CALERA: ENTREPRENEURSHIP, INNOVATION, AND SUSTAINABILITY

Introduction

Brent Constantz had three decades of entrepreneurial experience starting companies based on how cements formed in coral reefs and seashells. Yet those same reefs and shells were threatened by ocean acidification from anthropogenic carbon dioxide emissions (Exhibit 1). Constantz had a simple insight: if humans could make cement as marine life did (through biomimicry) without burning fuel and converting minerals in high-temperature processes, then greenhouse gas (GHG) emissions would be significantly reduced. With that idea, Calera Corporation was born.

Calera’s goal was to make synthetic limestone and carbonate cement, both used as major feedstock for concrete, by mimicking nature’s low-energy process. Calera’s process aimed to precipitate\(^1\) carbonate cement from seawater (ideally retentate left by desalination) and combine it with a strong alkaline base. When Constantz accidently discovered carbon dioxide (CO\(_2\)) could enhance his process, he realized he needed a source of CO\(_2\). When he brought his technology and his challenge to cleantech venture capitalist Vinod Khosla, Calera suddenly became a carbon capture and sequestration (CCS) technology company, one with massive storage potential if located proximate to point sources of pollution: Power plants emitted 40% of U.S. carbon dioxide in 2008 and industrial process facilities dispersed another 20%. Yet a high level of technical risk and a number of unknowns remained about the breadth of applicability due to the requirement for brines and alkaline materials. Khosla, as the principal investor, shared Constantz’s vision and saw the huge promise and the attendant risk of failure as a high-risk high-impact potential home run that would completely change assumptions about the power and cement industry or a strikeout.

In two and a half years, Calera had gone from small batch processing in a lab as a proof of concept to constructing a continuously operating demonstration plant suggesting the feasibility of large-scale operations. In the process, Constantz continued to uncover new possibilities. Since his process stripped magnesium and calcium ions from seawater or any water

\(^1\) Precipitation was the formation of solids from an aqueous solution.
charged with minerals such as some wastewaters and brines, it could potentially yield potable water. Could the venture provide water purification technology as well? Could it be economic? Furthermore, wherever seawater and strong bases were not available, Calera needed to replace or produce them. Consequently, Calera developed a more energy-efficient process to use saltwater to produce sodium hydroxide, the base it needed. With that technology, Calera could potentially affect the mature chlor-alkali industry. There were also environmental remediation possibilities. Calera’s initial process had used the base magnesium hydroxide that had been discarded by other companies at its Moss Landing demonstration site. In lieu of seawater, Calera could use subsurface brines, which were often left behind by oil and gas drilling as hazardous wastes. As Constantz and his growing team saw their opportunities expand, the company grew rapidly. If everything worked as hoped, Calera’s method seemed like a magic sponge capable of absorbing multiple pollutants and transforming them into desirable products. The reality, though full of possibilities, was complex, with many practical hurdles.

Along the way, the Calera team had identified and added to the firm’s multiple areas of expertise—often as they ran into the complexity of a developing process. Calera also attracted a wide range of curious onlookers who could someday turn into prospective customers. Government agencies and other companies also were eager to get in on the action. To position itself favorably, Calera needed to understand its core competencies and identify key collaborators to bring the new technology to full-scale operation at multiple sites. Simultaneously, it needed to protect its intellectual property and forge a defensible market position. Calera was a high-risk, highly capital-intensive start-up with a huge number of uncertainties and potential ways to address many markets and positively affect the environment, from low-carbon cement, to emissions remediation, to water production. Given these facts, what business model made sense?

The Cement Industry

Carbon-dioxide-sequestering cement could make a significant impact on the environment. In 2008, 2.5 billion metric tons of Portland cement was produced with between 0.8 tons and 1.0 ton of carbon dioxide emitted for every ton of cement. Consequently, production of Portland cement, the main binder for conventional concrete, accounted for between 5% and 8% of global GHG emissions, making it among the more GHG-intense industries (Exhibit 2). China produced nearly 1.4 billion tons of cement in 2008, followed by about 200 million tons in India, and 100 million tons in the United States.

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2 All tons indicate metric tons throughout this case. In 2001, in the United States, the world’s third-largest producer of cement, the average CO₂ intensity of cement production was 0.97 tons of CO₂ per ton of cement, ranging from 0.72 tons of CO₂ per ton of cement to 1.41 tons of CO₂ per ton of cement. Coal was the overwhelming energy source (71%) of cement kilns, followed by petroleum, coke, and other fuels. Globally, the average CO₂ intensity for cement production in 2001 was around 0.82 tons of CO₂ per ton of cement. Numbers from California alone in 2008 put CO₂ intensity there at 0.85 tons of CO₂ per ton of cement.
Portland cement production generated carbon dioxide in two ways (Exhibit 3). The first, calcination, decomposed quarried limestone (calcium carbonate) into quicklime (calcium oxide) and released CO₂ as a byproduct. The second source was the heat needed to achieve calcination, which required temperatures over 2,700°F (1,500°C), or almost one-third the sun’s surface temperature. These temperatures were generally achieved by burning fossil fuels or hazardous wastes containing carbon. Sustaining such temperatures consumed around three to six Gigajoules (1,000 to 2,000 kilowatt-hours [kWh]) of energy per ton of cement, making energy costs around 14% of the value of total shipments.³ (In comparison, the typical average home uses around 11,000 kWh per year.⁴)

Since emissions from calcination are dictated by the chemistry of the reaction and cannot be changed, to save energy and lower emissions, kilns have striven to use heat more efficiently. In California, for instance, emissions from calcination remained steady at 0.52 tons of CO₂ per ton of cement from 1990 to 2005 while emissions from combustion declined from 0.40 tons of CO₂ per ton of cement to 0.34 tons. Lowering emissions further, however, had proven difficult.⁵

Given the carbon intensity of cement production, governments increasingly had attended to emissions from cement kilns. Calcination alone emitted 0.7% of U.S. CO₂ in 2007, a 34% increase since 1990 and the most of any industrial processes except energy generation and steel production.⁶ California’s Global Warming Solutions Act of 2006, AB32, included cement kilns under its GHG emissions reduction program, which would require kilns to cut further their emissions, starting in 2012. The U.S. Environmental Protection Agency (EPA) Greenhouse Gas Reporting Rule from April 2009 also required kilns to send data about their GHG emissions to the EPA, a prerequisite for any eventual mandatory emissions reductions.

