

Evolution of CO₂ Resulting from the Process of Seawater Electrolysis

Energy Systems
E.J. Zita
March 6, 2008

Report By
Dan Gossett
Riley Rex
Ben Schiffbauer

Abstract

Seawater electrolysis has a host of applications relevant to issues surrounding climate change. Building materials and hydrogen can both be derived from seawater electrolysis. By powering this process by renewable energy sources, the prospect of reducing the sum total of anthropogenic CO₂ emissions exists. Quantified data regarding the consequence of the process on atmospheric CO₂ levels is scarce. This work contains the details of a series of seawater electrolysis experiments that focus on the quantification of CO₂ emissions from a seawater electrolyte during the electrolysis process. It represents an undergraduate first step in an exploration of this process.

Introduction

Electrolysis is the application of current to a chemical solution resulting in an oxidation/reduction reaction about the electrodes. The Electrolysis of seawater, depending on controllable variables, can result the accretion of Calcium Carbonate (CaCO₃) on the cathode terminal. Given proper amperage inputs, this material can have a tensile strength greater than conventionally produced cement (Hilbertz). Startlingly, conventional cement production produces nearly one kilogram of CO₂ for every kilogram of cement (Worrel). The research questions pursued by our group stemmed from our concern regarding the significant release of carbon dioxide into the earth's atmosphere by conventional cement production.

The prospect of a "grown" (through electrolysis) commercially viable building material, with a carbon footprint less than that of cement, was considered by our team a worthy pursuit of study. Beyond the realm of accreted calcium carbonate as a building material, the potential of seawater electrolysis is relevant to a host of applications pertaining both to the catalysts and effects of climate change: The process has been used to create invigorated coral habitats more resistant to the stresses of higher ambient ocean temperatures and acidity (Hilbertz, Goreau). Structures could be electro-accreted into existence as costal protection to rising sea levels. Perhaps most significantly, seawater electrolysis is an instrumental component in one proposed societal response to climate change; Hydrogen gas, lauded by many as the energy carrier of the future, is another product of seawater electrolysis.

There is yet another, less than desirable, product of seawater electrolysis. Electrolysis generates heat at the electrodes. This heat, in turn, reduces the solubility of carbon monoxide (CO) within the seawater solution (Hilbertz, pp 243). With reduced solubility, the carbon monoxide is likely to escape the hydrosphere either as CO or, having combined with free oxygen atoms in the solution, CO₂.

"To fully assess the role of [accreted building materials] in the global atmospheric balance, the net effect of all electrolytic and biogenic reactions needs to be measured experimentally."

– Wolf H. Hilbertz

If we, as a community of nations, choose a hydrogen economy, it should be done so with a detailed understanding of the hydrogen and calcium carbonate extraction process, its products and by-products.

Research Question and Hypotheses

Does the process of electro accretion of CaCO_3 and $[\text{Mg}(\text{OH})_2]$ from sea water alter the concentration of CO_2 in the atmosphere of a finite environment?

There will be no change in the atmosphere of the finite environment due to the process of electro accretion in the electrolyte.

The process will result in a net increase in CO_2 within the finite environment.

The process will result in a net reduction of CO_2 within the atmosphere.

Methods

Early on our team decided to employ Fourier Transform Infrared Spectroscopy (FT-IR) to determine the concentration of CO_2 in atmosphere proximally relevant to the process of seawater electrolysis. Additionally, we were interested in the formation and quantity of accreted material on the cathode. The scanning electron microscope was to be employed to this end.

Initially, and periodically thereafter, we collected seawater from Eld Inlet. The seawater was analyzed using a hand-held YSI Model #85 for temperature, salinity (in ppt), dissolved oxygen content, conductivity, and specific conductivity. A Sentron 1001 meter to used to gauge pH.

Our team began by creating an electrolysis chamber within in 2L Erlenmeyer vacuum flask. We selected an appropriately sized, singularly holed, rubber cork to cap our vessel. The leads of both electrodes were strung with narrow gauge copper wire and terminated by alligator clips of an unknown alloy. These leads were then run through the rubber corks. We then sealed the hole with aquarium grade 100% silicon sealant. The sealant was allowed to dry for several weeks before the data contained within this report was collected. Two Luer-lock valves were connected to the vacuum protrusion of the vessel by an airtight rubber hose. This arrangement allowed us to control the vessels gaseous outflow.

We chose an RSR DC Power Supply model #HY3005 rectifier to supply the current to our electrochemical cell via the aforementioned leads. This model of rectifier provided us the ability to modulate the amperage and voltage we were to apply to the cell. We selected 1/5000th of an inch platinum wire as the submersible component of our

anode, and 1/16th inch aluminum mesh as our cathodes. Having been weighed prior to its role within the cell, the cathode was removed and replaced after each test series. We then reweighed the former cathode to determine the mass of the accreted material.

Via a rubber hose, our team then connected one of the Luer-lock valves on the electrochemical Erlenmeyer vessel to a 10cm potassium bromide windowed IR single gas pass cell (model #SP-10-G1). This cell was slotted into the IR beam path of our Perkin-Elmer Spectrum 2000 FT-IR Spectrometer. We also clipped the single gas pass cell's outlet to another length of rubber hose, leading the terminal end of this hose (the chamber's final outlet) into our laboratory's hood. In order to prevent atmospheric backflow contamination and prevent excessive pressure within our system we *partially* obstructed the end of this hose with tissue. Our goal was to create a one-way flow of gasses from the electrochemical cell, to the IR gas cell chamber, through the outlet hose and into the hood.

Prior to the application of electricity we placed a ½ inch Teflon coated stir bar into the electrolyte. We placed the flask onto a Corning stir plate set to the lowest setting. In this way, we simulated the natural flow and motion of Puget Sound waters. We filled the flask with 500mL of Puget Sound water, and arranged the electrodes within 2cm of each other. The platinum anode was placed with care above the cathode so that only the platinum anode, and not its alligator clip lead, was submerged in the electrolyte. This was done to minimize the oxidation (and possible contamination of the atmosphere) of the anode's alligator clip, which suspended above the electrolyte, was also sheathed in plastic. The Luer-lock valve remained closed and the cork sealed the chamber.

