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Introduction

Chairman Markey and Members of the Committee, first, I would like say that I admire this Committee's vision and foresight in advancing solutions to climate change. Thank you for inviting me to testify on a carbon-mitigation sector that has been mischaracterized as "unproven" and "early stage", when in fact just the opposite is true: The conversion of carbon dioxide (CO_2) to mineral form for beneficial reuse has been practiced for over a century. It is one of the most common and important industrial processes now being applied to CO_2 sequestration, which I believe holds tremendous promise. CO_2 has been consumed to precipitate mineralized carbonates for inclusion in most common products we use every day, including the paper you're reading right now. Conversion of CO_2 to mineralized carbonates is broad in scope and represents a very large number of commercial enterprises, from the theoretical to the very mature and highly developed. Unfortunately, legislators have characterized all of these technologies as early stage and unproven.

This hearing comes at a critical time: Congress is debating climate change legislation; the President has promised a green energy policy that helps not hurts our economy; and almost 200 countries are preparing for the Copenhagen international climate change discussions. As these and other political decisions unfold against the backdrop of a global economic crisis, we must develop a broad array of cost-effective and preferably profitable methods to mitigate the release of CO_2 into the atmosphere.

My name is Brent Constantz, and I am the Chief Executive Officer of Calera Corporation, based in Los Gatos, California. Over the past 20 years, I have built three successful Silicon Valley companies based on innovative mineralization technologies, covered by approximately 70 issued U.S. patents I hold in this area. Additionally, I am a Consulting Professor at Stanford University, where my teaching and research are focused on carbonate mineral formation and global carbon balance.

My goal today is to urge Congress to think broadly in terms of the carbon capture and sequestration (CCS) technologies it supports to take full advantage of the opportunities these technologies can offer. The monies authorized and appropriated in past legislation need to be made available to promising technologies, and not reserved entirely for one concept, as is now the case. Past legislation has focused nearly entirely on the concept of geologic sequestration: chemical separation of CO_2 followed by injection into underground caverns or saline aquifers. Processes such as Calera's, based on CO_2 capture and conversion to carbonate minerals, have been denied access to tens of billions of dollars in grants, guaranteed loans, and tax incentives legislated exclusively for geologic sequestration.

Today, I call on this Committee to lead the way to making federal funds previously available for geologic sequestration *also available for alternative forms of capture and conversion* — as authorized under the *American Recovery and Reinvestment Act of 2009* (P.L. 111-5), the *Energy Independence and Security Act of 2007* (P.L. 110-140), the *Energy Policy Act of 2005* (P.L. 109-58) and related regulations, as well as the Climate Bill now under debate in the Senate.

It is not enough to simply provide money in new legislation for these technologies. The scope of the CO_2 problem and the rapidity with which mineralization processes can be scaled requires that money already authorized and appropriated be made immediately available to help fund multiple demonstration facilities in the 10MW to 80 MW scale. If we want to solve the climate-change problem, the U.S. Government must allocate resources in the timeliest manner to promising, potentially scalable technologies, and help bring them to the commercial scale that can provide significant reductions in greenhouse gas emissions.

My testimony will give you an overview of Calera and our CO_2-conversion technology; how it is possible to beneficially reuse CO_2 when it is converted to a mineral form; how our technology compares with other CO_2-capture options; and the commercial potential of beneficial CO_2 reuse. Finally, I will conclude with recommendations that not only align with this Committee's demonstrated commitment to CCS, but also help move beneficial CO_2-reuse technologies such as Calera's from pilot-scale to global innovation, thereby fostering other technologies that may be alternative or complementary to CO_2 separation and geologic sequestration.

Calera Corporation

Calera was founded with a promising vision to reverse global warming and ocean acidification by adapting and commercializing one of nature's oldest processes: carbonate mineralization. The precipitation of carbonate minerals by consuming CO_2 in aqueous solution is one of the oldest extraordinarily well proven industrial processes, as well as one of the most common. Products from this process are used in everything from paper to plastic, from milkshakes to wallboard. Calera has developed a transformational technology that converts CO_2 into green building materials like cement and aggregate. The process captures CO_2 emissions from power-plant flue gas, industrial smelters, refineries and cement manufacturing, and chemically combines it with a variety of natural dissolved minerals, water and solid waste materials to produce cementitious materials, aggregate and other related building material components. Thus, the process is more than CO_2 sequestration — it represents *permanent CO_2 conversion* from gas to solid mineral. The current market demand for these building materials is over *3 billion tons per year* in the US alone and over *30 billion tons per year* worldwide. This process has the potential to provide a positive use of the overwhelming majority of U.S. coal-fired power generation of CO_2 emissions.

Calera is backed by Khosla Ventures, a well-regarded venture capital firm specializing in "green" technology. With Mr. Vinod Khosla as a partner in this effort, Calera has been able to engage a formidable team of scientists and engineers to move beyond the laboratory and bench-scale research. We currently operate a continuous pilot facility that captures and converts CO_2 that we generate from burning 1 million BTUs per hour of coal. The facility is adjacent to a 1000 MW power plant in Moss Landing, California, on the coast of Monterey Bay. The continuous pilot facility allows us to test our technology with coals and fly ash from potential sites. We will soon be constructing a facility that scales our carbon capture and conversion technology to a 20MW scale. Located at Moss Landing, this facility will be operational in 2010, and it will make the step to a fully commercial facility relatively straightforward.

In less than a year Calera has grown from 12 to more than 80 employees, including more than 20 PhDs. Additionally, our pilot facility in Moss Landing is staffed with another 25 employees. Our senior executives possess hundreds of years of combined experience in power, water, environment, cement and concrete. Our technical staff holds well more than 100 U.S. patents, and our team of in-house patent attorneys and agents are filing patents on innovative ideas at the rate of one every day. Khosla Ventures has continued to provide the financing necessary for our growth and development.

But we have many milestones ahead to reach commercial scale, particularly in this difficult economic climate. Government support is necessary at this stage of development for demonstration facilities and early deployment in commercial plants. Coupled with commercial partner investment, this support will make the financial hurdle of financing these first scaled plants possible. Government policies that are directed toward mitigating carbon and stimulating the economy by the best available approaches will enable substantial progress for the profitable, beneficial reuse of CO_2.

Level the Playing Field for New Technologies:
Accurate Assessment of the Development State of Available Methods

The two primary methods for removing CO_2 from flue gases are 'purification via separation' vs. 'conversion to carbonate'. The first is energy intensive and costly and has not been proven for carbon sequestration (except in pending legislation), while the second consumes little energy, is inexpensive and is highly proven and dependable. I would like to underscore that CO_2 mitigation technologies are evolving rapidly. Calera is one of several companies focused on CO_2 conversion technologies with the potential for beneficial reuse. Yet, despite the promise of these technologies, funding for carbon mitigation has been narrowly focused on CO_2 separation and purification for geologic sequestration — a technology that is early-stage, unproven, and has never been demonstrated at any scale, and fraught with uncertainty and risk.