In addition to being energy- and CO₂ intense, cement production was also a capital-intensive industry. A kiln and its concomitant quarrying operations might require an investment of approximately (U.S. dollars) USD1 billion. Consequently, about a dozen large multinational companies dominated the industry. In 2010 there were 113 cement plants in the United States in 36 states, but foreign-owned companies accounted for about 80 percent of that U.S. cement production.

Despite this ownership structure, actual production and consumption was largely regional. The cement industry moved almost 100% of its product by truck; the majority went to ready-mix concrete operators, from plant to use. The entire U.S. cement industry shipped $7.5 billion of products in 2009, a decline from $15 billion in 2006 since domestic construction

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³ An alternative method, wet production, had largely been phased out due to its higher energy consumption.
had declined. Worldwide, the cement industry alone represented a USD140 billion market in 2009, with about 47% poured in China.

Although cement could be used to produce mortar, stucco, and grout, most cement was used to produce concrete. To make concrete, cement was mixed in various proportions with water and aggregates, including fine aggregates such as sand and coarse aggregates such as gravel and rocks. (Concrete cement was commonly called simply concrete, although asphalt was also technically a type of concrete, where the binder was asphalt instead of Portland cement.) Cement came in five basic classes, depending on the desired strength, time to set, resistance to corrosion, and heat emitted as the cement set, or hydrated. Though cement played a crucial role in the properties of concrete, the other ingredients also mattered. Aggregates helped give concrete its strength and appearance. Plasticizers could be added in smaller quantities, as could materials such as coal fly ash or slag from blast furnaces, to vary the concrete’s strength, weight, workability, and resistance to corrosion. Some states such as California required fly ash and slag be added to concrete to reduce its GHG intensity, improve the durability of the final material, and prevent these aggregates from entering landfills as waste materials.

A typical mix of concrete might contain by mass one part water, three parts cement, six parts fine aggregate, and nine parts coarse aggregate. Thus, a cubic yard of concrete, which weighed roughly two-and-one-half tons (2,000 to 2,400 kilograms per cubic meter), would require approximately 300 pounds (36 gallons) of water, 900 pounds of cement (9.5 bags, or 9.5 cubic feet), and 4,500 pounds of total aggregates. Varying amounts of air could also be trapped, or entrained, in the product. Cement, at around USD100 per ton in 2010, was normally about 60% of the total cost of poured concrete. Aggregates, in contrast, cost closer to USD10 per ton.

Making concrete added more greenhouse gas emissions from, for instance, quarrying and transporting stone and keeping the water at the right temperature (from 70ºF to 120ºF) to mix effectively. As the cement in concrete cured, it carbonated, which is the process in which carbon dioxide interacts with the alkaline pore solutions in the concrete to form calcium carbonate. This process took decades to occur and never accounted for more than a few percent carbon sequestrations in cement.

By using less energy, Calera’s process already promised lower emissions. More important, using a standard construction material—cement—to capture carbon dioxide would mean sequestration capacity scaled directly with economic activity as reflected in new construction. The Three Gorges Dam in China used approximately 55 million tons of concrete containing eight million tons of cement. The concrete in the dam was enough to pave a 16-lane highway from San Francisco to New York. Hence, had Calera cement been used in that dam, it could have sequestered roughly 4 million tons of CO₂ rather than emitting approximately

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7 million additional tons of it, for a net difference of 11 million tons. If Calera had manufactured the stones used as aggregate in the dam’s concrete, emissions potentially could have been reduced even further, so long as Calera’s process produced fewer emissions than quarrying the equivalent aggregate. The questions remained: In how many places was the Calera process viable, and where did the economics make sense?

**Constantz Looks for an Opening**

Constantz had focused his career on how nature made cements and how he could apply those techniques to other problems. He faced the challenge of moving from niche markets for small-scale, specialty, medical cements into the mainstream of international construction, commodity materials, and carbon sequestration. For these markets, Calera’s product promised negative net CO₂ emissions but first had to compete on cost, set time, strength, and durability. Calera would need to pass all appropriate standards as well as target applications in which people would be ready to pay a premium for carbon-negative concrete. In addition, the chain of liability often terminated at the cement producer in the highly litigious construction industry. Consequently, Calera cement had to be deemed beyond reproach to penetrate the market. But if it managed to achieve that, then its ability to reduce GHG gas emissions would appeal to many in the construction industry who sought to lower costs and improve their environmental image.

A rock climber and wind surfer, Constantz earned his BA in geological sciences and aquatic biology from the University of California, Santa Barbara, in 1981, and went on to earn his master’s (1984) and PhD (1986) in earth sciences from University of California, Santa Cruz (UCSC). He received a U.S. Geological Survey post-doctoral fellowship in Menlo Park, California, during which he studied isotope geochemistry. Next, as a Fulbright Scholar in Israel, he studied the interaction of crystals and proteins during biomineralization. At that time, Constantz developed medical cements to help heal fractured or worn bones, and in 1988, he founded his first company, Norian Corporation, in Cupertino, California, to commercialize those medical cements. When Norian was sold in 1998 to Synthes, a company with USD3.4 billion in sales in 2009, Constantz became a consulting professor at Stanford University, where he had continued to teach courses on biomineralization, carbonate sedimentology, and the “Role of Cement in Fracture Management” through 2010.