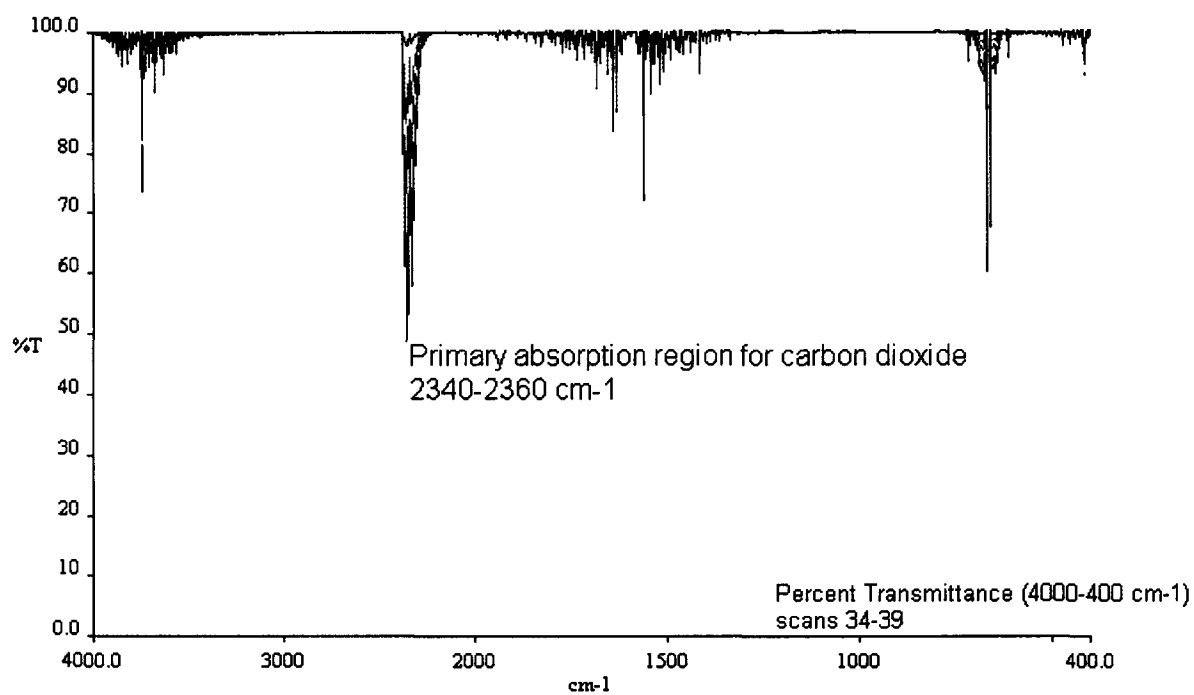
Together we decided to apply between 7.8 and 8.2 volts to our electrochemical cell within the flask. This produced a variable range of current from 400mA to 750mA. This range of currents primarily depended on the electrodes' proximity to one another. As current was applied, the Luer-lock valve was kept shut for the first five minutes to build up pressure while the FT-IR scanned the background. A background must be scanned in order to compare the sample scans to normal atmospheric gas composition. After five minutes, the Luer-lock valve was opened, allowing the accumulated and pressurized gas in the vessel to flow through the 10cm test chamber. We allowed the lines to flush for five minutes before running our first sample scan. Subsequent scans were run every ten minutes for one hour. The data presented in this report are the results from a series of five different 60 minute test runs in which a scan was performed 10 minutes after the initial application of current, and every ten minutes thereafter. Each test utilized a fresh quantity of Eld Inlet water and a new aluminum mesh cathode. The platinum anode was weighed after more than one of the tests and was found to have lost no measurable mass.

The final arrangement, as described above, was agreed upon after a long process of trial and error. Our first trial employed an anode of exposed copper wire and a cathode made from galvanized steel. The malleability of the copper wire allowed for the best proximal relationship of the electrodes and resulted in the most even coating of accreted material on the cathode. However, copper was quickly abandoned because of the obvious oxidation occurring at the anode. We also worked with stainless steel anodes, but here too oxidation was visibly evident. Upon weighing of the stainless steel anodes after electrolysis, they were found to have lost significant mass. Every anode material we used other than pure platinum severely changed the coloration of the water. In the end, platinum was the best choice for the anode.

The conditions of Test Series Five (T5) are slightly different from the other four test series. Rather than using just 500mL of seawater during electrolysis the T5 electrochemical cell contained 2000mL. In this configuration the electrodes were submersed well below the surface of the water.