At best case, even if the technical challenges could be solved, which could take decades, CO_2 separation and purification for geologic sequestration would be economically infeasible for industry and will always require government funding. Despite the slim odds, the current legislative focus is proscriptive toward this one method, assuring that carbon reduction dollars will be directed only towards this method's narrowly defined pool of projects in hopes of making geologic CO_2-sequestration a viable option. This is especially vexing, considering that the Calera process and comparable CO_2-capture technologies largely avoid the economic burden, carbon balance, risk and permitting constraints that accompany geologic CO_2-sequestration.

We submit that taxpayer support and funding should be based on carbon reduction outcomes and seek to advance the most effective technologies. While CO_2 separation and purification for geologic sequestration is unproven and carries substantial and multiple formidable risks, it is still one important potential method in the carbon-capture toolbox. But we need to consider all of the potential solutions to address the volume of CO_2 at issue. Broad statutory language and corresponding federal funding are needed that encourage innovation, and rewards breakthrough technologies consistent with our goals as a free-market nation. The methods we implement should be selected by how we best arrive at the desired outcome, and not constrained to any one particular method for CO_2 mitigation.

I will come back to the crucial point of how the federal government can level the playing field for other technologies after providing you with an overview of Calera's CO_2-conversion technology.

The Calera Process: CMAP Technology and Low-Voltage Base Production

Calera's technology is called *Carbonate Mineralization by Aqueous Precipitation (CMAP).* The Calera process is unique in how it essentially mimics the natural carbonate mineralization of corals when making their external skeleton. This technology captures CO_2 emissions by converting CO_2 to CO_3 (carbonate) and effectively storing it in a stable mineral form. This mineral can then be used to replace or supplement traditional portland cement, offsetting emissions that would otherwise result from the CO_2-intensive manufacture of conventional cement.

The biggest hurdle to the mineralization concepts studied has been high-energy demand or extremely slow rates of reaction occurring over geologic timeframes. Calera's CMAP bypasses the limitations of previous mineralization approaches, but it has not been broadly pursued in the past due to the requirement for sustainable, unlimited chemical-base sources. Amongst the many technologies now possible are novel base-production methods that are low in cost, energy, and carbon footprint. These Calera innovations — fully described in many USPTO patent applications as well as three issued patents — revolutionize the technical feasibility, carbon-mass balance and economics of carbonate mineralization for CO_2 capture and conversion via aqueous mineralization.

Calera's mineralization process utilizes break-through, low-voltage chemical base-production technology that makes the conversion from CO2 to carbonate cost-effective and sustainable. Using approximately one-fifth the voltage of conventional base-production processes, Calera's base production has a very low carbon-footprint and is an alternative to natural or waste sources of chemical base. Therefore, the process can occur irrespective of any specific site location. Extensive mass and energy balance studies performed at Calera's continuous pilot plant indicate that parasitic loads on host power plants (the electricity used to run these processes that can't be sold elsewhere) where CO_2 is captured and converted to carbonate will be less than 20% — in many cases as low as 6%! This compares to a thermodynamic floor on parasitic load of 25% for the current state-of-the-art in carbon separation technology, based on a recently published Harvard study. This does not even include the need for sulfur compound control, which send the parasitic load of these technologies even higher.

Calera's technology uses aqueous minerals and CO_2 from power plant flue gas. The CO_2 in the flue gas is dissolved in a reactor, where it becomes carbonic acid converted to carbonate ions that form a slurry containing the suspended mineral carbonates. A solid-liquid separation and dewatering step results in a pumpable suspension. Calera employs spray dryers that utilize the heat in the flue gas to dry the pumpable suspension. Once dried, the Calera cement looks like white chalk and can be blended with rock and other material to make concrete. A graphic illustration of this process is attached.

Once it is hydrated, Calera's carbonate mineral cement behaves like traditional portland cement, and it can be used as a supplementary cementitious material to replace portland cement at various levels. A 20%-50% replacement has been tested extensively against ASTM C 1157 concrete specifications. Based on worldwide production estimates, approximately 1.5 billion tons of portland cement could be substituted with carbonate cement, and another 30 billion tons of aggregate used in concrete, asphalt, and road base could be substituted — each ton of carbonate aggregate and cement containing one half-ton of CO_2. Thus, some16 billion tons of CO_2 could be permanently converted to CO_3 per year on an ongoing basis – with not only lower cost than other means, but with the potential for significant profit in view of active carbon markets. The Calera product would be stable for geologic time frames, as published by National Energy Technology Laboratories, Albany Research Center, and Los Alamos National Laboratory.

The Department of Energy, the National Energy Technology Labs, and several academic institutions in the United States and other countries have evaluated several methods for accelerating the natural chemical weathering of minerals to produce carbonate minerals. Research has focused both on aboveground conversion of CO_2 to carbonate minerals, and the potential for carbonate conversion belowground in brine reservoirs, or at geologic sequestration injection sites. These investigations began in the mid-1980s with Reddy's investigation of techniques to accelerate the natural mineral carbonation process.

Since then, there have been many well known scientists working in this study area: Herzog at MIT, Halevy and Schrag at Harvard, O'Connor, researchers at the National Energy Technology Laboratory in Albany, and others, active in mineralization research. The focus of this research was testing of various base materials, reducing the massive energy consumption in the processing of these materials, and acceleration of the reaction rates. Current research has moved toward carbonation of coal-combustion fly ash and accelerated dissolution techniques of magnesium- and iron-rich silicates (so-called mafic minerals) used in carbonation processes.

Cost-efficiency

Every carbon-capture technology struggles with the issue of cost. The economic viability of our carbonate mineralization business model is significantly enhanced by the ability to sell captured-and-converted-CO_2 building materials into large end-markets. For each ton of CO_2 captured, about two tons of building material can be produced. This process provides the opportunity to transform an environmental liability into a profit center. The market for these newly created materials can be significant. Based on USGS data showing worldwide annual cement consumption of 2.9 billion tons, approximately 12.5 billion tons of concrete are used yearly. Additional aggregate usage for asphalt and road base nearly triples the potential for storing this captured CO_2.