During his time at Stanford, Constantz founded and provided leadership for three more medical cement companies—Corazon, bought by Johnson & Johnson; Skeletal Kinetics, bought by Colson Associates; and Biomineral Holdings. He served on the board of directors of the Stanford Environmental Molecular Science Institute and won a variety of awards, including a UCSC Alumni Achievement Award in 1998 and a Global Oceans Award in 2004 for advancing human understanding of and helping to conserve oceans.

Indeed, climate change’s impact on oceans was increasingly on Constantz’s mind. In an interview with the *San Francisco Chronicle*, Constantz stated, “Climate change is the largest
challenge of our generation.” Constantz was concerned specifically with ocean acidification, which was destroying coral, the very topic that had inspired him for years. As carbon dioxide was emitted into the atmosphere, a portion was absorbed by the oceans, forming carbonic acid by roughly the same process that gave carbonated beverages their bubbles. When Constantz recognized the process threatened by carbon dioxide emissions—natural biomineralization—was also a solution, he founded Calera Corporation in 2007.

The name Calera was Spanish for lime kiln, but it also referred to a stratum of limestone that underlay parts of California. That layer likely formed 100 million years ago when seafloor vents triggered precipitation of calcium carbonate. Constantz found a similar inorganic process to precipitate carbonates could make construction-grade cement. In fact, early lab work revealed the surprising finding that adding CO₂ could increase the reaction’s yield eightfold. In one of his regular conversations with Khosla about the company, Constantz wondered aloud where to get more CO₂. Khosla, a prominent cleantech investor, immediately saw the answer: carbon sequestration. If Calera could make cement with CO₂, cement could now be produced that was, in fact, carbon negative. First-round funding came from Khosla in 2007. There was no business plan written, and in 2010, there was still no formal board or enough clarity to develop a strategic plan.

Calera’s method put power plant flue gases that contained carbon dioxide in contact with concentrated brines or concentrated seawater, which contained dissolved magnesium and calcium ions. Hydroxides and other alkaline materials were added to the seawater to speed the reaction between the carbon dioxide and minerals. That reaction precipitated carbonates of magnesium and calcium, the cementitious materials found in coral reefs and seashells, thus storing the CO₂ and leaving behind demineralized water. Unlike conventional cement kilns, Calera could produce its cement at temperatures below 200°F (90°C), dramatically lowering emissions of CO₂ from fuel combustion (Exhibit 4 and Exhibit 5). In principle, Calera could produce and sell its aggregate, essentially manufactured stones; powdered stones, cement, and the binder in concretes; or supplementary cementitious material (SCM), an additive to improve the performance of concrete, which could be added to the cement blend directly or later added to the concrete.

Yet in 2010, each of these materials was in the midst of optimization and testing. Some were early in their product development phase. Furthermore, even though Constantz held nearly 200 patents or pending patents, including 2 for Calera’s processes, one for producing the carbonate cement and the other for demineralizing water, the medical cements he was accustomed to typically used grams or less at a time, not tons or kilotons, and did not require massive machinery, tracts of land, and large capital investments. Calera faced another challenge: the industrial ecosystem.

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One practical application of industrial ecology concepts referred to the collocation of factories or processes that could use each other’s wastes as feedstock. When the waste stream of one plant became the material input of the next, the net effect was to save energy and material and reduce the necessary infrastructure. The most famous industrial ecology park in Kalundborg, Denmark, included a power plant, a refinery, a pharmaceutical company, a drywall manufacturer, and a fish farm. The power plant, for instance, treated its flue gas to trap SO₂ emissions and thereby produced gypsum, the raw material for drywall. Hot water from the power station went to the fish farm, as did wastes from the pharmaceutical company that could be used as fertilizer. Constantz saw an existing symbiosis between cement plants, power stations, and water supplies, but he would have to plan carefully to insert Calera effectively into that ecology.

But if he could enter the markets, Constantz felt the opportunity was there. He commented on the global market for Calera’s technology:

Almost everywhere else in the world but the U.S. can projects get the value for carbon emission reductions. In cap-and-trade systems, the government sets a “cap” on emissions; if a business’s emissions fall below the cap, it can sell the difference on the market to companies that want to exceed their cap. If Calera proves out, it can go anywhere, set up next to a power plant, and get our revenue just by selling carbon credits. That means we could produce cement in a developing country where they basically can’t afford concrete, so they otherwise couldn’t build out their infrastructure or even build houses. And the more cement Calera produces, the more carbon dioxide we remove from the atmosphere.

As Constantz reflected in his Los Gatos, California, office on Calera’s potential effect on climate change, he said, “A sufficiently high carbon price would enable a number of business models. Low prices limit the options available to Calera.”¹¹ Calera planned to offer sequestration services to power plants or other heavy industrial users as its primary business, and was therefore interested in any carbon dioxide emissions. “We look at CO₂ as a resource—not a pollutant—and a scarce resource. To replace all Portland cement with Calera cement, which we want to do, we would need about 19 billion tons of CO₂ annually, forever.”