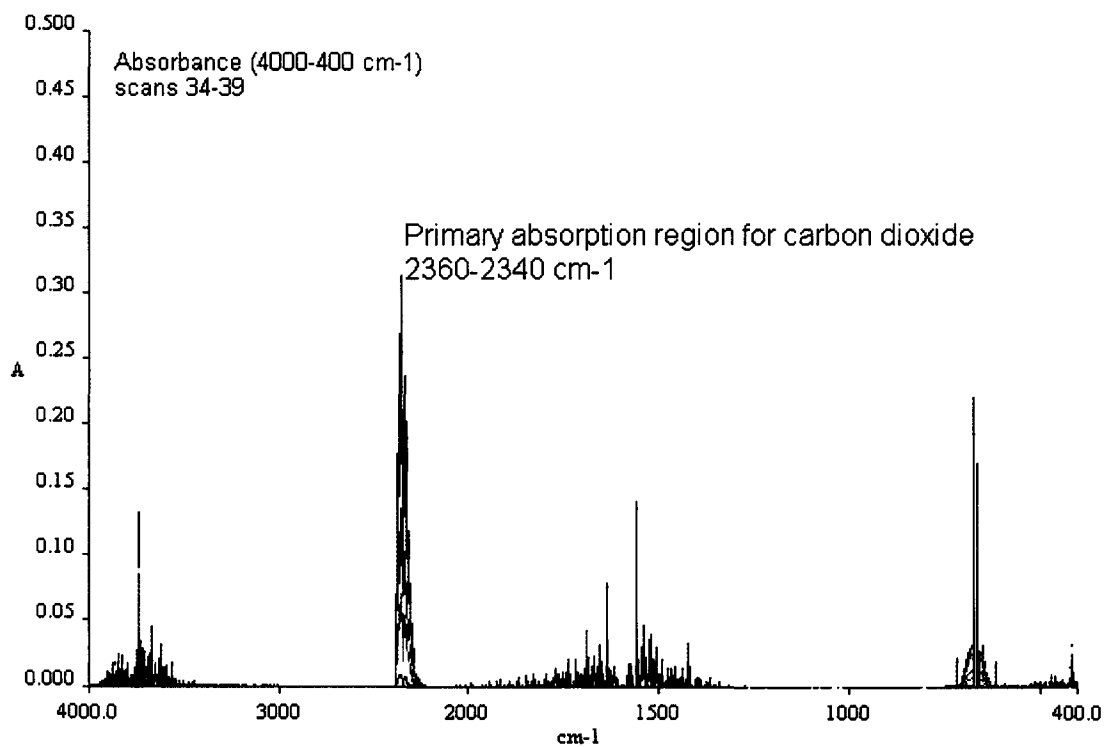
Results

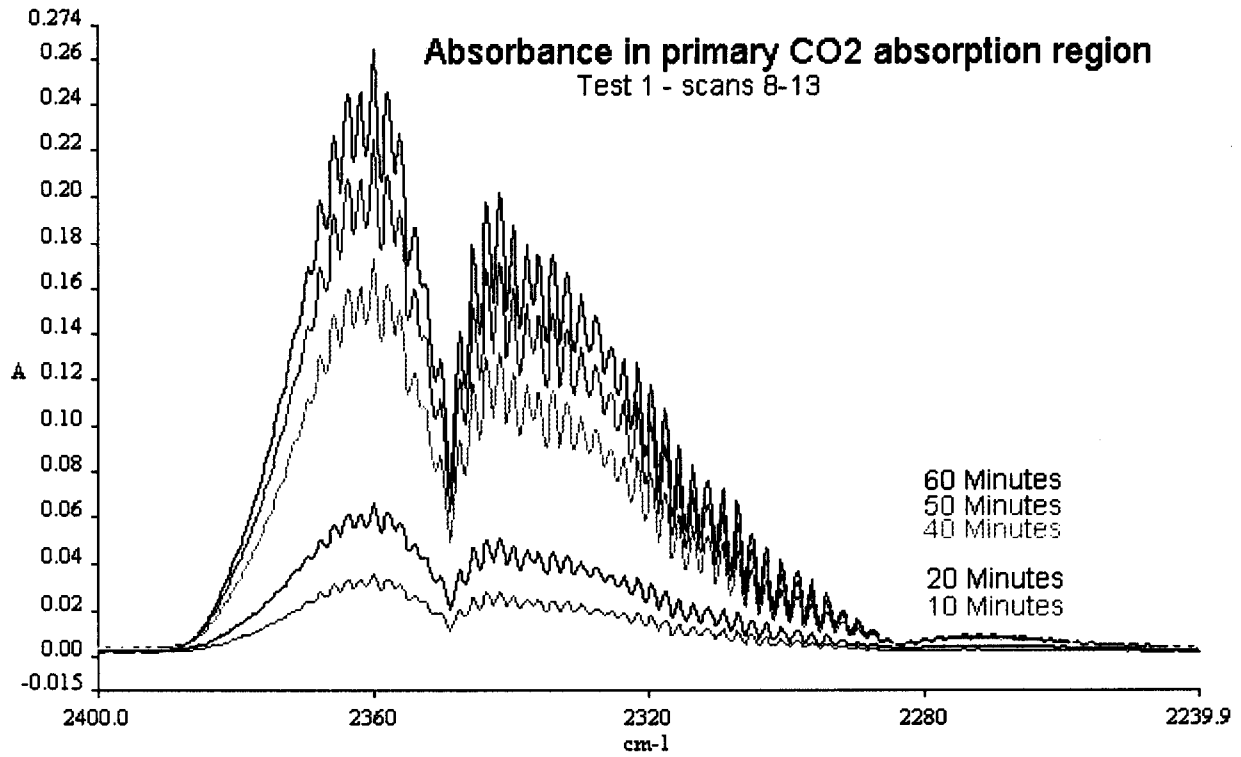
$$T=I/I_0$$



$$A = -\log T$$

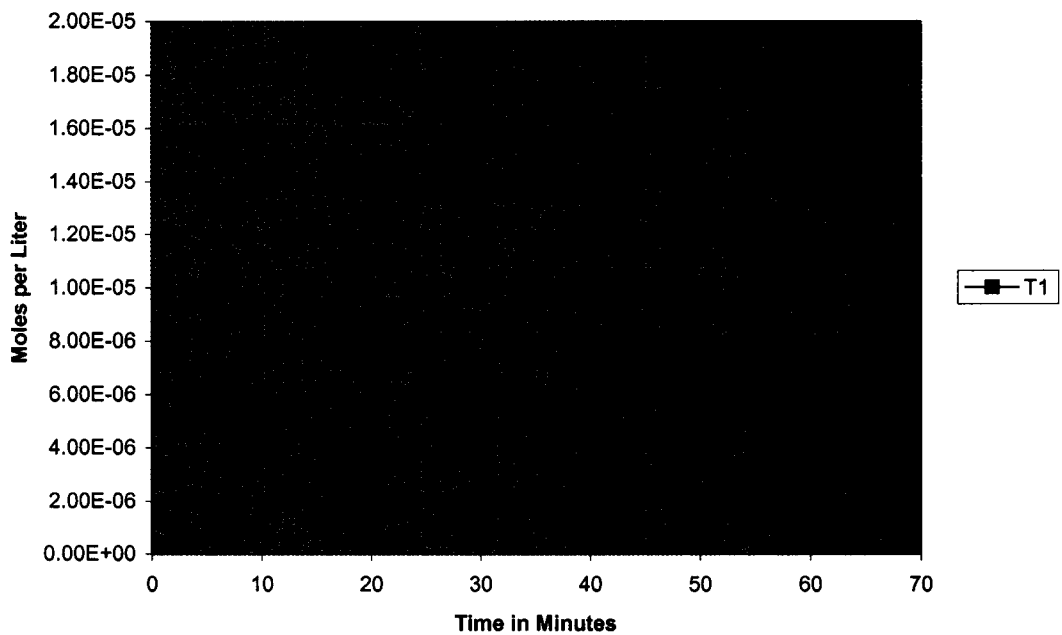
Date: 3/4/2008

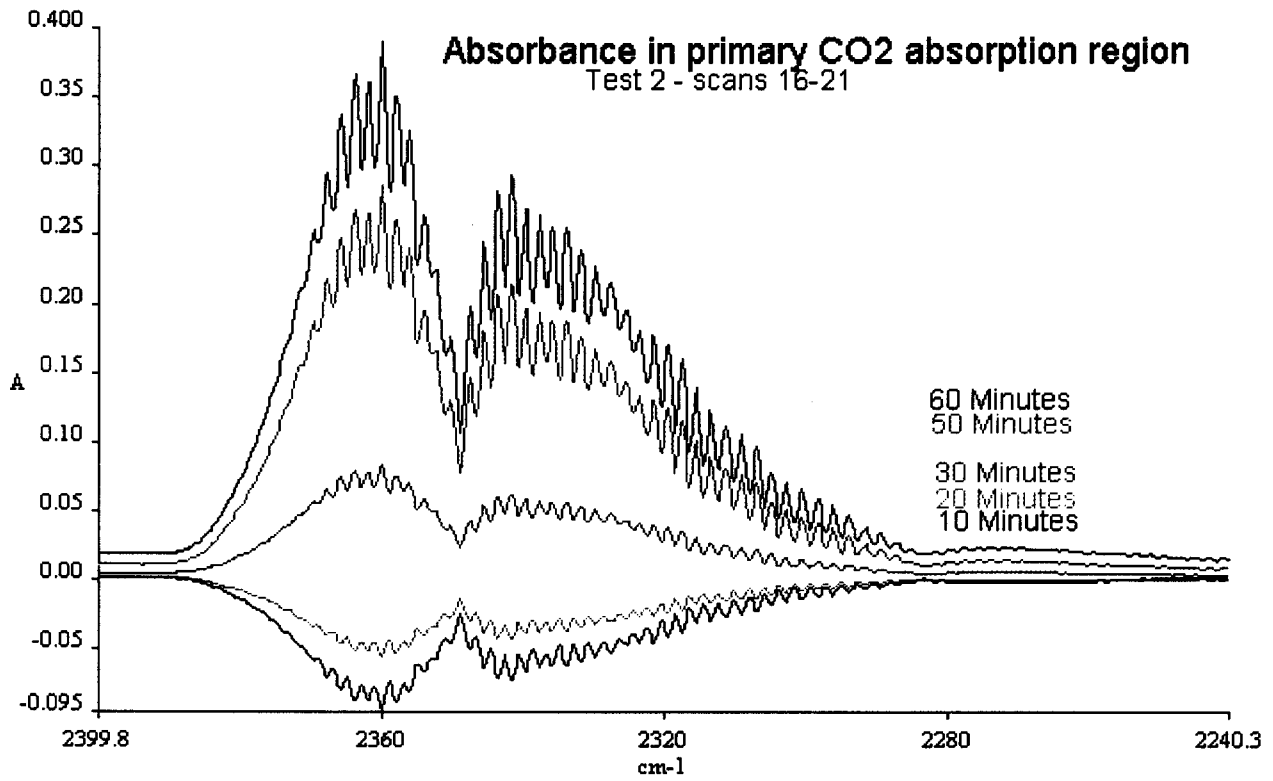




Voltage: 8.0-8.2
 Amperage: .39-.43
 Weight of the anode prior to electrolysis: .031g
 Weight of the anode after 60 minutes of electrolysis: .031g

