Regeneration of Sodium Carbonate using Solar Energy

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Acknowledgements

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Abstract

Global atmospheric carbon dioxide levels have been increasing at an alarming rate, from 280 ppm to 400 ppm in the last 150 years. CO_2 can be captured and removed from the atmosphere through the use of chemical cycles. In these cycles, a sorbent is used to capture CO_2. The new substance is decomposed in a closed system to reproduce the CO_2 (sent to storage) and to regenerate the sorbent (used to capture more CO_2). However, the decomposition reaction requires a large amount of heat energy. A sodium carbonate cycle was chosen for this project because of the low temperatures (100-200°C) needed, relative to other cycles. This project focused on creating an efficient and renewable method to regenerate sodium carbonate from sodium bicarbonate by concentrating the energy of the sun onto the sodium bicarbonate using a Fresnel lens. Twenty-four trials were performed to test the efficacy of different designs. The model that saw the most decomposition converted 58% of the sodium bicarbonate. An improved version of this method with a higher yield of sodium carbonate could be implemented in a filter to reduce the amount of CO_2 in the atmosphere.

Literature Review

Introduction

For the past hundred thousand years, the Earth's climate has been changing slowly, but recently, the Earth has been heating up at an unprecedented rate (National Aeronautics and Space Administration [NASA], 2017a). Since the Industrial Revolution in the 1700s, humans have radically changed the Earth by consuming fossil fuels for energy and by clearing land for agriculture and cities (Environmental Protection Agency [EPA], 2016). The main cause for the increase in global temperatures is the increase in greenhouse gas emissions in the atmosphere. When the rays of the sun reach Earth, some of the rays are absorbed by the surface of the Earth, while others are reflected back into space. However, greenhouse gases in the atmosphere such as carbon dioxide, methane, nitrous oxide, and water vapor absorb some of the energy, thereby

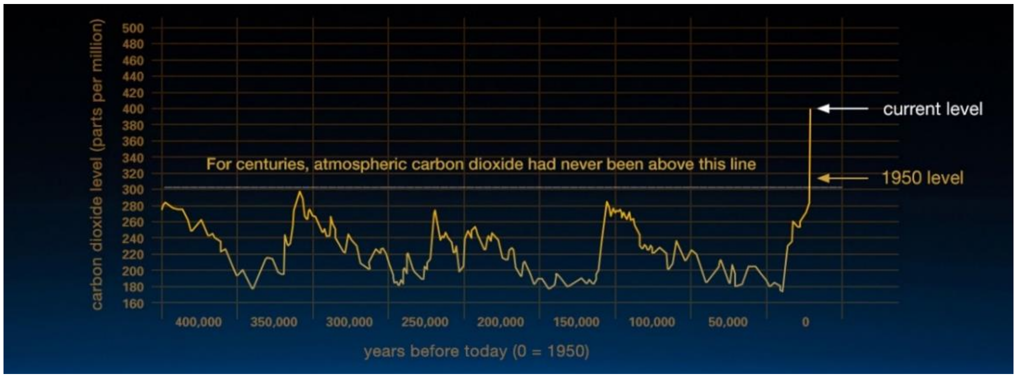

Figure 1. The graph shows the amount of carbon dioxide in the atmosphere for the past hundred thousand years (National Aeronautics and Space Administration, 2017b).

preventing the sun's heat from escaping into space. As the amount of carbon dioxide increased from 280 to 400 parts per million (ppm) in the last 150 years (see Figure 1), the Earth's temperature has increased as well (NASA, 2017a). An increase in Earth's temperature can lead to more severe droughts, heat waves, coastal flooding, wildfires, hurricanes, and other natural disasters (NASA, 2017c).

Current Carbon Capture Methods

One potential solution to the increase in atmospheric carbon dioxide is carbon capture and storage (CCS), which attempts to capture, isolate, and store carbon dioxide. The carbon dioxide can either be captured directly from the atmosphere or before it is released from the power plants. Currently, there are several different methods to capture carbon dioxide (Goeppert, Czaun, Prakash, and Olah, 2012, p. 7833).

Biomass

One renewable method to capture carbon dioxide is through photosynthesis; plants already use solar energy to capture carbon dioxide from the air. However, photosynthesis is rather inefficient as only 0.5-2% of the energy from sunlight is converted into biomass, which means that vast amounts of land and water must be utilized to capture large amounts of carbon dioxide. As available real estate decreases, deforestation, which is already an immense problem, would increase to make more space for additional plants, which would contribute to an increase in carbon emissions (Goeppert, Czaun, Prakash, and Olah, 2012, pp. 7837-7838).

Na/Ca cycle

Chemical cycles are another way to capture carbon dioxide. In general, chemical cycles utilize a sorbent, which is capable of reacting with carbon dioxide to form a different substance. The new substance is then moved to a closed system where another reaction takes place to release the carbon dioxide and regenerate the sorbent. The carbon dioxide is stored, and the regenerated sorbent can be used to capture more carbon dioxide. There are a variety of chemical cycles that can be used to capture and store carbon dioxide (Zeman, 2007, 7559).