Government carbon regulations might help Calera but were not viewed as crucial. In the European Union’s Emissions Trading Scheme, carbon dioxide in July 2010 traded at around (euros) EUR14 per ton, or (U.S. dollars) USD18 per ton. The northeastern states’ Regional Greenhouse Gas Initiative (RGGI) established in 2009 capped GHG emissions from power plants at 188 million tons immediately, roughly a quarter of total U.S. emissions, and would cut GHG emissions of RGGI sources 10% from that level by 2018. RGGI allowances sold at between USD1.86 and USD2.05 per ton at auction in December 2009.¹² Since RGGI allowed sources to cover up to 10% of their emissions by buying offsets, Calera planned to try to convince power companies to enter agreements with Calera rather than the company’s buying

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¹¹ Case writer interview with Brent Constanz, Los Gatos, California, 2010.
permits to meet its obligations. On the other side of the country, the Western Climate Initiative (WCI) was designing a cap-and-trade system for power generation and fuel consumption. The WCI comprised 11 Canadian provinces and western U.S. states and would take full force in 2015, with earlier phases beginning in 2012. In many cases there was strong interest for the future but little appetite for risk or actual implementation with the possible exception of suppliers to the California electricity market.

At the federal level, Calera lobbied hard to have the American Clean Energy and Security Act of 2009 (HR 2454, the Waxman-Markey Bill) include sequestration other than by solely geological means; otherwise, Calera would not be recognized as providing offsets worth allowances in a trading program. The bill exited committee in May 2009 with the expanded sequestration options, but then it stalled. CCS debates had focused until then on geological sequestration, but that solution was expensive, required massive federal subsidies to CO₂ emitters, and, according to a 2008 McKinsey & Company report, would not be commercially feasible for another 20 years. 13 Despite the enticing estimates that centuries’ worth of carbon dioxide emissions could be stored underground, 14 skeptics wondered how long the CO₂ would stay there; a sudden release of stored CO₂ could be catastrophic. They further noted gradual leaks would defeat the technology’s purpose and potentially acidify groundwater, causing new problems. Everyone, meanwhile, agreed much depended on the price of carbon, which was contingent on evolving carbon markets in the United States and Europe.

A new bill with a mix of carbon trading and taxes was in the works in March 2010, and in the absence of Congressional action, the EPA was preparing to regulate CO₂ under the Clean Air Act per order of the U.S. Supreme Court in its 2007 decision Massachusetts v. EPA. 15 Despite the overall failure of the Copenhagen Climate Conference in December 2009—Constantz considered the attempt to negotiate a successor to the Kyoto Protocol “a joke”—the United States did pledge, though not bindingly, to reduce its GHG emissions 17% from 2005 levels by 2020 and ultimately 83% by 2050, a significant departure from the previous Bush administration’s promises. Already in January 2010, President Obama announced by Executive Order 13514 that the federal government would reduce its GHG emissions 28% from 2008 levels by 2020. The federal government was the single-largest consumer of energy in the United States. Nonetheless, Constantz claimed that even without climate change regulations, “We will be profitable. We don’t care. We don’t need a price on carbon.”

Moss Landing

Aside from climate change legislation, Constantz witnessed regulatory agencies “bending over backward to help us. Fortunately, people are in favor of what we’re doing because I think they see the higher purpose toward which we’re dedicated.” Calera’s process had proven

effective, for instance, at trapping sulfur dioxide emissions, currently regulated in the United States under the Acid Rain Program and other standards. Water regulators and air boards alike, a total of nine agencies, eased the way for Calera’s first plant at Moss Landing, California. The site, 200 acres along the Monterey Bay, had seven three-million-gallon tanks for storing seawater, a total volume equivalent to 30 Olympic swimming pools, and permits for pumping 60 million gallons of seawater per day, or nearly 700 gallons per second, through the original World War II-era redwood pipe. The site also had five million tons of magnesium hydroxide left from earlier operations, which included making bombs.

In June 2008, Calera collaborated with nearby Monterey Bay Aquarium Research Institute and Moss Landing Marine Lab to assess and minimize impacts on the bay’s marine ecosystems. Water was a key element of the Calera process and everything was done to minimize the use of water. Constantz told a local paper:

We wanted to make sure we weren’t going to do any harm. We’re right next to these world-class oceanographic institutions. These places can publish papers about [the process], whereas most parts of the world don’t have scientists of that caliber to sign off on it.\(^\text{16}\)

Calera was interested in using the power plant’s water, potentially reducing demand for and impacts on Monterey Bay water. Constantz knew Moss Landing would set the standard for future plants. In fact, turning a site with a negative environmental history into a location that demonstrated clean energy and potable water technologies was very appealing to the entire management team.

The magnesium hydroxide, meanwhile, formed a gray-and-white crust that stretched for hundreds of yards and was visible from the sky. It provided the alkalinity for Calera’s early production. Massive metal sheds on the otherwise muddy soil housed a variety of production lines. As important, across the street stood the largest power plant on the West Coast, Dynegy’s 2,500 MW natural-gas fired plant.

In August 2008, Calera opened its test cement production plant. In April 2009, it achieved continuous operation and was capturing with 70% efficiency CO₂ emissions from a simulated 0.5 MW coal-fired power plant.\(^\text{17}\) In December 2009, Calera ran a pipe beneath the road to tap into Dynegy’s flue stack, somewhat like sticking a straw in a drink, to capture emissions equivalent to a 10 MW plant as Calera moved up to a demonstration scale project. By spring 2010, the demonstration plant, 20 times the size of the pilot plant, had achieved continuous operation.

A typical cement plant might produce between 500,000 and two million tons of cement annually, which meant Calera’s Moss Landing Cement Company (Figure 1) would remain a rather small player—or become a massive consumer of water. Seawater was typically only 0.1%

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\(^{17}\) Lassiter et al., 1.
magnesium ions and 0.04% calcium ions. Hence, if Calera could extract those ions with perfect efficiency, it could create about 240 tons of calcium and magnesium daily, enough to make just under 590 tons of Calera cement a day. At continuous operation, Calera could produce only about 215,000 tons of cement annually. Calera’s Moss Landing plant could therefore sequester just over 100,000 tons of CO₂ per year at full operation with its current water permit.