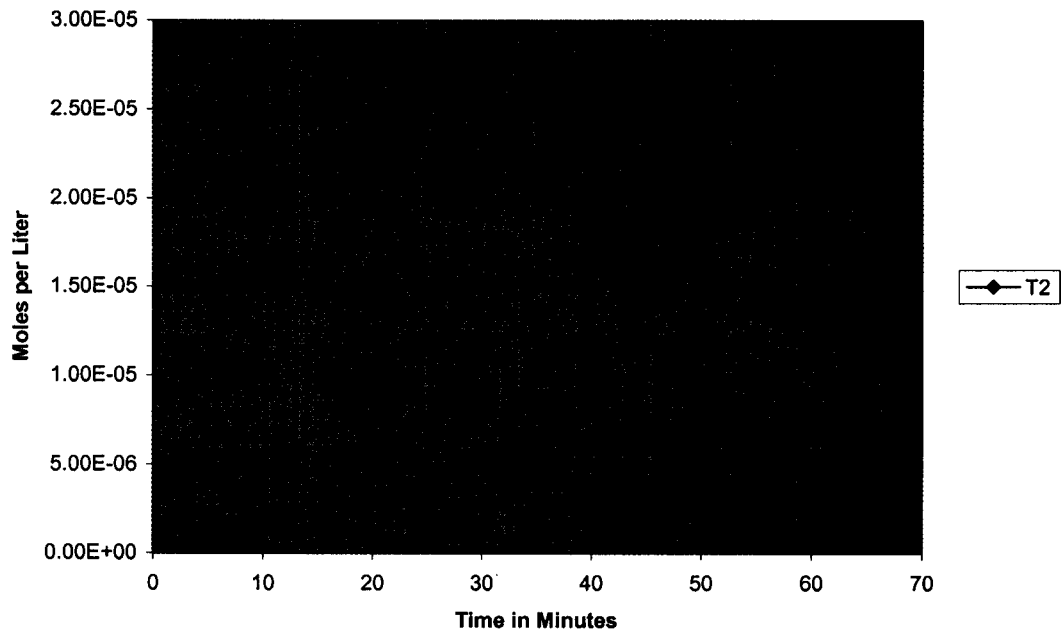
Test Series 1

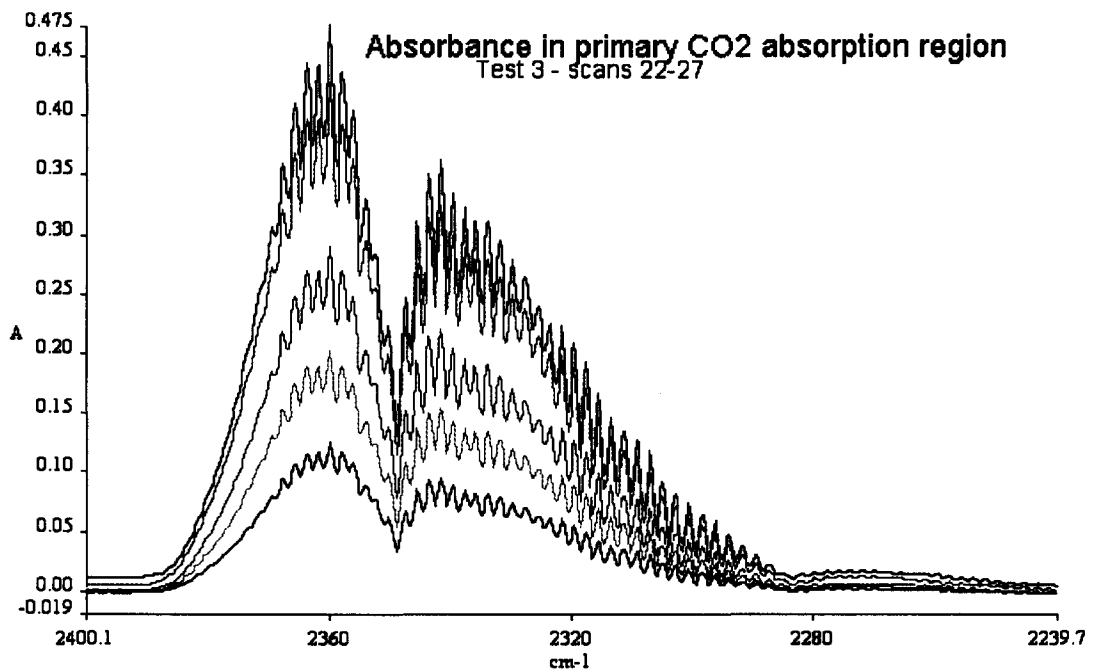




Voltage Range: 8.1v-8.2v
 Amperage Range: 750mA-790mA

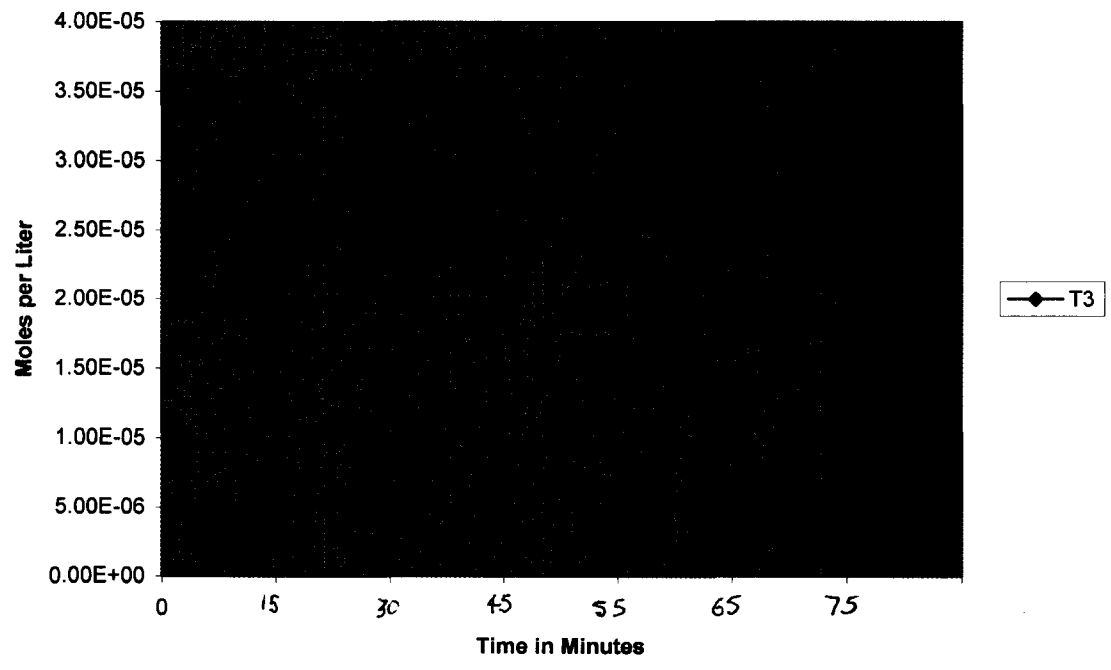
Test Series 2

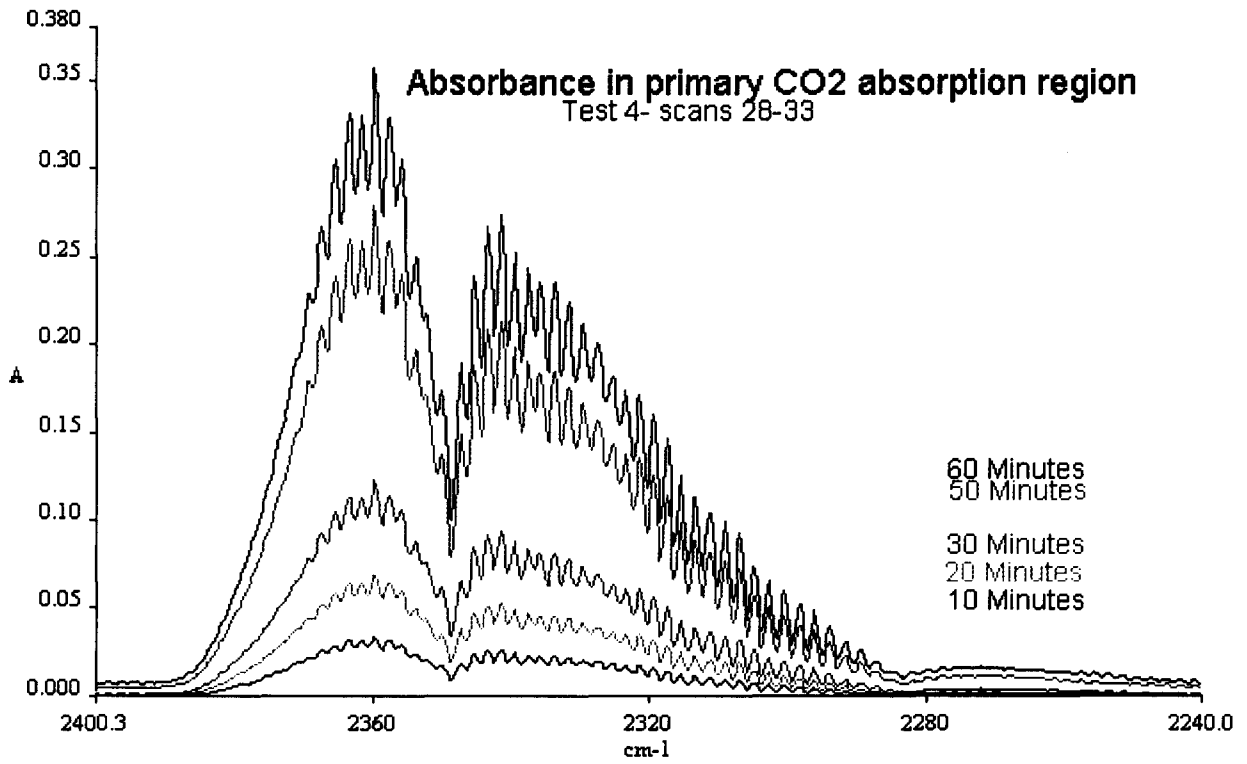




Voltage Range: 7.6v-7.7v
Amperage Range: 600mA-650mA

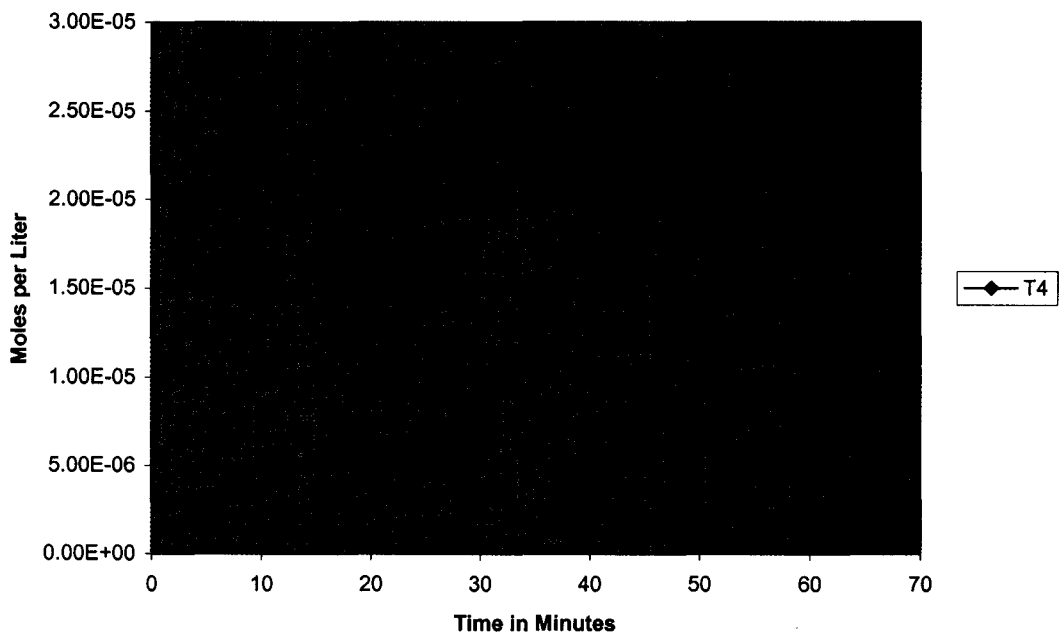
Test Series 3

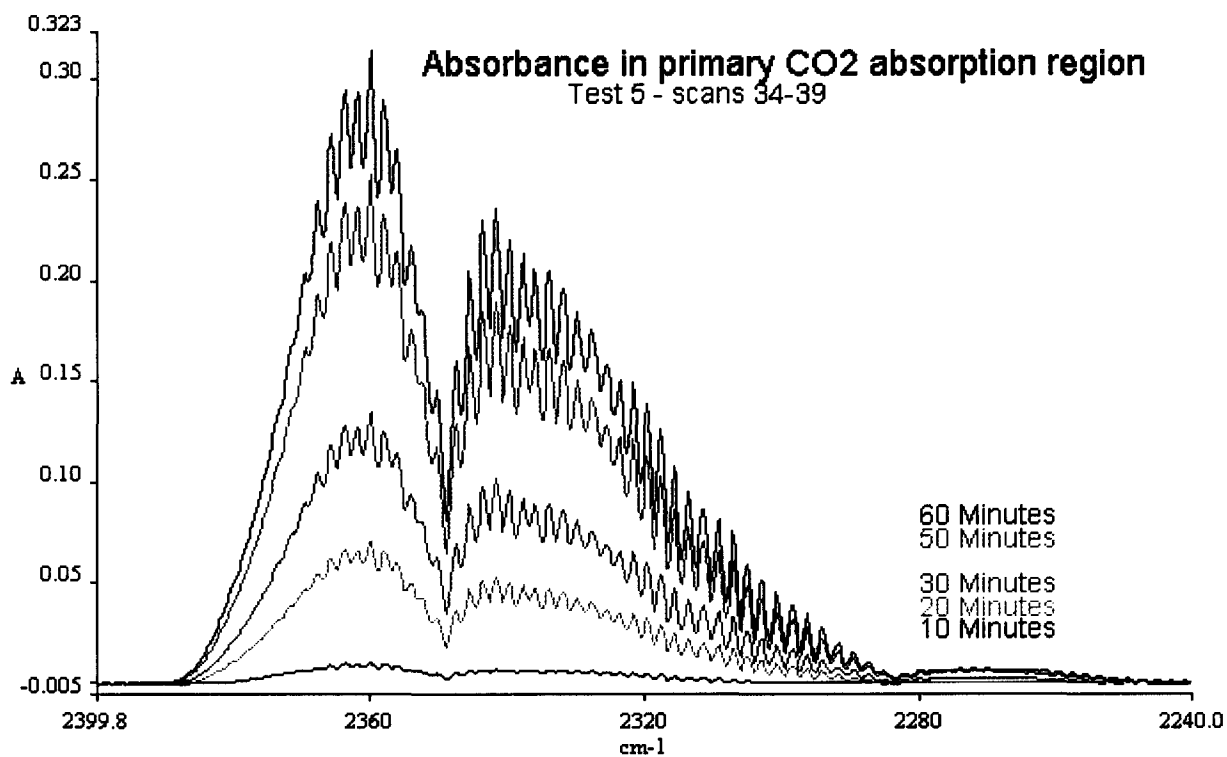




Voltage Range: 7.2v-7.5v
Amperage Range: 500mA-560mA

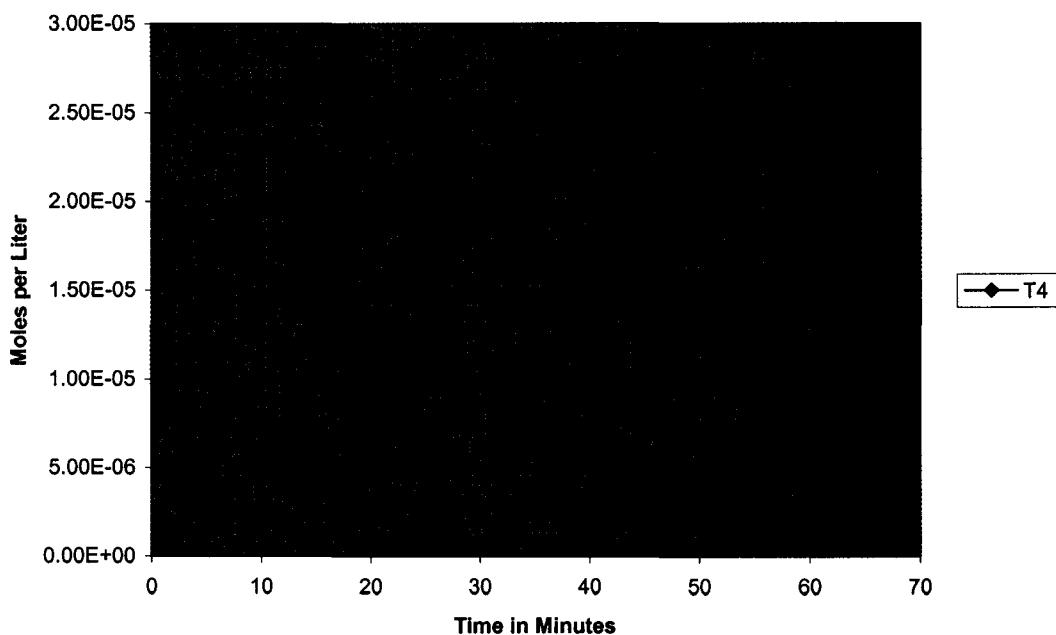
Test Series 4





Voltage Range: 6.7v-7.4v
 Amperage Range: 200mA-290mA
 Sea water volume: 2000mL

Test Series 4



Discussion

The infrared spectroscopy, which we employed for the purposes of analysis, is convention for the measurement of molecular compounds. When infrared radiation of a specific frequency encounters a molecule whose chemical bonds vibrate at an identical frequency, the molecule absorbs that radiation (Smith). The vibration/absorption frequencies of the CO₂ molecule, when converted into the wave number format (cm⁻¹) are 2350 and 667 (Brehens). During the course of our analysis, absorption of infrared radiation repeatedly occurred in both these bands of the spectra (see results). When quantifying atmospheric CO₂ concentrations our team chose the most prominent of CO₂ absorptions bands, that of the 2350 cm⁻¹ region. The foundations upon which these quantifications were produced are as follows: The intensity of IR of a specific frequency detected by the spectrograph after passing through the test gas divided by the intensity of the IR originally sent through the test gas is known as percent transmittance (T).

$$T=I/I_0$$

The negative log of this transmittance ratio is the absorbance (A).

$$A=-\log T$$

Utilizing the produced data and the Beer-Lambert Law, which states that absorbance is equal to the molar absorption (E) coefficient times the path length in cm (b) of the test chamber times the concentration of a component substance in moles per liter (c).

$$A=Ebc$$

$$A/Eb=c$$

In repeated tests, the results show an increase of CO₂ concentrations in the test cell. At 60 minutes in test one, the CO₂ approached 2.0x10⁻⁵ mol/L. This was the lowest 60-minute CO₂ level of any test. At an average of 410 mA, test one had the second lowest amperage. Test one and test four were most carefully run, with the best technique, and therefore are our most reliable data sets.

Test two had the highest amperage (avg. 770 mA) and showed the second highest 60 minute CO₂ concentration at almost 3.0x10⁻⁵ mol/L. This test certainly displayed the steepest increase in CO₂ levels over time. It must be noted that the background for test two was scanned when high CO₂ concentrations from test one were present in the test chamber. This CO₂ leaked from the chamber at a faster rate than the CO₂ from test two was initially flowing in. As seen in the results for test two, the 10 and 20-minute scans were reported as negative absorbance (meaning less CO₂ than the background) because the FT-IR was sensing the exiting CO₂. Regardless, test two still showed a trend

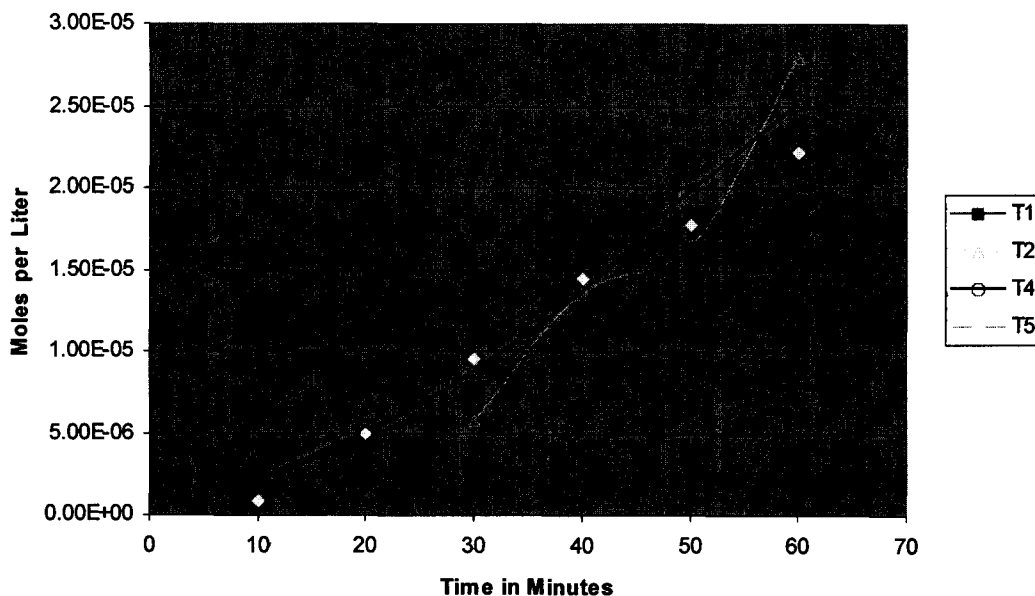
of increasing CO₂ concentrations being released in to the atmosphere as a result of seawater electrolysis.

At every time interval, test three had noticeably higher CO₂ levels than the other tests. With an average of 630 mA, test three was run with the second highest amperage. Our records show an irregularity in the time keeping pattern of test three. This test was run at fifteen-minute intervals instead of the ten-minute intervals. This clearly explains the outlying nature of test three data.

Test four is most comparable to test one, but run at slightly higher amperage (avg. 530 mA). Tests four and one start at the same point but four shows a steeper increase in CO₂ levels and ends at 2.5×10^{-5} mol/L. The data appears to show a correlation between amperage and the amount of CO₂ released into the atmosphere. This is an important correlation worthy of further investigation.