One of these chemical cycles include the Na/Ca cycle (see Figure 2), which can be summarized in the following four equations:

$$2\mathrm{NaOH} + \mathrm{CO_2} \rightarrow \mathrm{Na_2CO_3} + \mathrm{H_2O} \tag{1}$$

$$Na_2CO_3 + Ca(OH)_2 \rightarrow 2NaOH + CaCO_3 \tag{2}$$

$$CaCO_3 \rightarrow CaO + CO_2 \tag{3}$$

$$CaO + H_2O \rightarrow Ca(OH)_2 \tag{4}$$

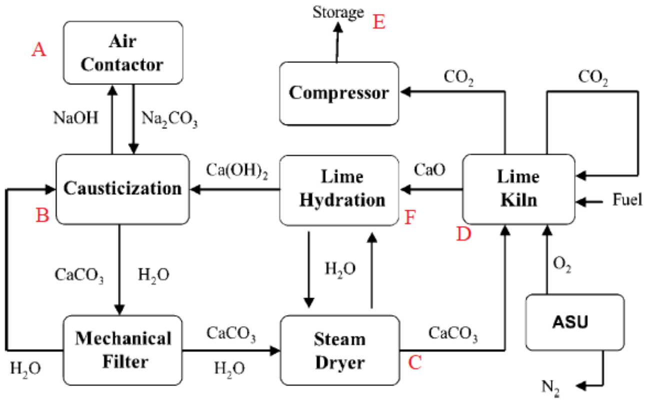

Figure 2. An overview of the Na/Ca cycle (Zeman, 2007, Figure 2, p. 7559)

In this method, carbon dioxide is captured by reacting a sodium hydroxide solution with carbon dioxide gas ("A" in Figure 2). There are many ways to perform this reaction, one of which includes dripping the sodium hydroxide solution through the top of a packed column and flowing the carbon dioxide through the column's bottom. As the carbon dioxide passes by the sodium hydroxide, the sodium hydroxide solution absorbs the carbon dioxide to produce sodium carbonate and water (eq. 1), and the sodium carbonate is then sent to a causticizer (B) where it reacts with calcium carbonate to form sodium hydroxide and calcium carbonate (eq. 2). The sodium hydroxide is sent back to the packed column (A), while the calcium carbonate is dried (C) and sent to the calciner (D) where it is heated in a lime kiln to 900°C and separated into calcium oxide and carbon dioxide (eq. 3). The separated carbon dioxide can then be stored (E), and the calcium oxide is reacted with water (F) to form calcium hydroxide (eq. 4), which is sent back to the causticizer (B). While the decomposition of calcium carbonate into calcium oxide and carbon dioxide (D) is the only step that requires energy input, the amount that is needed is quite high (Zeman, 2007, 7558-60).

Potassium Carbonate Cycle

One cycle that does not require as much energy as other cycles is the potassium carbonate cycle. This cycle is also much simpler as it only requires one reversible reaction:

$$K_2CO_3 + H_2O + CO_2 \rightleftharpoons 2KHCO_3 \quad (5)$$

Solid potassium carbonate and water are combined to form a potassium carbonate solution. The solution can then be reacted with carbon dioxide gas, using a packed column or another method, to form a potassium bicarbonate precipitate. The potassium bicarbonate is moved to a closed system. Between 100°C and 200°C of heat is added to the potassium bicarbonate to regenerate carbon dioxide gas, water vapor, and solid potassium carbonate. The potassium carbonate can then be used again to capture more carbon dioxide (Polak & Steinberg, 2012, p. 6).

There are many advantages to the potassium carbon cycle. In water, the solubility of potassium carbonate is 112 g/100 mL while the solubility of potassium bicarbonate is 22.4 g/100 mL, so potassium carbonate will be more likely to precipitate than stay in solution. This trait is particularly useful because less thermal energy is needed to decompose the potassium bicarbonate while it is a precipitate rather than in solution (Polak & Steinberg, 2012, p. 6). The method is also quite simple as it only requires two reactions which can be described as $A + CO_2 \rightarrow ACO_2$, followed by $ACO_2 \rightarrow A + CO_2$, where A is a sorbent. In these types of reactions, only an apparatus to capture carbon dioxide and an apparatus to heat the product are needed to perform the cycle (Goeppert, Czaun, Prakash, and Olah, 2012, p. 7843). Other alkali metals can be used in place of potassium, such as lithium or sodium. However, not all of these elements are as efficient as potassium.

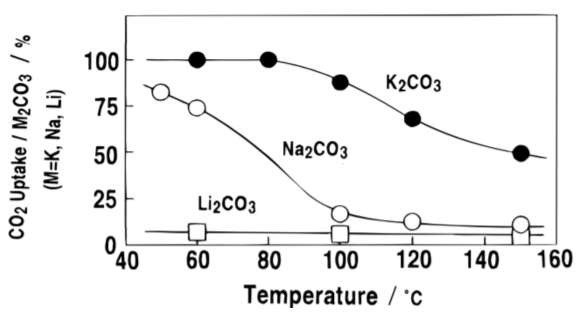

Figure 3. This graph shows the effect of temperature on the amount of carbon dioxide captured for potassium carbonate, sodium carbonate, and lithium carbonate (Hayashi et al., 1998, Figure 7, p. 188).

It has been shown that in an environment with 13.8 percent carbon dioxide and ten percent water vapor, potassium carbonate captures 100 percent of the carbon dioxide below 80°C (see

Figure 3). As the temperature increases above 80° C, it slowly becomes less efficient. Sodium carbonate could replace potassium carbonate (sodium carbonate cycle); sodium carbonate is similar but less efficient than potassium carbonate at lower temperatures. Lithium carbonate, on the other hand, is ineffective at capturing carbon dioxide by 60°C (Hayashi et al., 1998, p. 188). It is also interesting to note that in 2015, the average price of sodium carbonate, $140.88 per ton, was much lower than the average price of potassium carbonate, $595 per ton (United States Geological Survey [USGS], 2016, p. 70.2; USGS, 2017, p. 58.2).