Figure 1. Moss Landing Cement Company

Note: The smokestacks at the center were the Dynegy power plant. To the right was Calera’s Moss Landing Cement Company, including its demonstration plant, seawater holding tanks, and remaining magnesium hydroxide.


Disruption: Opponents and Competitors

Calera, however, had the promise to be more than a cement plant. In taking raw flue gas into its process, Calera could also sequester (SO₂), a regulated pollutant responsible for acid rain. Because it could sequester CO₂ and SO₂ as well as mercury into carbonates, Calera offered a multipollutant control and remediation technology that might prove to be cheaper than existing methods and generated additional income from the sale of its byproducts, cement, and demineralized water. The promise of the multiple benefits of Calera’s process attracted attention from many quarters. California’s Department of Transportation was interested, since California used more concrete than any other state and had its own GHG cap-and-trade program. Egyptian, Moroccan, and Saudi Arabian researchers and builders had expressed interest in the process.

19 These values assumed all of Calera’s cement was calcium and magnesium carbonates. Calcium carbonate had a molecular weight of 100 g per mole; magnesium carbonate had a molecular weight of 84 per mole. CO₂ thus represented almost exactly half the weight of each ton of Calera cement produced from standard seawater. This CO₂ proportion, however, would not include emissions from energy needed to operate the plant.
because of its desalination aspect; Masdar City, a zero-emissions showcase in the United Arab Emirates, had considered using Calera cement.\textsuperscript{20} And power plants and cement kilns were seeking ways to lower their emissions. Calera was awarded a grant early in 2010 from the Australian government to build a demonstration plant to capture carbon from a coal-fired plant. Australia’s coal plants burned particularly dirty brown coal. By January 2010, Constantz had “a backlog” of 70 people representing 100 projects. “Selecting the right one,” he said, “is a proprietary, large process,” which included consideration of local feedstock, regulations, buyers and suppliers, and incentives, among other factors.

In addition to considering his suitors, material resources, and business opportunities, Constantz had to consider his competition. Other companies were also trying to make cement in innovative ways to reduce GHG emissions. Already, in 1979, German-born architect Wolf Hilbertz had published a way to produce calcium carbonate from seawater via electrolysis.\textsuperscript{21} That method had been commercialized as Biorock, used to help restore coral reefs by plating calcium carbonate onto rebar. Biorock, however, did not seem interested in pursuing terrestrial applications. In contrast, Novacem, in England, planned to use magnesium oxide and other additives to lower processing temperatures and obviate GHG emissions from cement kilns. Other companies were attempting to sequester carbon dioxide in cement as well. Carbon Sciences of Santa Barbara planned to use mine slimes (water plus magnesium and calcium residues left in mines) and flue gas to make cement, and Carbon Sense Solutions in Nova Scotia planned to use flue gases to cure cement, thereby absorbing carbon dioxide. Nonetheless, Calera so far had kept ahead of these possible competitors and worked on ensuring its products met familiar engineering performance standards in order to speed adoption.

Building performance aside, climate scientist Ken Caldeira at the Carnegie Institution for Science’s Department of Global Ecology had publicly expressed doubt that the Calera process would reduce net carbon emissions, given that it currently used magnesium or sodium hydroxides, which would have to be produced somehow and did not seem included in lifecycle analyses of carbon emissions. Caldeira had also said Calera basically took dissolved limestone and converted it back into limestone, and there were active discussions online around this issue.\textsuperscript{22} Calera simply waited for its patents to be published rather than directly refute the charge.

Meanwhile, Portland cement was the industrial standard and had been since its invention in 1824. Any change was likely to meet with resistance from producers and consumers, and the standards-setting bodies were necessarily conservative and cautious. An array of diverse organizations including the American National Standards Institute’s American Standards for Testing and Materials and the Portland Cement Association and American Concrete Institute conducted their own rigorous quality tests and set many standards.

\textsuperscript{20} Ben Block, “Capturing Carbon Emissions…in Cement?” Worldwatch Institute, January 26, 2009.
\textsuperscript{22} The debate seemed to occur mainly via e-mail and groups, for instance, http://groups.google.com/group/climateintervention/browse_thread/thread/7b5ff4ee64ce759d?pli=1 (accessed August 26, 2010).
Ironically, far from seeing an opponent in the Portland cement industry, Constantz considered himself an ally:

I think we’re going to save their entire industry. As soon as there’s carbon legislation, the asphalt industry is going to eat their lunch. The Portland cement industry is really in trouble without us and they know that. That’s why they’re calling us up.

After all, the industry had tried to reduce emissions by increasing efficiency but could only do so much. Calera’s process appeared the breakthrough the industry needed. Moreover, the infrastructure already existed to link cement plants with power plants because the latter often had to dispose of fly ash. Likewise, power plants consumed lots of water, meaning the infrastructure existed to supply the Calera process, presuming the water contained sufficient salts.

Constantz believed Calera could disrupt the carbon sequestration industry, primarily oil and gas exploration companies that had been advocating enhanced recovery through injecting CO₂ underground as a form of geological carbon sequestration: Injecting compressed CO₂ underground forced more oil and gas to the surface. Khosla agreed but was uncertain about the breadth of applicability of the Calera process. An attractive business and a few plants were definitely possible but Calera had yet to prove it was anything more than a solution for some special cases.