In test five, by increasing the volume of water by 1500 mL, we attempted to determine if processes in the water would inhibit CO₂ from exiting the hydrosphere. In order to place the electrodes near the bottom of the vessel, we had to submerge to alligator clip portion of the anode. Even though it was almost entirely covered by plastic, the alligator clip quickly became oxidized and degraded. The alligator clip then failed and led to the breaking away of the platinum portion. As mentioned in the methods, the alligator clip was made of an unknown alloy. We are uncertain of the effect of this alloy had on the seawater composition and possibly the composition of the atmosphere.

**Test Series Comparative
CO₂ Concentrations**



Because T5 is unique, and the unknowns caused by the oxidation of the alligator clip cannot be quantified, the data it contains cannot be compared to T1 and T4. The parameters of this test are sound. The questions we were attempting to answer with this test, whether the volume of water effects the movement of carbon to the atmosphere, will be a significant component of future work.

Conclusions

During the process of seawater electrolysis, carbon dioxide does reach the atmosphere. Given the variables specific to our T1 test, carbon dioxide built up in the test cell at a rate of 3.37×10^{-7} moles/liter per minute. For the variables specific to our T4 test, carbon dioxide built up at a rate of 4.98×10^{-7} moles/liter per minute. The one truly common denominator of all five of the test series was a steady increase over the course of an hour in the amount of CO₂ being detected by the FT-IR spectrometer. If our data can withstand further scrutiny, then the hydrogen generated by seawater electrolysis cannot be considered an entirely “green” energy carrier. The information we have so far gathered confirms that the process of accreting calcium carbonate as a building material has its own environmental consequences.

Future Work

It is easy to conclude that our research techniques have not produced the highest quality of information. It is our observation that in future scientific analysis, greater control of variables, and more stringent monitoring of the experiments outputs would greatly enhance our ability to produce meaningful conclusions. To that end, future work on the electrolysis process will include more thorough temperature and ph monitoring, greater control and standardization of amperage inputs, complete knowledge of chemical composition of all parts of the electrodes, deeper analysis of the seawater’s chemical make-up and more precise time keeping. With these lessons in mind, future questions we’d like to answer would be:

What is the effect of depth and electrolytic volume on the carbon output of this process?

What is the effect of amperage on the carbon output of this process?

What effect does the anodic material have on CO₂ emissions? What is the effect of anodic oxidation on the hydrosphere?

What biological processes could impede the escape of carbon dioxide from the hydrosphere?

What are the environmental consequences of this process on an industrial scale?

Acknowledgements

We'd like to thank the Evergreen State College for putting up with our radical ways, Evergreen State College Lab Stores for smiling though our incessant requests for the impossible, A. Jones, Mikako Gillespie, Peter Robinson, Paul Schofield, the occasional SIT, and E.J. Zita for inspiring our efforts by increasing our understanding and awareness.

Annotated Bibliography

Brehens, Harald, Nathalie Tamic and Francios Holtz. "Determination of the molar absorption coefficient for the infrared absorption band of CO₂ in rhyolitic glasses." American Mineralogist, Vol. 89 (2004): pp 301-306.

From this article, we obtained the molar absorbance coefficient for carbon dioxide. Given the peer-reviewed scientific journal in which the article is printed, this resource can be deemed reliable.

Hilbertz, Wolf H. "Solar-generated Building Material from Seawater as a Sink for Carbon." Building Research and Information, Vol. 19 (1991): pp 242-255.

The work contains information regarding seawater electrolysis that led to our main motivation for carrying out the research. The author was a leading expert on reef building with seawater electrolysis and the journal is a peer-reviewed scientific journal. We have determined the work to be absolutely reliable.

Hilbertz, Wolf H. and Thomas J. Goreau. United States Patent Number: 5,543,034; Method of Enhancing the Growth of Aquatic Organisms, and Structures Created Thereby. United States Patent Office, Filed Aug. 28, 1995.

The patent is particularly useful due to the high level of detail regarding the process. A clear understanding of the methods employed and the chemical reactions generated by those methods was attained from the patent. This reference is very reliable due to the authors and institution from which it emanates.

Munowitz, Michael. Principles of Chemistry. W.W. Norton and Company, New York: 2000. pp 607-637.

This chemistry textbook provided us with basic oxidation/reduction reaction, and the consequences of introducing electricity to an electrolyte.

Smith, Brian C. Fundamentals of Fourier Transform Spectroscopy. CRC Press, 1996. pp 30.

The work contained extensive information regarding topics related to our analysis method of FT-IR Spectroscopy. Specifically, we obtained the wave numbers at which carbon dioxide absorbs infrared radiation. Given the good reputation of the CRC Press, the credibility of this text is not in question.

Worrel, Ernst, Lynn Price, Nathan Martin, Chris Hendriks, and Leticia Ozawa Meida. "Carbon Dioxide Emissions from the Global Cement Industry." Annual Review of Energy and the Environment. Vol. 26 (2001): pp 303-329.

From this peer-reviewed journal, we sourced the information regarding carbon dioxide production from cement production.

The Processes and Applications of Electrolytically Induced Mineral Accretion

**Ben Schiffbauer and Miles Franzoni
E.J. Zita
Energy Systems Fall 2007**

“caution needs to be taken in equating carbon removal from the ocean with carbon removal from the atmosphere. When one molecule CaCO_3 , is precipitated from seawater, charge balance requires the formation of one molecule of carbonic acid and supersaturation of carbonic dioxide. If this escapes to the atmosphere, carbon is removed from the hydrosphere, but CO_2 added to the atmosphere. Therefore, deposition of CaCO_3 is often seen as a source of atmospheric CO_2 , ignoring all other reactions which could produce or consume acidity or CO_2 , SBM [Solar-generated Building Material] is a sink for carbon although its direct effect on the atmosphere has to be treated as controversial. To fully assess the role of SBM in the global atmospheric balance the net effect of all electrolytic and biogenic reactions needs to be measured experimentally” (SBM, Goreau, 1991, 4).

Hilbertz and Goreau may disagree about the properties of MA when the question of carbon sequestration is raised. In the September 1997 issue of Popular Mechanics, Wolfe Hilbertz exhibits his idea for a city, Autopia Ampere, grown using MA technology. He likens the ocean to a carbon ‘sponge’, and mentions “by removing carbon-containing compounds from the oceans, the mineral accretion process would help reduce the buildup of CO_2 , which is a greenhouse gas.” Obviously, questions will remain about the efficacy of SBM as a sink for carbon until “the net effect of all electrolytic and biogenic reactions [is] measured experimentally” (SBM, Goreau, 1991, 4).

The process of MA has been shown to stimulate coral growth significantly “often 3-5 times normal [growth rate], [with] brighter tissue color, increased polyp extension, and better branching morphology” (Zooxanthellae, Goreau et al, 2004, 3). Zooxanthellae are symbiotic algae with coral. “Zooxanthellae play a critical role in providing alkalinity for coral calcification by withdrawing carbon dioxide for photosynthesis, and energy for proton and calcium pumping” (Zooxanthellae, Goreau et al, 2004, 1). Coral grown using MA techniques have also exhibited “higher densities of Zooxanthellae and higher rates of symbiotic algal division, but generally lower chlorophyll per Zooxanthella. These patterns are coincident with [healthier and more robust coral], higher rates of resistance to environmental stresses, including elevated temperatures, nutrients, and sediments” (Zooxanthellae, Goreau et al, 2004, 1).

The MA process reduces the metabolic energy requirements for coral skeleton formation, replacing the role of Zooxanthellae calcium and proton pumping. This leaves the coral with “more metabolic energy for growth, reproduction, and resisting environmental stresses” (Zooxanthellae, Goreau et al, 2004, 2). The surplus of metabolic energy helps coral survive bleaching events and increased pollution. The MA process also aids in the reduction of acidity caused by rising CO_2 concentrations, and “may prove crucial to the long term survival of coral reef species and ecosystem functions” (Zooxanthellae, Goreau et al, 2004, 2).