Test data has shown that we can capture and convert CO_2 at 90%+ efficiency with our current absorption configuration on flue gas typical of coal fired utility boilers (about 10%-15% CO_2). We have higher capture efficiencies for other industrial combustion sources, with higher concentrations of CO_2 such as cement kilns (about 20%-40% CO_2) and refinery operations (about 95%-100% CO_2). In addition to our high-capture efficiencies, we produce materials that offset other products that have large carbon emissions such as cement. When we include the "avoided" CO_2 of our capture and conversion into materials, this results in CO_2 efficiency greater than 100%.

We believe our CMAP technology can be cost-competitive and economically sustainable. Particularly advantageous as compared to traditional CCS methods, our conversion technology does not require CO_2 separation, which can be more energy, cost and carbon-intensive as the CO_2 gas becomes more dilute or compressed. Separating CO_2 emission from dilute streams, such as a coal-fired plant or a cement plant, is far more difficult than from a refinery that is almost pure CO_2, and in all cases is much more carbon intensive and expensive than conversion to carbonate. In addition, our process does not require transportation, injection, storage or monitoring. Rather than billions of dollars of pipelines for high-pressure liquid CO_2 transport, the only transportation infrastructure required will be additional rail spurs, material storage and loading facilities at each plant — a substantial reduction in the nation's investment in climate mitigation. Finally, it is important to keep in mind that as our plants grow and scale, we believe our costs will be largely off set by product revenues, enabling a more rapid and extensive scale-up to address large-scale CO_2 mitigation.

Pollutant Removal

Unlike other carbon-mitigation technologies, CMAP removes sulfur compounds and other pollutants. We are developing a multi-pollutant control option using the same basic absorption and conversion techniques we are using for CO_2. The basis of our process for SO_2 (sulphur dioxide) control is similar to seawater scrubbers that have been used in the world's largest power plants. We have generated data showing SO_2 capture efficiencies of greater than 95%.

We are also working on new systems that will control NOx compounds by converting NO (nitrogen monoxide) to NO_2 (nitrous oxide), serious greenhouse gases that are water-soluble and can be stabilized in our mineral product. A significant advantage of our carbonate mineralization technology is that scrubbing SO_2, NOx, particulate matter and other regulated air pollutants are not required in order for the process to capture CO_2. This robust feature is in sharp contrast to other CO_2-capture technologies such as those based on amine (MEA) and chilled ammonia, which require stringent control of SO_2 because it interferes with the absorption process. Therefore, to adequately compare carbonate mineral-CO_2 reduction to conventional CO_2-reduction methods would require that the cost and energy consumption of the additional SO_2 control be included with the conventional method for comparison sake.

Demonstration Plants

Calera's business model is focused on the global potential of our technology with a milestone-driven plan to demonstrate capture rate and scalability. Our plan calls for building electric power and cement plants that capture and convert flue gas CO_2. These projects will benefit the socioeconomic status of the local communities by creating new jobs and business opportunities. Each plant will create 200-300 construction jobs over a 2-year construction phase. Job types required include pipe fitters, electricians, operators, carpenters, laborers, steel workers, ironworkers, mechanics, bookkeepers, and bookkeepers, clerical staff, among others. The completed facility will also provide new permanent jobs.

We have completed a substantial amount of laboratory and scaled batch-process development, and we have been operating a continuous pilot plant at Moss Landing, Calif., producing an average of one ton of material per day (a photo of this site is attached at the end of this document). From there we can quickly scale up the process to 10-80 MW for demonstration at coal-fired, electricity-generating units and cement manufacturing plants. Though the capital expenditures on these demonstration facilities are lower than many other CO_2 mitigation technologies, they require investments in the tens to hundreds of millions of dollars. Hence, my testimony today in support of a more balanced legislative support to foster the commercial development and scale-up of innovative technologies such as ours — *and to ask for the utmost expediency in making those funds accessible.*

Our process converts CO_2 into carbonate minerals, thus permanently converting CO_2 into a stable mineral form. When compared to traditional CCS methods, this conversion technology does not require costly and carbon intensive CO_2 separation or compression. Like any other manufacturer, energy is required to produce this product. Unlike other processes, our technology has the flexibility to capture CO_2 and produce products continuously, while shifting a large fraction of the electrical power consumption to off-peak hours. The shifting of power consumption is accomplished through energy storage in chemical intermediates specific to the mineral sequestration chemistry. By producing and storing these intermediates during periods of low power demand, this process not only avoids straining the grid, but also better utilizes off-peak sources of power such as solar and wind.

Calera's technology also reduces energy consumption and carbon footprint by utilizing power plant waste-heat for product processing. The use of waste heat is enabled by the process chemistry, which requires only low temperatures — in contrast to the very high temperature processes employed in the manufacture of other building materials. As a further means of reducing environmental impact, advanced versions of the process employ recirculation of process water. Although recirculation of process water may be desirable in arid regions, other process options under development may exploit synergies between the mineralization process and desalination technologies, resulting in improved economics and lower carbon footprint for freshwater production.

Another key breakthrough of our technology is the capacity to incorporate solid waste normally bound for landfills into useful products. Waste (such as fly ash) or aluminum smelter by-products (such as red mud and other waste products) can be incorporated into this process.

Beyond Cement

Calera will be important and valuable to states producing and/or consuming coal as they attempt to meet future carbon capture and trading requirements. Calera projects will bring long-term benefits to the coal industry by allowing existing coal plants to continue their operations under new air compliance regulations and avoid shutting down plants producing electricity at the lowest cost. This will save jobs at coal plants, mining sites and in transportation. The low cost of implementing Calera's technology compared to other CCS technologies reduces the impact of new CO_2 regulations on the cost of energy and avoids leakage of U.S. operations oversees to countries that don't have CO_2 regulations.

By shifting the treatment of CO_2 from a pollutant that needs to be disposed at a high price, to a potential raw material for clean manufacturing, our process enables a sustainable and cost-effective capture of a significant portion of the anthropogenic CO_2. In fact, when factoring the long-term potential revenues, revenues from building materials, carbon incentives and water treatment using a carbonate mineral process will be offset by the cost of capturing a ton of CO_2.

Based on our current estimates for construction and operating costs, and our forecasts for the building material and carbon markets, we expect a capital cost payback period of less than 10 years. Furthermore, based on our experience we believe our costs will go down as we learn to build and operate our plants, to the extent that our payback period could be reduced to 7 years. In our two years of operation we have made significant progress in understanding the scientific and engineering tasks of building a full-scale plant. From a small one-liter batch process to a 1-ton per day continuous pilot plant, we have learned how to optimize our capture rates and reduce our footprint and costs. Our progress is supported enthusiastically by the scientific community, environmental groups, potential business partners and the public. However, as for any industrial large-scale process, the next step requires a large investment to build a full-scale plant confirming our commercial scalability. Furthermore, the urgency of the climate challenge calls for an accelerated development path that demands special investments and support.