To do so, Calera hoped to outperform all other existing CCS options, especially retrofits of existing plants. Even if the technical and environmental problems could be solved for widespread CCS, it would be costly, especially in a world without a price on carbon. In April 2010, the U.S. Interagency Task Force on Carbon Capture and Storage estimated the cost of building typical CCS into new coal-fired plants (greenfield development) to be $60 to $114 per metric ton of CO₂ avoided, and $103 per ton for retrofitting existing plants. That translated into increased capital costs of 25% to 80%. Such plants were also expected to consume 35% to 90% more water than similar plants without CCS.

To operate, conventionally available CCS technology required energy, the so-called parasitic load it placed on power plants whose emissions it sequestered. This parasitic load represented a very high cost and penalty for the power plant, as it was essentially lost electricity, translating directly into lost revenue. To cover the electricity needed to operate any system that trapped CO₂ emissions from the flue and still supply its other customers, the power plant would have to consume more coal and operate longer for the same income. Constantz noted that geologic CCS typically had parasitic loads around 30%; to solve this issue, Calera’s business model was to buy power at wholesale price, becoming the power plant’s electricity customer. The plant could increase its capacity factor to cover this additional power demand or reduce its power sales to the grid without a change in revenue. From the perspective of the plant, then, Calera did not alter revenue, unlike it would have for other options. Constantz believed Calera’s

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23 Report of the Interagency Task Force on Carbon Capture and Storage, April 2010, 27, 33–35. The report did not consider a model such as Calera’s to be CCS; instead, it defined CCS only as geological sequestration.
energy consumption could be much lower than those of CCS, assuming the right local mineral and brine inputs could be exploited. In addition, to optimize its power use and price, Calera was designing a process that could take advantage of off-peak power. But it remained uncertain how many locations met mineral input requirements to make the Calera process economically attractive.

Calera could disrupt other conventional pollution control industries. Existing technologies to control SOx, mercury, and other emissions could be supplanted by Calera’s technology. Such pollutants were subject to either cap-and-trade programs or Best Available Control Technology (a U.S. Clean Air Act pollution control standard). The cost to power plants could be as high as USD500 to USD700 per kWh to remove these pollutants from flue gas. Early experiments suggested that Calera’s process could trap these pollutants with over 90% efficiency in a single system, though NOx would still need to be dealt with.

Conceivably, utilities could balk at the prospect of selling a large portion of their electricity to Calera, even if Calera set up shop where carbon was capped, such as the European Union, or approached companies wanting to reduce their emissions voluntarily. Utilities could switch to natural gas or find other ways to cut emissions. Calera, however, saw enough value in its own process and the coal-fired infrastructure that it had considered buying power plants outright and operating them itself.

Finally, Calera considered the possibility of providing a form of energy storage. Power plants could operate more at night (typically when demand was lower) to supply energy for Calera’s electrochemistry process, effectively storing energy in the form of other chemicals. During the day, there would be no increased energy demand from Calera, effectively increasing a power plant’s peak energy output. In the same manner, Calera could also store energy from wind farms or other renewable sources.

Managing Growth

With many people eager to exploit Calera’s technology, the company emphasized maintaining control. From the beginning, Constantz had limited the number of outside investors to the well-known venture capital investor Vinod Khosla. Khosla cofounded Sun Microsystems in 1982 and left five years later for the venture capital firm Kleiner Perkins Caufield & Byers. Khosla founded his own firm, Khosla Ventures, in Menlo Park, California, in 2004, and invested his own money in sustainable and environmental business innovations. By May 2009, Khosla had put a significant investment into Calera. Despite two rounds of investments, adding seven seasoned vice presidents for functions ranging from intellectual property to government affairs, and successful movement from batch process, to continuous-operation pilot plant, to demonstration plant, Calera still had a board of only two members: Constantz and Samir Kaul of Khosla Ventures. “The largest risk of this company or any other company in this space is board problems,” Constantz explained. “Because Calera had just one investor, it had been spared the

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24 Lassiter et al., 7.
problems of several board members, which can tank visionary startups.” Bad advice or conflicts posed a bigger threat than “the technology or the market,” a lesson he had taken to heart from his previous enterprises.

The company also protected itself from liability by creating special purpose entities (SPEs) to operate individual projects. According to Constantz, “We’re a corporation licensing its technology and intellectual property to other [SPEs] we’ve set up.” For example, the Moss Landing facility was owned and operated by the Moss Landing Cement Company, of which Calera owned 100%. This division allowed Calera to reduce the threat of litigation as well as insurance costs at its nearby Silicon Valley office headquarters; this was significant because cement production and associated construction were heavy industries in which equipment scale and complexity could involve expensive mistakes and working conditions posed many hazards. At Moss Landing, for example, the sodium hydroxide produced by electrochemistry on-site was a toxic product; everyone at the Moss Landing site was required to wear hardhats and protective eyewear.

The company also had grown to absorb more areas of technical expertise. Aurelia Setton had come to Calera in mid-2008 as senior manager of corporate development after completing her MBA at Stanford Business School; she went on to become director of strategic planning in the summer of 2009. Young and committed to sustainable business thinking, Setton had seen the company realize the implications of different technology applications and then move to recruit experts in those areas. First, it was how to produce cement with less energy and then how to boost its ability to sequester CO₂. Then it was water purification. Then it was electrochemistry, the process of extracting chemicals through splitting them in solution. “If we see enough value in it, we bring it in-house,” Setton said.

Nonetheless, Calera had to recognize limits. For instance, Setton said, “We are not a manufacturing company. Those partnerships are very complicated. People are very interested in getting into our IP, and we need their help, but there’s only one Calera and several of them.” Hence, Calera management believed the company could dictate its terms.

