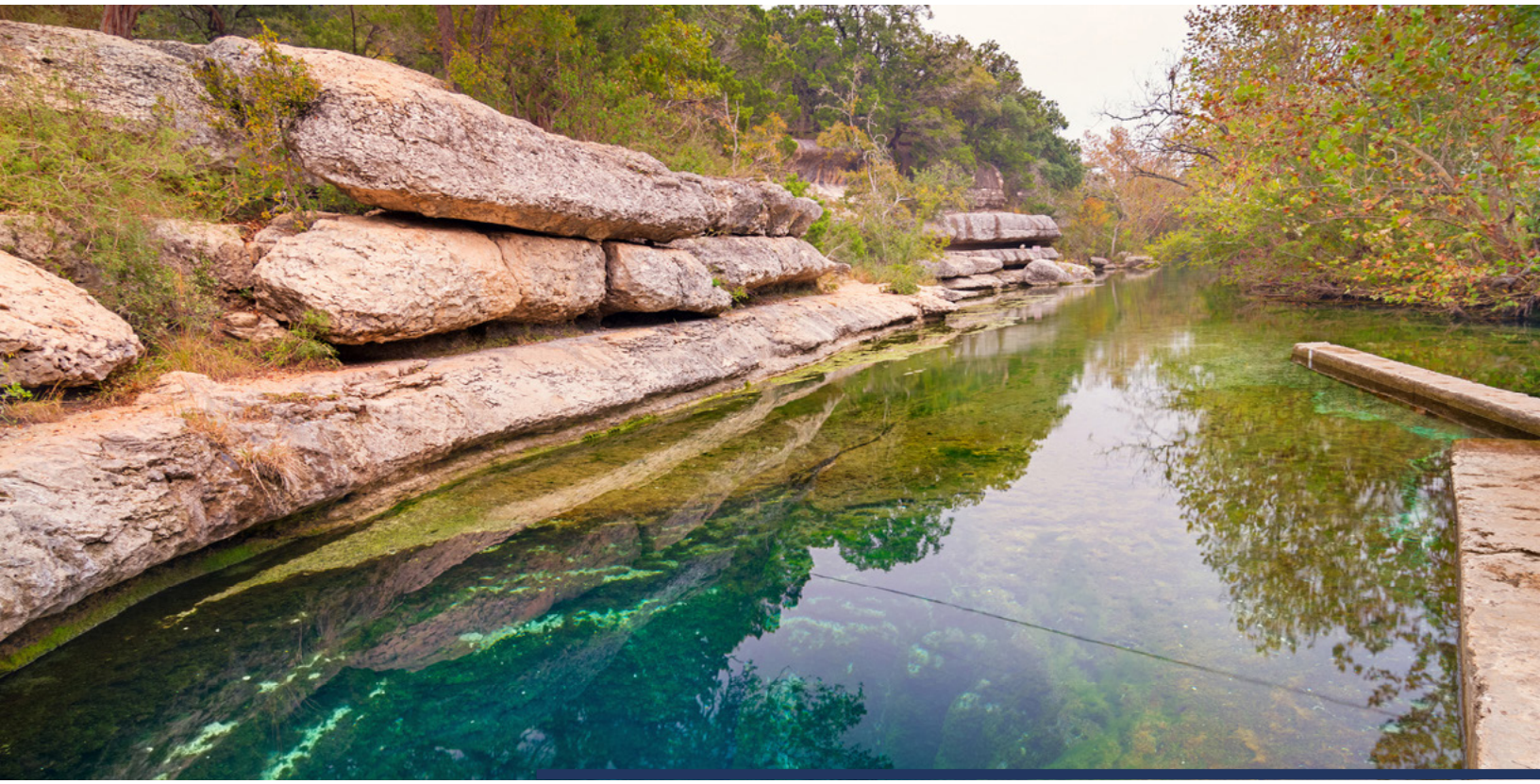
1. A fair method of measuring emissions and carbon credits;
2. Recognition of carbon capture, utilization, and storage (CCUS);
3. Support for CCUS infrastructure, including transport;
4. Recognition of and credit for recarbonization of lime products;
5. Recognition that process (calcination) emissions cannot be regulated in the same manner as energy-related emissions;
6. Support for development and use of alternative fuels;
7. Recognition of biomass fuels as carbon-neutral;
8. Protection of energy-intensive trade exposed industries through carbon border adjustment; and
9. Support for incentives for the creation of tradeable carbon emission credits.

INVESTMENT

Success will also depend on a commitment to invest the funds, time, and other resources necessary to make carbon neutrality a reality. This commitment will be needed from the lime industry, but also from government and other sectors of the economy.

There will need to be substantial investment in infrastructure, especially to make transport and storage of CO_2 possible across the United States. There will also need to be investment in new technologies, including kiln design, CO_2 purification, electrification of mine and other vehicles, effective use of biomass fuel, innovative fuels such as hydrogen and oxyfuels, and more.

The lime industry is prepared to do its part to invest in these developments, but will also look to government and other economic actors for opportunities to partner and to cost-share where possible, including grants, loans, private-public partnerships, and other methods of cooperating on these important goals.



14

WHAT'S NEXT?

Achieving carbon neutrality by 2050 is a worthy, but challenging, goal for the lime industry. NLA's Board of Directors and member companies are committed to pursuing the steps necessary to achieve the goal and will continue to assist the industry in developing industry-wide approaches and in pursuing advocacy on climate issues. The lime producing members of NLA will continue to take steps to use the options laid out in this roadmap to reduce their own carbon footprints. With the assistance of partners in government and other economic sectors, the lime industry looks forward to meeting this important goal.

For more information, please visit www.lime.org.

Lime is used to soften and purify drinking water—just one of the many uses of lime.