Recommendations

Congress is working hard to address CCS and to rethink product manufacturing. We admire the Committee for acknowledging the importance of CCS and funding innovations in this area. However, past legislative language and government funding consistently targets separation and geological sequestration, which disadvantages other CCS options. While we acknowledge the remote potential value of geologic CO_2 sequestration, we recommend placing other more viable CO_2-sequestering technologies on at least an equal playing field with separation and geological sequestration. Lower risk, proven approaches like Calera's warrant more immediate funding schedules than separation and geologic sequestration. This leveling of the playing field to reflect real technical merit and reduced development risk should extend to recent authorizations limited only to separation and geologic sequestration programs.

It is our hope that your committee will also consider supporting an independent assessment by the National Academy of Sciences that reviews the opportunities and challenges of beneficial reuse and carbon conversion as part of the larger national CO_2-reduction strategy.

Calera is one of many breakthrough clean technologies that are evolving rapidly. Companies like ours need government funding to help move this process towards commercialization. It is in the best economic interest of our country to advance the most effective technologies by providing grants, loan guarantees, tax incentives and other sources of financial support. For this reason, I urge Congress to broaden its perspective and move beyond existing carbon separation and geologic sequestration approaches by enacting more expansive statutory language and provide federal support that encourages innovation and rewards breakthrough opportunities. Ideally, legislative language would not be prescriptive to any one method, targeting certain companies or sectors, as we see today toward separation and geologic sequestration.

Finally, we seek federal government support because — despite the promise of technologies such as ours, the capital requirements are high in an extremely challenging macroeconomic environment and the risk of any new business venture is significant. The market for CO_2-reduction solutions such as ours is tremendous, but our product will take time and considerable capital to develop sufficiently in order to offset our development costs. Thus we need to scale up rapidly.

On behalf of Calera Corporation and our stakeholders, I respectfully thank Chairman Markey and the Committee Members for your time and consideration. We see an important new option with the recovery funding, and we thank the Select Committee on Global Warming for providing us with this opportunity to explore with you the beneficial reuse of CO_2. The funding we seek could be both stimulating and transformative to energy policy, climate change, and the future of our economy. We look forward to working with the U.S. Congress and the appropriate committees of jurisdiction (i.e., Senate Energy, Senate Finance, and others) to ensure equitable policies are established that provide federal support of CO_2-beneficial reuse technology.

Background on Testimony Request

Leveling the Playing Field

In addition to the *American Clean Energy and Security Act of 2009*, the *American Recovery and Reinvestment Act of 2009* (P.L. 111-5), the *Energy Independence and Security Act of 2007* (P.L. 110-140), and the *Energy Policy Act of 2005* (P.L. 109-58) have authorized funds and programs for the research, development, and deployment of geologic sequestration projects. As Congress contemplates implementing an economy-wide cap-and-trade program, it is imperative that Members take the opportunity to level the playing field and make all forms of CO_2 capture, storage and use eligible for government financial support. The playing field must include dollars and programs already authorized and allocated in order to accelerate the scale-up of multiple carbon mitigation technologies. This will allow more rapid implementation of these alternatives to conventional CCS and will enable the U.S. to meet its climate change goals.

More Than One Carbon Sequestration Method Must Be Supported To Meet Climate-Change Goals

The carbon mitigation challenge facing the United States and the rest of the world will require a multi-faceted approach to rapidly reduce anthropogenic emissions of CO2. The United States possesses both a large coal-energy generation fleet and abundant coal reserves. Meeting climate change objectives, while maintaining a higher level of energy independence, requires that U.S. coal power be made clean power. The ability to retrofit the existing coal fleet in a timely manner is especially important to both of these goals. Establishing coal as a clean energy source has national security implications as well, given that ability to better utilize coal can substantially reduce U.S. dependence on foreign oil.

In the IPCC Fourth Assessment Report (AR4), Volume Climate Change 2007: Mitigation of Climate Change (chapter 4, page 285), industrial fixation through formation of mineral carbonates is referred to as having high energy usage and cost, and indicates that significant technological breakthroughs are needed before deployment can be considered. See Attachment A.

Technological breakthroughs since the 2007 report include Calera Corp.'s aqueous carbonate mineral precipitation process, as well as new technologies from other firms. The Calera process provides a low-cost, low-energy, low-carbon footprint means of capture and conversion of carbon dioxide into permanent mineral forms. A further benefit of the process is the ability to provide revenue through the use of captured CO_2 as replacements for portland cement and natural aggregates. This beneficial use improves the economic sustainability of the process, as well as providing (in the U.S. alone) a repository for as much as 1.5 billion tons of CO_2 per year in the built environment (roads, buildings, houses, etc.).

Calera's Request Benefits Multiple Sequestration Technologies

The following are other firms, spanning a large range of development, that are developing permanent sequestration or beneficial-use technologies that do not involve injection into geologic formations or conversion of CO_2 to fuels:

- Skyonic: formation of bicarbonate from flue gas
- Greensols: formation of carbonate from flue gas
- Carbon Sciences: formation of mineral carbonates from flue gas
- Novomer: polymers from CO_2
- Carbon Sense Solutions: mineralization; accelerated concrete curing, carbonation using flue gas

- Catelectic: electrolytic conversion of CO_2 to chemicals
- Mantra: conversion of CO_2 to formic acid
- Carbon 8 Systems: carbonation of industrial waste — atmospheric or with flue gas
- Novacem: atmospheric CO_2 absorbing cement

There is also a growing effort toward "biochar": pyrolysis of biomass to extract energy, but leaving much of the carbon in a stable form to use as a soil amendment. This constitutes another potential form of permanent sequestration that is excluded from support funding due to the narrow focus and definition of geologic sequestration. Carbonscape is an example of a firm working in this arena.

The Department of Energy Supports Mineral Carbonation

An excerpt from the Department of Energy's website indicates recognition of the advantages of mineral carbonation:

> ***Advanced Chemical and Biological Approaches***
> *Recycling or reuse of CO_2 from energy systems would be an attractive alternative to storage of CO_2. The goal of this program area is to reduce the cost and energy required to chemically and/or biologically convert CO_2 into either commercial products that are inert and long-lived or stable solid compounds.*
>
> *Two promising chemical pathways are magnesium carbonate and CO_2 clathrate, an ice-like material. Both provide quantum increases in volume density compared to gaseous CO_2.*
>
> *As an example of the potential of chemical pathways, the entire global emissions of carbon in 1990 could be contained as magnesium carbonate in a space 10 kilometers by 10 kilometers by 150 meters.*
>
> *See* http://www.fossil.energy.gov/programs/sequestration/novelconcepts/.