Calera entered a worldwide strategic alliance with Bechtel in December 2009. Bechtel was a global engineering, procurement, and construction (EPC) firm with 49,000 employees. Based in San Francisco, Bechtel operated in about 50 countries and generated USD31.4 billion in revenues in 2008. Its past projects included the Channel Tunnel connecting England and France and the San Francisco-area metro system, BART (Bay Area Rapid Transit), as well as military bases, oil refineries, airports and seaports, nuclear and fossil-fired power plants, and railroad infrastructure. Calera worked closely with Renewables and New Technology inside Bechtel’s Power Business Unit. That division had experience with CCS and government grant applications and contracts, all of which could help Calera. Bechtel also offered a massive network of suppliers. “We didn’t want to go out to a lot of EPC firms,” Constantz explained. “We opted to

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25 Case writer interview with Aurelia Setton, Los Gatos, California, 2010; unless otherwise indicated, all subsequent attributions derive from this interview.
just go to one firm and let them see what we’re doing.” Bechtel advised Calera on the
collection of its demonstration plant and played a pivotal role in worldwide deployment.

Calera was pursuing other possible collaborators. One was Schlumberger, the oil field
and drilling firm with 77,000 employees and USD27 billion in revenues in 2008. Calera sought
Schlumberger’s expertise in extracting subsurface brines, which were needed to replace seawater
for Calera’s process for inland locations. In early 2010, Calera was also in the midst of signing a
deal with a big supplier for its electrochemistry operations. Finally, for power plants, Constantz
considered Calera “just another industrial user. We can fight over who keeps carbon credits and
all that, but the only time we have a relationship is if they invest in a plant, and we don’t need
them to invest.” Nonetheless, Setton believed Calera had leverage in negotiating the terms with a
power plant for electricity and carbon dioxide.

Quantifying Economic Opportunities

Setton divided Calera’s possible services into four major categories (Exhibit 5): clean
power, material efficiency, carbon management, and environmental sustainability. These
opportunities were often interconnected, complex, and affected by changing regulations and
markets; so to make money, the company had to manage this complexity and educate multiple
audiences. It seemed a daunting, if exciting, balancing act for Setton. Yet in the Australian
government and TRUenergy, Calera found a client eager to see what it could do.

The Latrobe Valley, site of TRUenergy’s Yallourn power station in the state of Victoria,
Australia, contained about 20% of the world’s and over 90% of Australia’s known reserves of
lignite, brown coal—an especially dirty and consequently cheap coal. In 2006–07, Australia
produced 65.6 million metric tons of brown coal valued at (Australian dollar) AUD820 million,
or about USD10 per ton.26 Australia accounted for about 8% of the world’s coal exports, and its
lignite accounted for about 85% of electricity generation in Victoria. The Labor government had
proposed carbon trading in 2009, but that plan had been faltering through 2010. The coal
industry, nonetheless, had invested in various demonstration projects to make brown coal a
cleaner source of electricity. Bringing a Calera demonstration plant to the Yallourn power station
was another such endeavor. The Calera project would eventually be increased to a scale of 200
megawatts (MW).

The entire Yallourn power station had a capacity of 1,480 MW and voracious demand for
resources. The plant needed thousands of tons of water per hour at full capacity. Some of that
water would need to be sent to treatment afterward. The plant also had the low energy-
conversion efficiency typical of coal-fired plants. Compounding that, the plant’s brown coal had
a low energy density, about 8.6 gigajoules (GJ) per ton. In addition, combusting brown coal

2010).
creates more SOx and NOx than other fuels, and both pollutants were regulated in Australia. (Although it was difficult to put an exact price on the cost of controlling emissions in Australia, trading programs in the United States provided some insight. The United States ran a cap-and-trade program for NOx and SOx for power plants on the East Coast, and from January 2008 to July 2010, permits to emit one ton of SOx varied from USD600 to USD50 per ton; during that time, NOx allowances declined from USD800 to USD50 per ton. Since the price of an allowance ideally represented the marginal cost to abate an additional ton of emissions, it reflects the cost of control technology. Calera claimed its process, as noted earlier, could achieve up to 90% CO2 reduction and do so at a lower price if local resources could provide valuable feedstock.)

Calera planned to look for brines to provide alkalinity for the Calera process. If they were not available locally, Calera knew it would have to produce alkalinity with its proprietary electrochemistry process, which would increase the cost of cement production. The economics of the project would depend highly on the price it could get for its cement. Calera had the potential to use wastewater to provide calcium (Exhibit 6): About 100 miles from the TRUenergy plant, a large-scale desalination project was under construction, which would provide a potential feedstock for the Calera process. Utilizing wastewater streams also offered potential revenue: For example, in Europe, a desalination plant had to pay up to EU200 per ton to dispose of its brine. Calera considered using fly ash, a coal-combustion waste, for additional alkaline material. Although prices would be different for Australia, Calera could turn a local waste into an asset. Calera also considered using fly ash, a coal-combustion waste, for additional alkaline material.

With many variables and several unknowns, it was critical to determine the cost of each part of the process to establish the viability of the entire project. Nonetheless, the models depended on various assumptions, and those assumptions changed constantly as the project configuration and other factors changed. Nobody had ever before built a Calera system in the field. That left much uncertainty in actual numbers. It also left uncertainty in broader strategies. Under many scenarios, Calera’s energy demand would remain far less than the parasitic load of other CCS options. On the other hand, in some scenarios, Calera would need to have closer to 50% echem, which would represent a high energy requirement. How many sites could compete with CCS in energy requirements? How should that affect the business model and expansion plan of the Calera model?