Solar Concentrators

While the sodium carbonate cycle requires less heat energy than other cycles to remove carbon dioxide from the air, 100-200°C of thermal energy is still required to perform the regeneration reaction. There are many methods of producing this heat, including the use of solar concentrators. Solar concentrators, unlike regular ovens, utilize solar energy, a renewable source of energy, to focus a large area of sunlight into a smaller area to increase the temperature of a surface. The amount of energy that can be collected depends on the type of concentrator and its location in the world (Kaplan, 1985, p. 1).

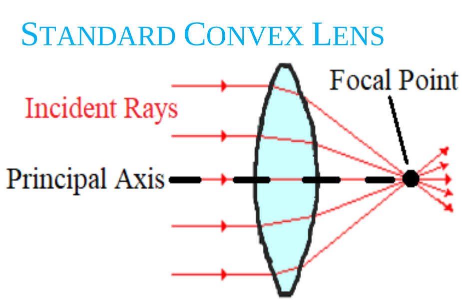

Figure 4a. Light rays parallel to the principal axis of a standard convex lens converge at the focal point (The Physics Classroom, n.d.).

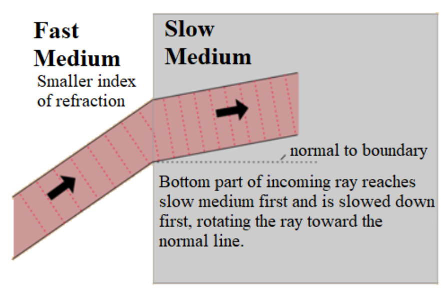

Figure 4b. When light travels through a different medium, the light ray bends due to a change in density of the material (Nave, n.d.).

Solar energy can be collected using standard convex lenses (Kaplan, 1985, p. 6). The convex lens uses refraction to concentrate incoming light rays, called incident rays, onto one point, called the focal point. The light ray must be parallel to the principal axis, which is the axis that runs horizontally through a lens, in order to converge at the focal point (see Figure 4a). Fortunately, the rays of the sun hitting the Earth's surface are considered parallel to each other (Khan, 2010a). The lens, which is denser than the air, causes the light to travel at a slower speed (Khan, 2010b). As a light ray enters the "slow medium," or the medium of higher density, one side of the ray hits the new medium before the other side, causing the first side to begin moving at a slower speed before the second side, which bends the light ray (see Figure 4b). The shape of the lens allows for all of the individual light rays hitting the lens to bend such that they converge at the focal point, allowing the energy in all the rays to concentrate in one place (Nave, n.d.).

Unfortunately, in order to collect and concentrate more energy, the surface area available for light collection must increase. To accommodate the surface area requirements of the sodium carbonate cycle, the size of the lens needs to increase, which means the thickness of a standard convex lens must increase as well. As a lens increases in width, the rays of the sun have to travel through the lens for a longer duration, and energy is lost. Most standard convex lenses are made of glass, which makes larger lenses heavier and impractical (Kaplan, 1985, p. 6).

Fresnel Lens

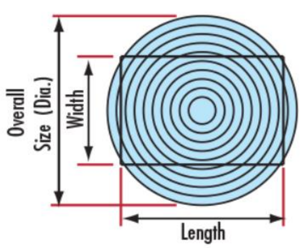

Figure 5a. The rings of a Fresnel lens (Edmund Optics, n.d., Figure 1).

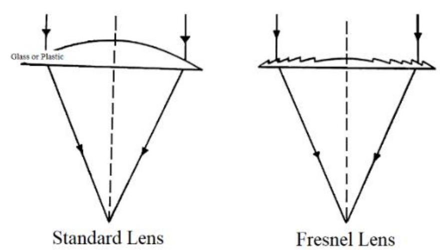

Figure 5b. The Fresnel lens is a flattened version of the standard lens (Kaplan, 1985, Figures 3 & 4, p. 6).

One solution to the problems of the standard convex lens is the Fresnel lens. The Fresnel lens is similar to the standard convex lens conceptually, but instead, it is a thin, flat sheet of glass or plastic filled with concentric grooves to imitate the standard lens (see Figures 5a & 5b). It is impossible to compress a curve onto a flat surface and not lose the angle of the curve, so Fresnel lenses utilize concentric grooves to recreate the effect of a standard lens. The angle of the grooves toward the center are lower, and the angle of the grooves toward the edge are higher to maintain the same curvature of a standard lens. Only the curvature of the surface of a medium affects the angle of refraction, not the volume of the medium. This property allows for a standard convex lens to be compressed into a flat sheet. As a result, Fresnel lenses are much lighter and therefore, can be much larger in surface area than a standard lens (Edmund Optics, n.d.).

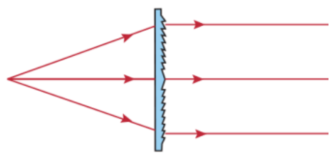

Figure 6a. Light collimation with a Fresnel lens (Edmund Optics, n.d., Figure 3)

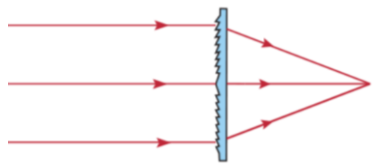

Figure 6b. Light collection with a Fresnel lens (Edmund Optics, n.d., Figure 4)

Fresnel lenses can be used for both light collimation and light collection (see figures 6a & 6b). If the source of light is coming from a single point, a Fresnel lens can refract the light rays to make them parallel. French physicist Augustin-Jean Fresnel (1788-1827) popularized the Fresnel lens by using this concept to improve the distance that the light of a lighthouse could travel. If the source of light were parallel rays, the Fresnel lens could be used to focus all the rays into a single point. (Edmund Optics, n.d.). A Fresnel lens can be used to concentrate the energy of the sun's rays into a single point to produce temperatures capable of reaching thousands of degrees Celsius (Kaplan, 1985, p. 17).