Carbonate Mineralization Mitigates Multiple Waste Streams

An additional advantage of the aqueous carbonate mineral precipitation process is that, at continuous process pilot scale, the process has been demonstrated to remove sulfur oxides (SOx). According to U.S. Energy Information Administration data (table 5.2 below), as of 2005 only 1/6th of the U.S. fossil fuel energy generation fleet was equipped with SOx scrubbers. Conventional CO_2 separation technologies, such as amine solvent or chilled ammonia systems, require extremely efficient SOx removal prior to the separation step. This adds significantly to the capital cost of retrofitting existing coal plants without SOx scrubbers, as these scrubbers must be added upstream of the CO_2 separation equipment. The ability to implement only a single process at lower capital cost to capture both SOx and CO_2 makes aqueous carbonate mineral precipitation a more viable alternative for existing coal plants without SOx scrubbers. This advantage makes rapid deployment of the aqueous carbonate mineral precipitation process in the existing coal-power generation fleet much more likely than rapid deployment of traditional CCS for these same plants.

The aqueous mineral carbonate precipitation process also utilizes solid waste such as fly ash that results from burning coal, red mud that results from aluminum ore (bauxite) refining, slags from smelting of steel, copper, phosphorus, and so on. Liquid waste streams such as geologic brine pumped in oil extraction, or brine discharge from desalination plants, can be a valuable part of the process as well. The ability to use these waste products — not only to capture CO_2, but also to convert them into cementitious materials that can be sold to build roads, hospitals and schools, and cleaner water — provides the most compelling example of *sustainability*. Providing such integrated sustainable processes with equal access to funding incentives now enjoyed by geological sequestration is critical to deploying technologies such as Calera's in a timely manner.

Carbonate Mineralization Is Moving Toward Commercial Scale

Many of the incentives authorized under the legislation listed in this document are aimed at taking proven technologies beyond research to full commercial scale. Calera has been operating a continuous pilot facility burning coal at a rate of one million BTU per hour for several months, capturing CO_2 from raw flue gas and converting it to carbonate minerals from which cementitious materials and aggregates have been made. A ten-megawatt (20MW) scale facility is under design, and construction is expected to start in the 3rd quarter of 2009, with operation to begin in 2010. Demonstrations on this large scale show that the technology is ready for the planning and design of mid-size (10-100 MW) and commercial scale (300+MW) facilities. The capital cost of these larger facilities, though less than many other carbon-capture systems, is substantial. This makes the availability of government financial incentives key to accelerating the deployment at scale of this important technology for mitigating climate change.

Attachment A

Excerpt from *IPCC Fourth Assessment Report (AR4), Volume Climate Change 2007: Mitigation of Climate Change*:

to large carbon point sources including coal-, gas- or biomass-fired electric power-generation or cogeneration (CHP) facilities, major energy-using industries, synthetic fuel plants, natural gas fields and chemical facilities for producing hydrogen, ammonia, cement and coke. Potential storage methods include injection into underground geological formations, in the deep ocean or industrial fixation as inorganic carbonates (Figure 4.22). Application of CCS for biomass sources (such as when co-fired with coal) could result in the net removal of CO_2 from the atmosphere.

Injection of CO_2 in suitable geological reservoirs could lead to permanent storage of CO_2. Geological storage is the most mature of the storage methods, with a number of commercial projects in operation. Ocean storage, however, is in the research phase and will not retain CO_2 permanently as the CO_2 will re-equilibrate with the atmosphere over the course of several centuries. Industrial fixation through the formation of mineral carbonates requires a large amount of energy and costs are high. Significant technological breakthroughs will be needed before deployment can be considered.

Estimates of the role CCS will play over the course of the century to reduce GHG emissions vary. It has been seen as a ‘transitional technology’, with deployment anticipated from 2015 onwards, peaking after 2050 as existing heat and power-plant stock is turned over, and declining thereafter as the decarbonization of energy sources progresses (IEA, 2006a). Other studies show a more rapid deployment starting around the same time, but with continuous expansion even towards the end of the century (IPCC, 2005). Yet other studies show no significant use of CCS until 2050, relying more on energy efficiency and renewable energy (IPCC, 2005). Long-term analyses by use of integrated assessment models, although using a simplified carbon cycle (Read and Lermit, 2005; Smith, 2006b), indicated that a combination of bioenergy technologies together with CCS could decrease costs and increase attainability of low stabilization levels (below 450 ppmv).

New power plants built today could be designed and located to be CCS-ready if rapid deployment is desired (Gibbins *et al.*, 2006). All types of power plants can be made CCS-ready, although the costs and technical measures vary between different types of power plants. However, beyond space reservation for the capture, installation and siting of the plant to enable access to storage reservoirs, significant capital pre-investments at build time do not appear to be justified by the cost reductions that can be achieved (Bohm, 2006; Sekar, 2005). Although generic outline engineering studies for retro-fitting capture technologies to natural-gas GTCC plants have been undertaken, detailed reports on CCS-ready plant-design studies are not yet in the public domain.

Storage of CO_2 can be achieved in deep saline formations, oil and gas reservoirs and deep unminable coal seams using injection and monitoring techniques similar to those utilized by

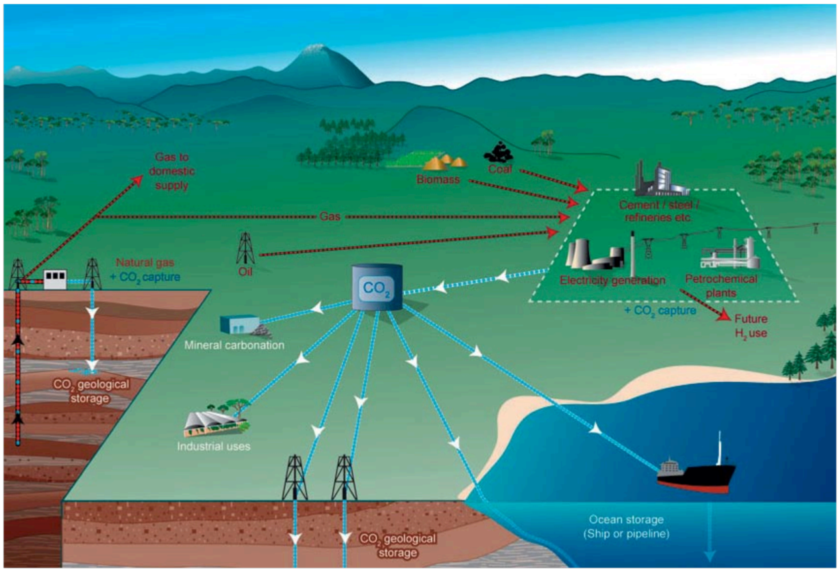


Figure 4.22: *CCS systems showing the carbon sources for which CCS might be relevant, and options for the transport and storage of CO_2.*

Source: IPCC, 2005.