The process of artificially inducing the deposition and calcification of minerals from the environment is called an oxidation-reduction reaction, or redox reaction for short. This redox reaction is initiated when a current is passed across the electrolyte (seawater). A redox reaction in terms of electrons means that an atom is *oxidized* when it loses electrons, and an atom is *reduced* if it gains electrons. The positive charge is *reduced* with the addition of an electron. In terms of Oxygen, *oxidation* occurs with the

Laboratory Experiment #1:

Seeking to determine the atmospheric affects of electro-deposition within the hydrosphere, we will construct a finite environment using a corked 4 liter Erlenmeyer flask containing 2 to 3 liters of Eld inlet water. Into the electrolyte a square of 19 gauge galvanized, steel, mesh cloth of a yet undermined surface area, will be placed. We will have soldered 19 gauge cathode lead to this mesh. The led anode will be placed in a measured proximity to the cathodic mesh. We will run these leads through the air tight seal of a rubber cork. The flask, having the appropriate appendage, will be fitted by us with a Luer lock valve, creating an airtight seal. We will fortify the seals at the cork and the valve with a silicon aquarium sealant prior to electrolysis process. Next, we will connect the leads to an electrical source. This experiment will be conducted many times under variable conditions of voltage, amperage, electrolyte and atmospheric volumes, and periods. Ideally, water temperature will be maintained within the range of the naturally occurring, seasonal temperatures of Eld inlet, and wave and tidal action will be simulated using a shaker (.....). At predetermined periods, and without contamination by the external environment, a sample portion of the atmosphere will be extracted through the Luer lock valve. We will then subject these samples, for both quantitative and qualitative analysis, to gas (.....) and thin layer chromatography. It is through this process that our team will test our hypothesis regarding the affect of CO2 levels, as well as any other gas content anomalies within the finite environment of the Erlenmeyer flask.

Laboratory Experiment #2:

While the focus of experiment #1 is the determination and measurements of any changes within the atmosphere relative to the hydrosphere in which electro-deposition/accretion is occurring, experiment #2's primary concern is the quantity, quality, and rate of deposition of the accreted material itself. In experiment #2 our team will attempt electro-deposition/accretion on the cathode in an 8 to 40 liter electrolyte (Eld inlet water) environment. Steps will be taken to minimize evaporation of the electrolyte but no attempt at an airtight seal will be made. Cathodes of a variety of shapes, having cathodic surfaces in a variety of spatial relationships with themselves and the anode, will be supplied with direct current electricity. Objects of identical design will be administered different voltages and amperages of electricity, the goal being to determine both the behavior of accretion at variable voltages and shapes.

In order to produce the widest array of analyzable results, the team will attempt to maximize the period over which this experiment will be conducted. It is yet undermined whether this experiment can be run 24 hours a day, or for shorter episodic periods. We will attempt to provide an electrolytic environment with the maximum volumetric capacity. Periodically, the electrolyte will be replenished, from the sound. The presence of a small water pump within the tank itself will be used to simulate a natural flow of water over the cathodes/anode. Ideally, the

Materials:

Experiment #1

Four L Erlenmeyer flask, Luer lock valve, rubber cork, galvanized steel mesh, D/C power supply, shaker, 19 gauge wire leads, aquarium sealant, anode

Experiment #2

40 L+ container, D/C power supply, soldered wire cathodic surfaces, anodes, 19 gauge wire leads, small submersible water pump

Experiment #3

Galvanized steel wire mesh cloth, frame material, cylindrical bouncy apparatus', 12v deep cycle marine battery, anodes, insulated wire leads etc.

Projected Budget and Funding Mechanism:

Less than \$1000.00 per team member (detailed budget to follow)

Evergreen Foundation Activity Grants

<http://www.evergreen.edu/sponsoredresearch/foundationactivitygrants.htm>

**“United States Patent Number 5,543,034:
Method of Enhancing the Growth of Aquatic Organisms,
and Structures Created Thereby”**

**Wolf H. Hilbertz, Thomas J. Goreau, United States Patent Office,
Filed Aug. 28, 1995**

This patent details a method of enhancing the growth of aquatic organisms such as coral and the structures they build. This method also relates to the creation of artificial reefs, aquaculture facilities, and coastal defense structures. The creation of these structures relies on a method of electrolysis known as electrodeposition, or electroaccretion. The patent reviews the most common elements in seawater, and the compounds from which the target structures are to be constructed from. Specifically, CaCO_3 and $[\text{Mg}(\text{OH})_2]$ are precipitated from seawater in the presence of an electrical current on to the desired cathode. The patent also examines other precipitants and gases created by the electrolytic process, and environmental concerns to be aware of.

This is a United States patent. It includes experimental setup diagrams, and a visual representation of the chemical process as CaCO_3 and $[\text{Mg}(\text{OH})_2]$ are precipitated. Also, included are case study successes and examples of the processes being used in the field.

The patent is particularly useful due to the high level of detail regarding the process. A clear understanding of the methods employed and the chemical reactions generated by those methods, is attainable from the patent.

**Solar-generated Building Material from Seawater as a Sink for Carbon
Wolf H. Hilbertz,
Building Research & Information, Volume 19, Issue 4 July 1991 , pages 242 - 255**

This article notes the world's oceans as “the earth's largest continuous ore-carrying body”, and proposes a means for the electro-accretion of calcium-carbonate and magnesium hydroxide from the oceans as a building material. It outlines the fossil fuel inputs of conventional building materials, and suggests the economic competitiveness of ocean accreted materials. Lastly, and most significantly, it explores the potential of the accretion process as a carbon sequestration mechanism.

The work scratches the surface of the questions we'd like to answer. It provides references to several other works, and researchers, worthy of continued investigation.

Reef Restoration Using Seawater Electrolysis in Jamaica

**Thomas J. Goreau, Wolf Hilbertz,
Global Coral Reef Alliance,**

http://www.globalcoral.org/reef_restoration_seawater.htm

This article is not from a peer reviewed journal. It is however written by the two PhD's who hold the patent on the electro deposition process. This article details a specific experiment using the process. The materials and methods portion of the work is most the most relevant to our endeavors.

**Increased Zooxanthellae Numbers and Mitotic Index in
Electrically Stimulated Corals**

**Thomas J. Goreau, James M. Cervino, Rachael Pollina
Symbiosis (2004) 37:107-120**

This peer reviewed article lays down the basis for stimulated corral growth in the vicinity of the cathode of the electro-deposition process. Also, the symbiotic relationship of Zooxanthellae to Coral is explained in detail.

Marine Ecosystem Restoration: Costs and Benefits for Coral Reefs

**Thomas J. Goreau, Wolf Hilbertz
World Resource Review Vol. 17 No. 3 (2005)**

A global perspective on the degradation of coral reefs is outlined by this distinguished team. A plan for "active global ecosystem restoration" is suggested. The role of the electro-deposition of calcium carbonate within that plan is given. A cost benefit of thriving coral ecosystems in terms of biodiversity, tourism, and most notably the impact on coral reefs on fish populations is provided, in detail. The effects of localized, as well as global (climate change), anthropogenic environmental events on the marine environment is presented. The necessity of measures of restoration, in terms of the financial and nutritional impact of oceans with significantly less coral are made clear. The benefits and costs of coral reef restorations of various proportions are clearly articulated within the work.