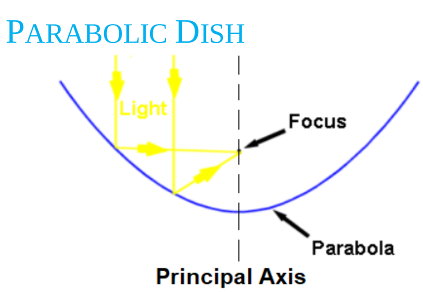

Figure 7a. Light rays parallel to the principal axis that are reflected off a parabola converge at the focus (Solar-Facts, n.d.).

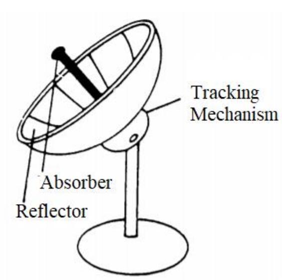

Figure 7b. A parabolic dish utilizes a three-dimensional parabola to concentrate light on a focal point (Kaplan, 1985, Figure 7, p. 8).

In addition to lenses, which use refraction, curved mirrors can be used to capture the energy of the sun through reflection (see Figure 7a). One type of solar concentrator that utilizes reflection is the parabolic dish (see Figure 7b). The parabolic dish is a mirror in the shape of a three-dimensional parabola. When light rays parallel to the principal axis strikes the mirror, all of the light rays are reflected, and they converge at the focal point (Kaplan, 1985, p. 8). The mirrors of parabolic dishes are mainly made of one of two materials: silver or aluminum. Silver is highly reflective, yet it degrades easily, while aluminum is less reflective but can last longer than silver. To effectively concentrate sunlight, parabolic dishes need to be clean and smooth so that reflected sunlight can reach the focal point (Kaplan, 1985, p. 6).

Parabolic Trough

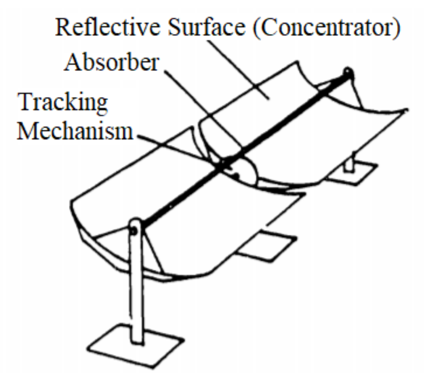

Figure 8. The parabolic trough uses a two-dimensional parabola to focus light along a line (Kaplan, 1985, Figure 9, p. 9).

A parabolic trough is like the parabolic dish, but instead of utilizing a three-dimensional parabola, it uses a two-dimensional one (see Figure 8). As a result, light is focused in a line, creating a channel for the sorbent to travel through. Just like the parabolic dish, the trough utilizes mirrors to reflect the sun (Kaplan, 1985, p. 9).

Problems with Solar Concentrators

The performance of solar concentrators is best on cloudless sunny days as direct radiation is needed. Clouds or fog reduce the intensity of the sunlight that reaches the concentrators and consequently, reduce the concentrators’ effectiveness. The effectiveness of a concentrator also depends on its location in the world. Locations facing the sun directly receive more concentrated sunlight, and the sunlight travels less through the atmosphere, which allows for sunlight of higher intensity to reach the concentrators. However, places not directly facing the sun receive less concentrated sunlight and require the sunlight to travel through more atmosphere, causing the sunlight to be less intense by the time it reaches the concentrator (Kaplan, 1985, p. 4). The sun also moves from horizon to horizon throughout the day. If a concentrator does not move with the sun, the light rays will hit its surface at a less-than-ideal angle, changing the location and size of the area of concentrated light. Therefore, a solar concentrator needs a mechanism to track the sun throughout the day and the year to keep it aligned with the sun so that the light rays will always hit the same location. (Kaplan, 1985, p. 14).

Conclusion

With an increasing level of carbon dioxide in the atmosphere, it is necessary to lower its level before it causes too much damage to the environment. Carbon dioxide can be removed from the atmosphere through a variety of ways including through the use of biomass, the Na/Ca cycle, the potassium carbonate cycle, or the sodium carbonate cycle. However, biomass is inefficient, and the chemical cycles require a source of heat to regenerate the sorbent. The amount of heat energy needed for each chemical cycle differs, but the potassium carbonate and sodium carbonate cycles require only about 100-200°C of heat. Sodium carbonate, however, costs less than potassium carbonate. To reach temperatures of 100-200°C, solar concentrators, such as a Fresnel lens, can be used to concentrate and directly transfer energy from the sun into the sodium carbonate. Solar energy is also a renewable energy source, which will not contribute to the increase in carbon dioxide in the atmosphere. With this concept carbon dioxide removal, it could be possible to slow or reduce the amount of carbon dioxide in the atmosphere.

Plan

Engineering Problem

Carbon dioxide filters can remove carbon dioxide directly from the atmosphere through the use of chemical cycles, such as the sodium carbonate cycle, but they require a large amount of energy to operate.

Engineering Goal

The goal of this project is to develop a clean and efficient method to regenerate sodium carbonate from sodium bicarbonate.

Procedure Overview

A large Fresnel lens was used to concentrate the energy of the sun onto a single point where a small glass jar filled with sodium bicarbonate was put. The temperature of the sample was measured every minute using an infrared thermometer by opening the lid of the jar and pointing the thermometer straight down at the center-top of the sample. The temperature was then recorded. Trials lasted either twenty minutes or forty minutes.