Table 4.5: *Current cost ranges for the components of a CCS system applied to a given type of power plant or industrial source*

CCS system components	Cost range	Remarks
Capture from a coal- or gas-fired power plant	15-75 US$/t$CO_2$ net captured	Net costs of captured CO_2 compared to the same plant without capture
Capture from hydrogen and ammonia production or gas processing	5-55 US$/t$CO_2$ net captured	Applies to high-purity sources requiring simple drying and compression
Capture from other industrial sources	25-115 US$/t$CO_2$ net captured	Range reflects use of a number of different technologies and fuels
Transport	1-8 US$/t$CO_2$ transported	Per 250 km pipeline or shipping for mass flow rates of 5 (high end) to 40 (low end) MtCO_2/yr.
Geological storage[a]	0.5-8 US$/t$CO_2$ net injected	Excluding potential revenues from EOR or ECBM.
Geological storage: monitoring and verification	0.1-0.3 US$/t$CO_2$ injected	This covers pre-injection, injection, and post-injection monitoring, and depends on the regulatory requirements
Ocean storage	5-30 US$/t$CO_2$ net injected	Including offshore transportation of 100–500 km, excluding monitoring and verification
Mineral carbonation	50-100 US$/t$CO_2$ net mineralized	Range for the best case studied. Includes additional energy use for carbonation

[a] Over the long term, there may be additional costs for remediation and liabilities

Source: IPCC, 2005.

Table 5.1. Emissions from Energy Consumption at Conventional Power Plants and Combined-Heat-and-Power Plants, 1996 through 2007

(Thousand Metric Tons)

Emission	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996
Carbon Dioxide (CO_2).....	2,516,580	2,459,800	2,513,609	2,456,934	2,415,680	2,395,048	2,389,745	2,441,722	2,338,660	2,324,139	2,232,709	2,161,258
Sulfur Dioxide (SO_2)	9,042	9,524	10,340	10,309	10,646	10,881	11,174	11,963[R]	12,843[R]	13,464[R]	13,480[R]	12,991[R]
Nitrogen Oxides (NO_x)	3,650	3,799	3,961	4,143	4,532	5,194	5,290	5,638[R]	5,955[R]	6,459[R]	6,500[R]	6,474[R]

R = Revised.

Notes: • See Appendix A, Technical Notes, for a description of the sources and methodology used to develop the emissions estimates. • CO2 emissions for 1995 - 2000 have been revised to reflect the emission factors shown in Table A3.

Source: Calculations made by the Electric Power Division, Einergy Information Administration.

Table 5.2. Number and Capacity of Fossil-Fueled Steam-Electric Generators with Environmental Equipment, 1996 through 2007

Year	Flue Gas Desulfurization (Scrubbers)		Particulate Collectors		Cooling Towers		Total[1]	
	Number of Generators	Capacity[2] (megawatts)	Number of Generators	Capacity[2] (megawatts)	Number of Generators	Capacity[2] (megawatts)	Number of Generators	Capacity[2] (megawatts)
1996....................................	182	85,842	1,134	352,154	477	166,749	1,299	377,144
1997....................................	183	86,605	1,133	352,068	480	166,886	1,301	377,195
1998....................................	186	87,783	1,130	351,790	474	166,896	1,294	377,117
1999....................................	192	89,666	1,148	353,480	505	175,520	1,343	387,192
2000....................................	192	89,675	1,141	352,727	505	175,520	1,336	386,438
2001....................................	236	97,988	1,273	360,762	616	189,396	1,485	390,821
2002....................................	243	98,673	1,256	359,338	670	200,670	1,522	401,341
2003....................................	246	99,567	1,244	358,009	695	210,928	1,546	409,954
2004....................................	248	101,492	1,217	355,782	732	214,989	1,536	409,769
2005....................................	248	101,648	1,216	355,599	730	217,646	1,535	411,840
2006....................................	NA	NA	NA	NA	NA	NA	NA	NA
2007....................................	NA	NA	NA	NA	NA	NA	NA	NA

[1] Components are not additive since some generators are included in more than one category.

[2] Nameplate capacity

NA = Not available. Form EIA-767 data collection was suspended in the data year 2006.

Notes: • These data are for plants with a fossil-fueled steam-electric capacity of 100 megawatts or more . • Data for Independent Power Producer and Combined Heat and Power plants are included beginning with 2001 data. • Beginning in 2001, data for plants with combustible renewable steam-electric capacity of 10 megawatts or more were also included. • Totals may not equal sum of components because of independent rounding.

Source: Energy Information Administration, Form EIA-767, "Steam-Electric Plant Operation and Design Report."

Table 5.3. Average Flue Gas Desulfurization Costs, 1996 through 2007

Year	Average Overhead & Maintenance Costs (mills per kilowatthour)[1]	Average Installed Capital Costs (dollars per kilowatt)
1996...	1.07	128.00
1997...	1.09	129.00
1998...	1.12	126.00
1999...	1.13	125.00
2000...	.96	124.00
2001...	1.27	130.80
2002...	1.11	124.18
2003...	1.23	123.75
2004...	1.38	144.64
2005...	1.23	141.34
2006...	NA	NA
2007...	NA	NA

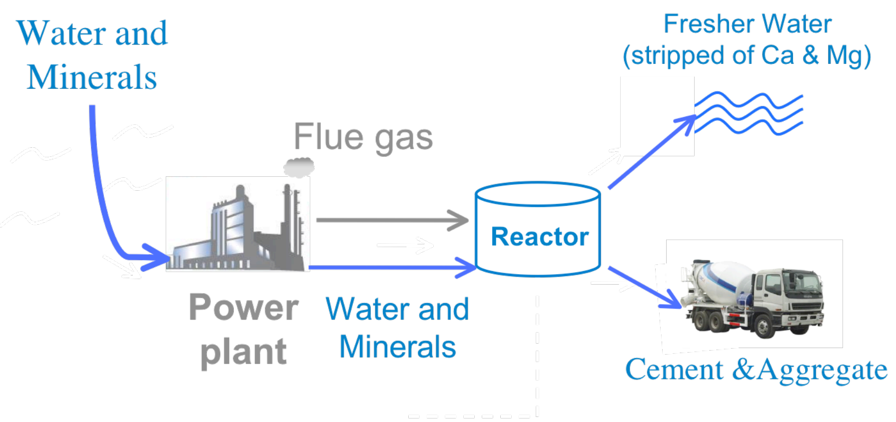
[1] A mill is one tenth of one cent.