TRUenergy, for sure, could greatly benefit from Calera, beyond the CO2 capture potential. TRUenergy was a wholly owned subsidiary of the CLP Holdings Group, an electricity generation, distribution, and transmission investor based in Hong Kong with assets in India, China, Southeast Asia, and Australia. Lessons CLP learned now could pay dividends later, and

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27 The exact NOx and SOx emissions, before pollution control, depended on the design of the combustion unit, but for a variety of designs, U.S. EPA estimated SOx emissions to be 5 kg to 15 kg per ton of lignite burned and NOx emissions to be 1.8 to 7.5 kg per ton of lignite burned. EPA, “Chapter 1: External Combustion Sources,” AP 42, 5th ed., 1998, 1.7–8.

the company had committed to lowering its carbon intensity.\textsuperscript{29} The Yallourn power station, which could have an operating life of 40 or more years, could attempt to gain a strategic advantage and improved public image by reducing its carbon emissions in anticipation of eventual regulation. The plant could also potentially use Calera’s processes to lower SOx emissions. Calera’s cement could directly trap these particulates. Indirectly, the plant could decrease generation at times when SOx emissions were most destructive (typically hot, sunny days) and SOx controls typically most expensive. This load shifting could save money on pollution controls or new generation capacity and could be compensated for by increased production for Calera at other times.

Next Steps

Setton sat in her office, which adjoined Constantz’s in the building Calera shared with the Los Gatos Public Library. Outside her door, a dozen employees worked at cubicles whose low partitions made them function more like side-by-side desks. In the foyer, a light flashed in a bubble containing a toy-sized display representing carbon dioxide moving from a power plant to a Calera cement plant and then to a concrete mixer truck. Bits of chalky stones, like the ones in vials on Constantz’s desk, represented Calera’s product. The company had grown rapidly and showed enormous promise, but it had yet to build full-scale commercial plants to fulfill that promise. Setton summarized the situation:

To innovate means you have to protect yourself, have to convince people, have to prove quickly, and have to deploy widely. Two strategic questions are important: One, what are the partnerships that will help us convince the world and bring it to reality? And second, how fast can we deploy? That means resources and allocation. How much do we keep in house; how much do we outsource without losing our protection? Those are key questions as we grow fast.

Exhibit 1

CALERA: ENTREPRENEURSHIP, INNOVATION, AND SUSTAINABILITY

U.S. GHG Emissions by Gas, 2008, MtCO$_2$eq

MtCO$_2$eq = million metric tons of carbon dioxide equivalent.

Exhibit 2
CALERA: ENTREPRENEURSHIP, INNOVATION, AND SUSTAINABILITY

Global CO₂ Emissions from Stationary Sources Greater than 100,000 Tons of CO₂

(a) Global CO₂ Emissions, Major Stationary Sources

Exhibit 2 (continued)

(b) Global Stationary CO₂ Emissions
(percentage of total)

Note: Values for power generation were from 2000; other values were from 2003; 90% of all emissions from stationary sources came from stationary sources that emitted more than 100,000 tons per year. Asia comprised about 40% of such sources, followed by 20% in North America.

Exhibit 3
CALERA: ENTREPRENEURSHIP, INNOVATION, AND SUSTAINABILITY
Lifecycle for Portland Cement Produced by Dry Process and Mixed into Concrete

Data source: Created by case writer.
Exhibit 4
CALERA: ENTREPRENEURSHIP, INNOVATION, AND SUSTAINABILITY

Approximate Lifecycle for Calera Cement

Data source: Calera.

- Pump seawater into storage tanks
- Contact CO₂ with seawater and additives
- Collect calcium carbonate and magnesium carbonate that forms
- Dry and grind

- Energy to pump
- Additives, including hydroxide
- CO₂

- Emissions from pumping
- Emissions from creating additives
- Demineralized water
- Emissions from fossil fuels

- Emissions from creating additives
- Additives, including hydroxide
- CO₂

- Calera cement enters same lifecycle as Portland cement at this point (Distribute, mix to make concrete, etc.)
Exhibit 5

CALERA: ENTREPRENEURSHIP, INNOVATION, AND SUSTAINABILITY

Calera Industrial Ecosystem Material and Energy Flows

Source: Created by case writer.
Exhibit 5

CALERA: ENTREPRENEURSHIP, INNOVATION, AND SUSTAINABILITY

Calera Revenue Opportunities

Climate Change Revenue Opportunities

**Clean Power**
- Clean Coal
- Plant Life Extension (kWh)
- Greenfield Development
- Energy storage
- Load Shifting

**Material Efficiency**
- Green Building Material
- Lightweight Structural Applications
- Freshwater Production

**Carbon Management**
- Carbon Credit Development
- Negative Carbon Life Cycle

**Environmental Sustainability**
- Waste Remediation
- Air Pollution Control

Source: Calera.
Exhibit 6
CALERA: ENTREPRENEURSHIP, INNOVATION, AND SUSTAINABILITY
Simplified Material and Energy Demands of Yallourn Demonstration Plant
Exhibit 6 (continued)

Exhibit 7
CALERA: ENTREPRENEURSHIP, INNOVATION, AND SUSTAINABILITY

Estimated Costs of CCS Technologies (Other than Calera)

Cost per Metric Ton CO$_2$ Avoided

<table>
<thead>
<tr>
<th>Technology</th>
<th>Cost (2010 $/ton CO$_2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New IGCC</td>
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</tr>
<tr>
<td>New Post-Combustion</td>
<td>$95</td>
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<tr>
<td>New Oxy-Combustion</td>
<td>$68</td>
</tr>
<tr>
<td>New NGCC</td>
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<tr>
<td>Retrofit Post-Combustion</td>
<td>$103</td>
</tr>
</tbody>
</table>

Note: IGCC = Integrated Gasification Combined Cycle; Post-Combustion = scrubber systems in flue gas; Oxy-Combustion = burning goal with purified oxygen instead of air; NGCC = Natural Gas Combined Cycle.

Data source: Modified from Report of the Interagency Task Force on Carbon Capture and Storage, Fig. III-1, p. 34