There were many components to this project in an attempt to increase the temperature of the sodium bicarbonate, which included covering the jar in a layer of black spray paint, putting the jar inside a larger jar, putting lids on both the jars instead of only the larger jar, and putting an aluminum foil layer around the larger jar. When testing a new component, only one variable was changed at a time. The results of the new iteration were compared to the results of the best trial at the current time. The better of the two was then improved, and the improved iteration was then compared to that iteration.

Materials and Methods

Materials

Table 1. The table shows the materials used in the project in addition to their sizes and place obtained.

Item	Size	Place Obtained
1 linear Fresnel lens	36 X 28 inches	Green Power Science
1 Studio Décor picture frame	24 X 36 inches	Michaels
1 baseball pitching net frame	132 X 97 X 97 cm	Home
3 boxes Market Basket sodium bicarbonate	454 g	Market Basket
6 pieces of wood	35.6 X 3.8 X 6.4 cm	Home
1 aluminum baking tray	44.5 X 28 cm	Home
8 small glass round jars	200 mL	Home
1 medium glass round jar	450 mL	Home
1 medium-large glass round jar	1000 mL	Home

1 large glass round jar	2000 mL	Home
1 can of Rust-Oleum gloss black spray paint	340 g	Aubuchon Hardware
1 Ohrus triple-beam balance	610 g	Mass Academy
1 Flinn Scientific Electronic balance	120 g	Mass Academy
1 Fisher Scientific Electronic balance		Mass Academy
Weigh boats		Mass Academy
Centrifuge tubes	50 mL	Mass Academy
Centrifuge tube racks		Mass Academy
Deionized water		Mass Academy
1 Fisher Scientific accumet AB 15 Basic pH meter		WPI
1 Etekcity infrared thermometer	-50 — 550°C	Home
Tap water	550 mL	Home
Paperclips		Home
Scotch and duct tape		Home
Reynold’s Wrap aluminum foil		Market Basket
3 large binder clips		Staples

Procedure

Testing Area Set-up

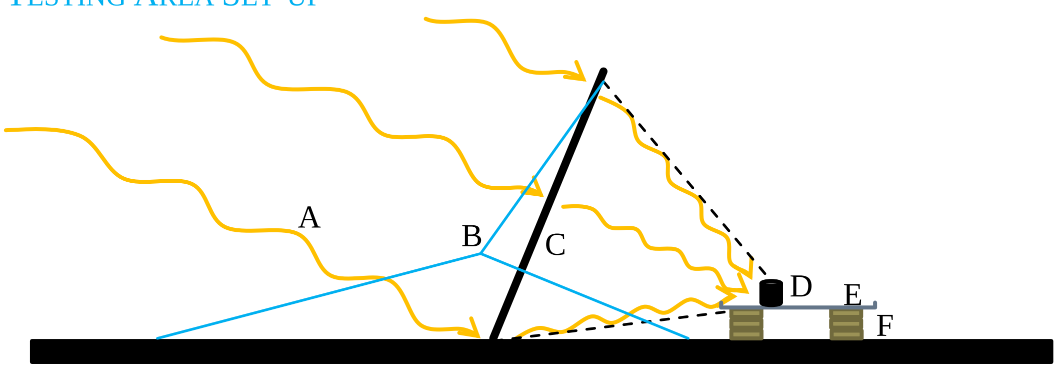

Figure 9. This is a side view of the set-up for all the experiments. (A) shows the rays of the sunlight. (B) shows the baseball pitching net frame on its side. (C) shows the picture frame and lens, which is perpendicular to the light rays. (D) shows the jar containing the sample, which is at the focal point of the lens. (E) shows the baking tray. (F) shows the wood used to raise the baking tray.

The Fresnel lens was put on top of the picture frame and attached with one large binder clip at the center top and two at the bottom. The baseball pitching net frame was then put on its side such that one of the “legs” of the frame was in the air, creating a crossbar where the lens could rest. The lens and frame were angled such that the lens was perpendicular to the rays of the sunlight.

The blocks of wood were stacked into two equal piles. The baking tray was put on top of the piles of wood such that one pile of wood was under one end of the baking tray, while the other pile of wood was under the other end of the baking tray. The wood and the tray were put under the lens with the focal point hitting toward the front of the tray. The jar of the sample was placed on the baking tray with the focal point hitting the side of the jar. There was never more than one sample being tested at a time. The temperature of the sample was measured at the top-center of the sample using an infrared thermometer every sixty seconds. If the jar had a lid, the lid was taken off before the temperature was measured. Because of the movement of the sun, the lens had to be readjusted during testing to maintain its perpendicular state with respect to the rays of the sun.

To track the movements of the sun, a solar tracker was created using an empty box of sodium bicarbonate. A hole with a diameter of 2.5 mm was made in the center of the side with the most surface area. A string with a paperclip attached to the end was put through the hole. The box was placed on a flat surface with the hole facing up, and a white dot with a diameter of 2.5 mm was placed directly below the paperclip. The box was placed on the lens, and the lens was adjusted until the sunlight coming into the box through the hole hit the white dot.

Preliminary Testing

Preliminary testing with the Fresnel lens was done on November 24, 2017 in Littleton, MA at about solar noon. Tap water was used in place of sodium bicarbonate. Four different trials were performed using the 1000 mL, 450 mL, and two 200 mL jars to hold the water. The 1000 mL jar was filled with 250 mL of water, the 450 mL was filled with 150 mL, and the two 200 mL jars were filled with 75 mL each. All the trials were performed with the lids on, except for one of the small jars. Each jar was placed on the tray as described above, and the data was recorded as described above. Each trial lasted twenty minutes.