NA = Not available. Form EIA-767 data collection was suspended in the data year 2006.

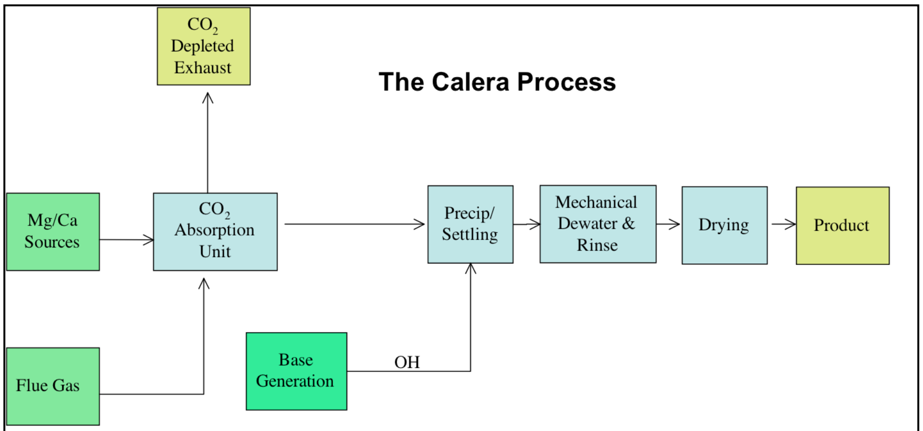
Notes: • These data are for plants with a fossil-fueled steam-electric capacity of 100 megawatts or more. • Beginning in 2001, data for plants with combustible renewable steam-electric capacity of 10 megawatts or more were also included. • Data for Independent Power Producer and Combined Heat and Power plants are included beginning with 2001 data. • Totals may not equal sum of components because of independent rounding.

Source: Energy Information Administration, Form EIA-767, "Steam-Electric Plant Operation and Design Report."

The Calera Process: Mineral Carbonation



The Calera Process



Basic Chemistry of the Calera Process

$$Ca^{+2} + 2OH^{-} + CO_2 \rightarrow CaCO_3 + H_2O$$

$$Mg^{+2} + 2OH^{-} + CO_2 \rightarrow MgCO_3 + H_2O$$

Excerpts from: ***Mineral Sequestration Studies in US***

…..carbonates have a lower energy state than CO2, which is why mineral carbonation is thermodynamically favorable and occurs naturally (e.g., the weathering of rock over geologic time periods). Secondly, the raw materials such as magnesium based minerals are abundant. **Finally, the produced carbonates are unarguably stable and thus re-release of CO2 into the atmosphere is not an issue.**

The major advantages of CO2 sequestration by mineral carbonation are:

- **Long Term Stability - Mineral carbonation is a natural process that is known to produce environmentally safe and stable material over geological time frames.** The production of mineral carbonates insures a permanent fixation rather than temporary storage of the CO2, thereby guaranteeing no legacy issues for future generations.

- **Vast Capacity -** Raw materials for binding the CO2 exist in vast quantities across the globe. Readily accessible deposits exist in quantities that far exceed even the most optimistic estimate of coal reserves (~10,000 × 109 tons)

- **Potential to be Economically Viable -** The overall process is exothermic and, hence, has the potential to be economically viable. In addition, its potential to produce value-added by-products during the carbonation process may further compensate its costs.

There are adequate mineral deposits to support mineral sequestration. Several ultramafic complexes in North America contain sufficient quantity of magnesium silicate mineral to provide raw materials for the mineral carbonation of all annual CO2 emissions for many years

National Energy Technology Laboratory
Philip Goldberg

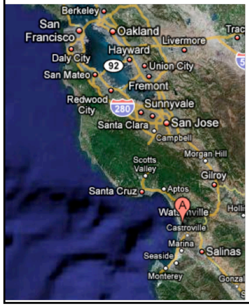
Los Alamos National Laboratory
Hans Ziock

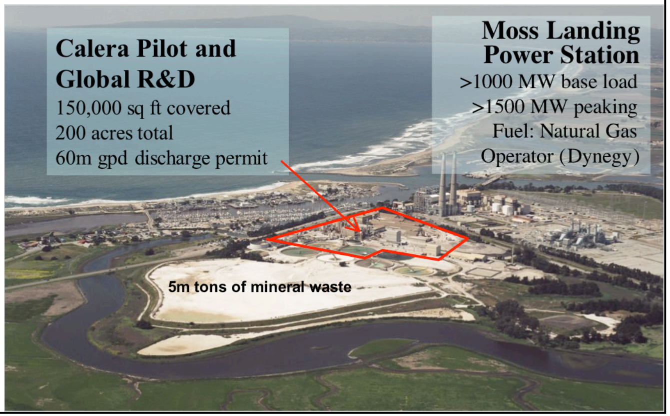
Albany Research Center
William O'Connor
Richard Walters

Science Applications International Corp
Zhong-Ying Chen

CA Pilots Validate Process, Product and Environmental Feasibility

- Pilot plants running large-scale batch and continuous processes
- Flue gas simulator – Ability to test any type of coal and flue gas composition
- Producing material for product development and testing
- Demonstration of waste mineral utilization
- Monterey Bay Marine Sanctuary requires highest level of environmental performance





Calera Pilot and Global R&D
150,000 sq ft covered
200 acres total
60m gpd discharge permit