EXPERIMENTATION

Twenty-four trials with sodium bicarbonate were conducted. These trials were conducted between November 25, 2017 and January 20, 2018 in Littleton, MA around the time of solar noon. All trials used the small jars to hold the sodium bicarbonate, and they all began in direct sunlight, but clouds began to cover the sun in some of the trials. There were many iterations during experimentation. Often, components of excellent trials would be combined together. Some trials repeated outstanding trials to confirm their results. See below for a table of iterations and the procedure for creating the components for the iterations.

Spray Paint

Five of the eight small jars were coated in black spray paint. One layer of spray paint was applied to all outside parts of the jar except for the bottom and the cap. The spray paint was left to dry overnight. During the trials, a small area of spray paint around the front of the jars completely vaporized because of contact with direct sunlight. However, to allow for some sunlight to directly heat the sodium bicarbonate, the spray paint was not reapplied. As jars were reused for other trials, the vaporized spot always faced the sun.

Jar Inside Jar

In these trials, the small jar of sodium bicarbonate was placed inside the center of the large jar for the duration of the trial. The lid of the small jar was off, while the lid of the large jar was on for most of these trials (see section below). The focal point of the light was positioned at the smaller jar, not the larger jar.

Small Jar Lid On

In a few trials, the lids for both the smaller and larger jar were put on. The cap of the smaller jar had to be attached to the larger jar, so that when measuring the temperature, lifting the cap of the larger jar would also lift the cap of the smaller jar. In the first couple iterations of this component, a paperclip was stretched and attached to the underside of the larger jar lid and the top of the smaller jar lid. Scotch and duct tape were used in different iterations. However, the smaller jar lid kept falling off as the tape on that lid melted.

In another iteration, strips of aluminum foil were used to hold the smaller jar lid. Two 2 x 11 inches strips of aluminum foil were cut and folded into two 0.5 x 11 inches strips. The center of one of the strips was placed at the center on the underside of the smaller jar lid. The strip was molded into the shape of the lid. When the strip reached the top of the lid, the strip was folded ninety degrees such that it was perpendicular to the top of the lid. The strip was bent another ninety degrees, toward the center of the jar and parallel to the lid, when it was about five centimeters above the lid. This process was repeated with the other strip. This strip was perpendicular to the first strip on the underside of the jar. After the second strip was bent, four ends of the aluminum foil converged at a point above the lid. This point was placed on the underside of the larger jar lid and attached with Scotch tape.

Aluminum Foil Wrapping

For many trials, aluminum foil was placed around the back half of the larger jar, and it covered the entire height of the jar. The foil was pushed tightly against the jar so that adhesives were not necessary to attach the foil to the jar. In the later trials, the aluminum foil was spray-painted black. The foil was molded around the jar before the side of the aluminum foil facing the inside of the jar was covered in one layer of spray paint. After drying overnight, the foil was put back on the jar. In trial 16, aluminum foil with no spray paint was placed around both the back half of the larger and smaller jars. The process to put on the aluminum foil for the smaller jar was the same process as the larger jar. The smaller jar used was one of the three unpainted jars.

Oven Experiments

Trials were also performed in a controlled environment using a toaster oven. The oven was heated to a desired temperature, and three 200 mL jars, holding 50 g of sodium bicarbonate each, were placed inside. The temperature of the sodium bicarbonate was taken every five minutes using the infrared thermometer, and the jars were removed after the desired time.

Data Analysis

Immediately after each trial, the mass of the sodium bicarbonate was measured. The masses of Trial 7 and those previous were measured using the Flinn Scientific electronic balance. However, because the balance could not support the mass of the jar, the sample had to be measured on a weight boat. Before the trial began, the mass had to be transferred from the weigh boat to the jar, and after the trial, the mass had to be transferred from the jar to the weight boat. Because of the potential loss in some mass, a triple-beam balance was used for the subsequent trials so that the mass of the sodium bicarbonate could be measured directly in the jar, despite the loss of one significant figure. After the mass was taken, sample was transferred into a centrifuge tube, and the jar was cleaned.

To confirm the change in sample composition, the pH of the samples was taken using a pH meter. To create solutions, about one gram of the sample was measured in a weigh boat using the Fisher Scientific electronic balance. The mass was transferred into a centrifuge tube after which deionized water was poured to about the thirty-milliliter mark. Using the pH meter, the pH of each of the samples were taken and recorded.

Trial Components

Table 2. The table shows the components of each trial. Cloud data is also provided. All trials began with no clouds over the sun. The cloud data provided does not mean that the entire trial was under that condition; it lists the most amount of clouds recorded during the trial.

Trial	Smaller Jar Spray Painted	Inside Larger Jar	Aluminum Foil on Larger Jar	Lid on Smaller Jar	Aluminum Foil Spray Painted	Other
1	No	No	No	Yes	No	Thin layer clouds
2	No	No	No	Yes	No	No lid; thin layer clouds
3	No	No	No	Yes	No	4 blocks of wood, not 6 blocks; overcast
4	Yes	No	No	Yes	No	Thin layer clouds
5	Yes	Yes	No	No	No	Thin layer clouds

6	Yes	Yes	No	No	No	Overcast
7	Yes	Yes	No	No	No	Small cloud
8	Yes	Yes	No	No	No	
9	Yes	Yes	Yes	No	No	
10	Yes	Yes	Yes	No	No	
11	Yes	Yes	Yes	No	No	
12	Yes	Yes	Yes	No	No	
13	Yes	Yes	Yes	No	No	
14	Yes	Yes	Yes	No	No	
15	Yes	Yes	Yes	Yes	No	
16	No	Yes	Yes	Yes	No	Aluminum foil on smaller jar; thin layer clouds
17	Yes	Yes	Yes	Yes	No	
18	Yes	Yes	Yes	Yes	No	
19	Yes	Yes	Yes	Yes	No	
20	Yes	Yes	Yes	Yes	Yes	
21	Yes	Yes	Yes	No	Yes	
22	Yes	Yes	Yes	No	Yes	
23	Yes	Yes	Yes	No	Yes	Two layers of wood
24	Yes	Yes	Yes	No	Yes	Two layers of wood

Results

Twenty-four trials were done. Sixteen of the trials were twenty minutes long, seven were forty minutes long, and one was thirty minutes long.

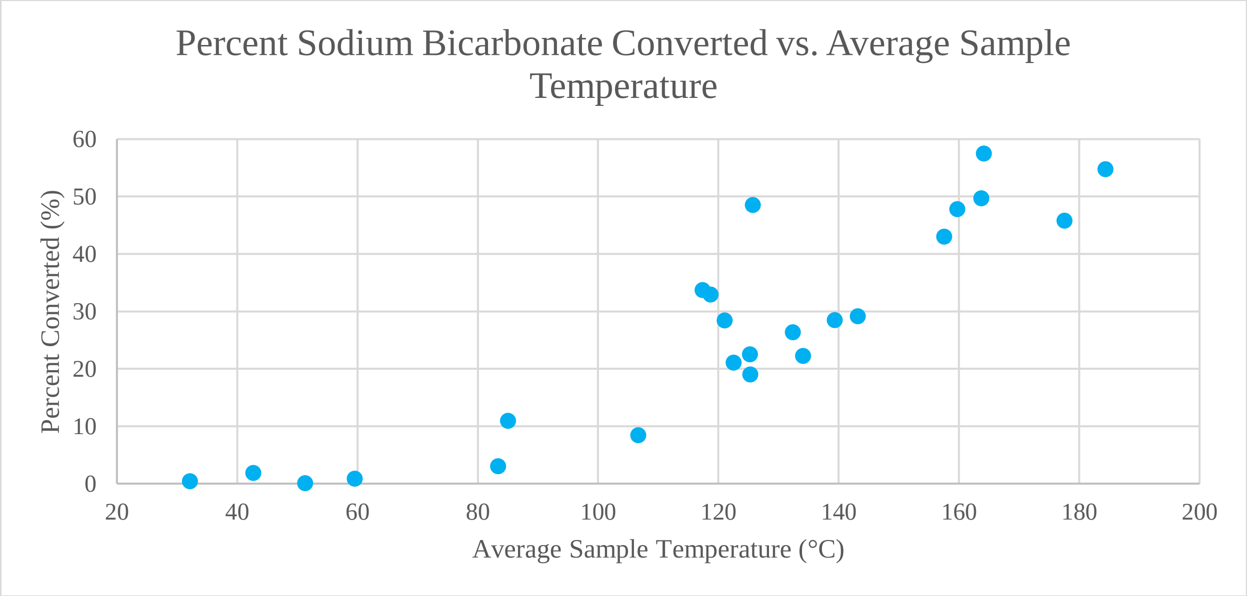

Figure 10. This graph compares the percent sodium bicarbonate converted to the average temperature of each sample.

As shown in Figure 10, there appears to be a positive correlation between the average sample temperature and the amount of sodium bicarbonate converted. Most of the trials reached an average temperature of over 100°C. Some trials reached maximum temperatures of over 200°C (see Figure 13 in Appendix B). Some of the different trial components appear to have increased the percent sodium bicarbonate converted, as shown in Figure 11. It appears that spray painting the smaller jar and putting the smaller jar in a larger jar increased percent conversion significantly.

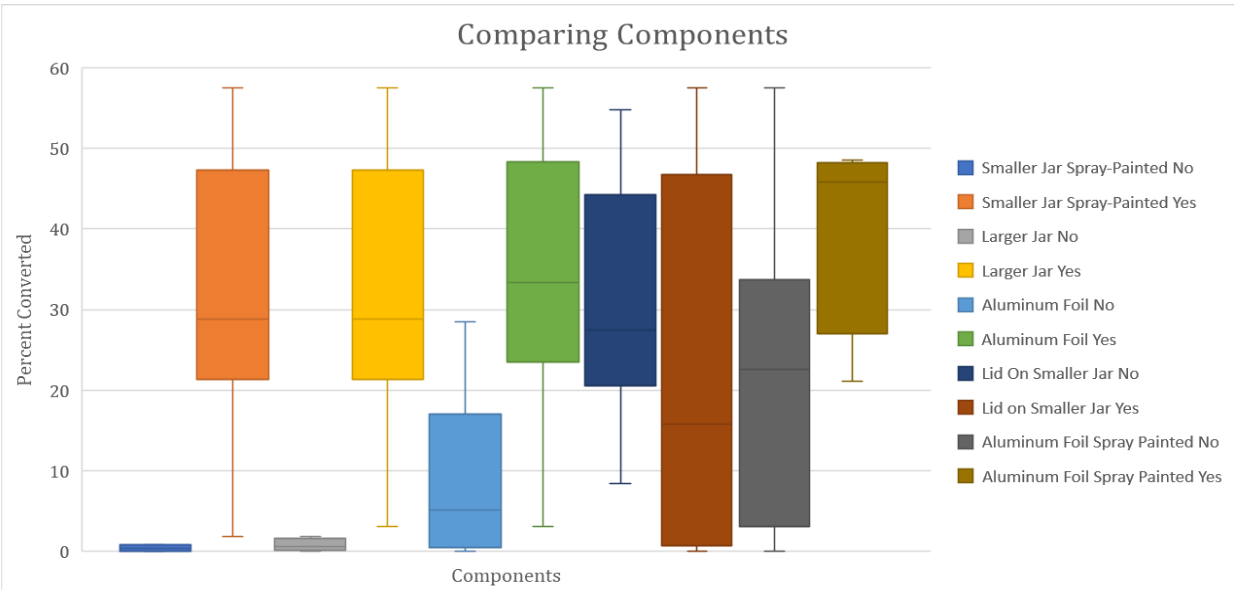

Figure 11. These box and whisker plots compare the different components used to insulate the sodium bicarbonate to the amount of sodium bicarbonate converted into sodium carbonate.