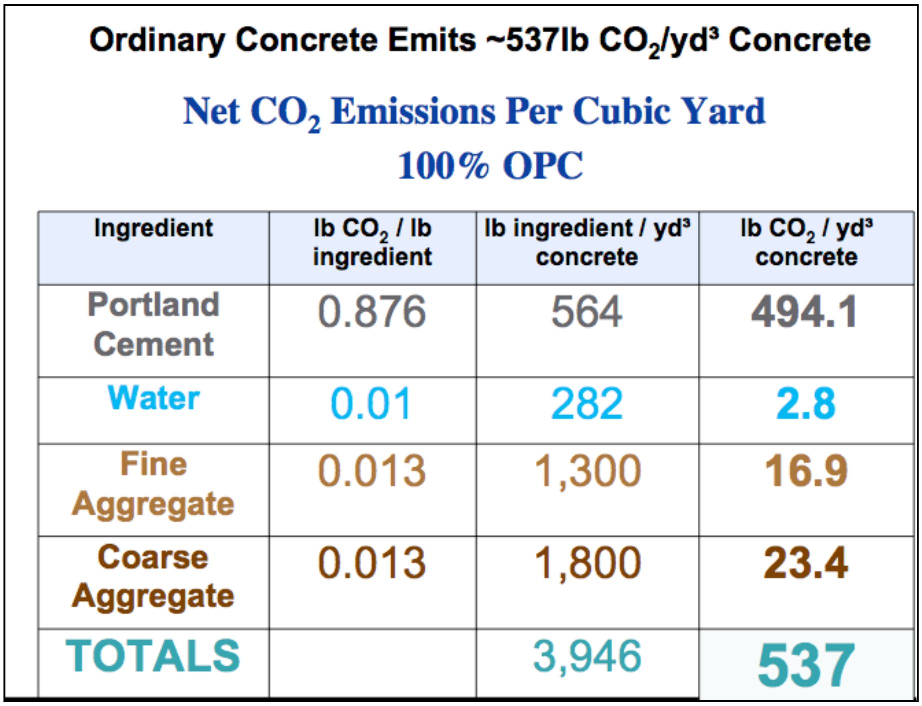
Moss Landing Power Station
>1000 MW base load
>1500 MW peaking
Fuel: Natural Gas
Operator (Dynegy)

5m tons of mineral waste

Carbon Footprint Basic Calculation

Embodied CO_2 of Ingredient x Pounds of Ingredient (per cubic yard) → **Sum All Ingredients** → **Concrete Carbon Footprint**

First Carbonate Mineral concrete – July 2008

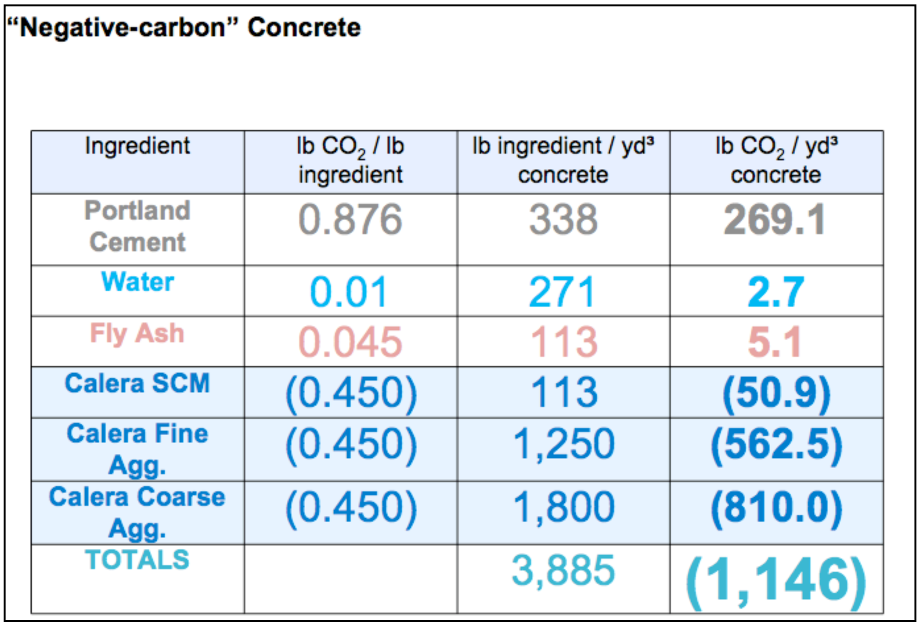


Ordinary Concrete Emits ~537lb CO_2/yd³ Concrete

Net CO_2 Emissions Per Cubic Yard

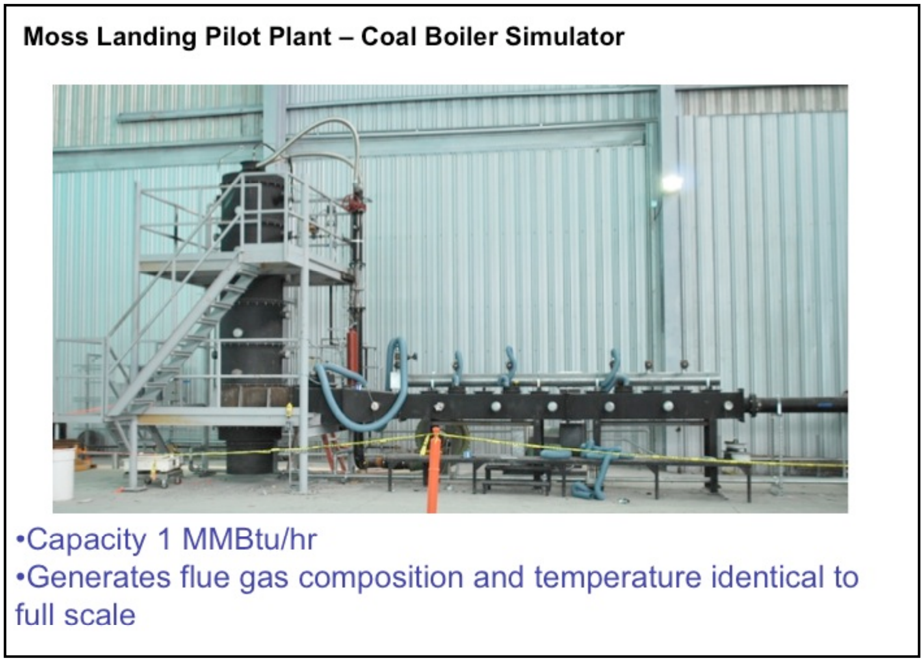
100% OPC

Ingredient	lb CO_2 / lb ingredient	lb ingredient / yd³ concrete	lb CO_2 / yd³ concrete
Portland Cement	0.876	564	**494.1**
Water	0.01	282	**2.8**
Fine Aggregate	0.013	1,300	**16.9**
Coarse Aggregate	0.013	1,800	**23.4**
TOTALS		3,946	**537**



"Negative-carbon" Concrete

Ingredient	lb CO_2 / lb ingredient	lb ingredient / yd³ concrete	lb CO_2 / yd³ concrete
Portland Cement	0.876	338	**269.1**
Water	0.01	271	**2.7**
Fly Ash	0.045	113	**5.1**
Calera SCM	(0.450)	113	**(50.9)**
Calera Fine Agg.	(0.450)	1,250	**(562.5)**
Calera Coarse Agg.	(0.450)	1,800	**(810.0)**
TOTALS		3,885	**(1,146)**



Moss Landing Pilot Plant – Coal Boiler Simulator

- Capacity 1 MMBtu/hr
- Generates flue gas composition and temperature identical to full scale