The percent of sodium bicarbonate converted to sodium carbonate was calculated for each trial. The pH was also measured for each sample. As shown in Figure 12, there appears to be a correlation between the percent sodium bicarbonate converted and pH.

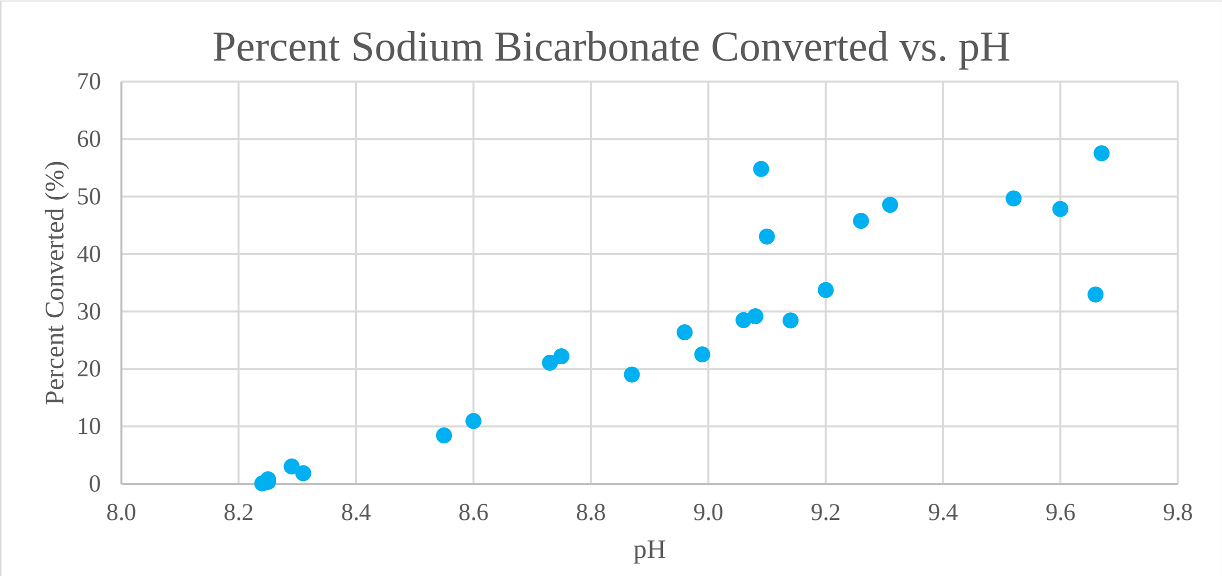

Figure 12. This figure shows the percent of sodium bicarbonate converted to sodium carbonate and the pHs of each trial.

Table 3. An abridged version of the scoring matrix. Each criterion contains sub-categories, which are scored and added together to form a subtotal. The criteria are weighted, and the sum of the subtotals yield the total score for a trial. The Oven column is the average for all twelve oven trials. The matrix also shows the scores for outdoor trials 1, 15, and 24.

Criteria	Sub-Categories	Max	Trial			
			Oven	1	15	24
High Efficiency	Efficiency	10.0	1.1	0.1	3.4	2.4
	High Efficiency subtotal *1	10.0	1.1	0.1	3.4	2.4
Low Environmental Impact	Process does not emit greenhouse gas	4.0	2.0	4.0	4.0	4.0
	Materials are eco-friendly	4.0	2.0	3.5	3.0	3.0
	Low Environmental Impact subtotal *1	8.0	4.0	7.5	7.0	7.0
High Feasibility	Easiness to Obtain/Assemble Materials	4.0	4.0	3.5	3.5	3.5
	Easiness to Operate/Maintain Apparatus	4.0	3.5	3.5	3.5	3.5
	High Uptime	4.0	4.0	2.0	2.0	2.0
	Efficiency	4.0	1.1	0.1	3.4	2.4
	High Feasibility subtotal *0.8	12.8	10.1	7.3	9.9	9.1
High Safety	Not Fire Hazard	4.0	3.0	3.0	3.0	3.0
	Not General Health Hazard	4.0	3.5	3.5	3.0	3.0
	High Safety subtotal *0.8	6.4	5.2	5.2	4.8	4.8
Low Cost	To Run	4.0	2.0	4.0	4.0	4.0
	To Maintain/Fix	4.0	2.0	4.0	4.0	4.0
	Low Cost subtotal *0.6	4.8	2.4	4.8	4.8	4.8
Total	Sum of Subtotals	42.0	22.8	24.9	29.9	28.1

CONCLUSIONS

The goal of this project was to create a clean and efficient method to sodium carbonate from sodium bicarbonate. A mildly successful apparatus was created with a maximum of about 60 percent conversion in 40 minutes. Different components were used in an attempt to insulate the sodium bicarbonate. It appears that spray painting the smaller jar and inserting that jar inside a larger jar increased the amount of heat insulated (See Figure **[xx]** in Appendix B), which in turn, converted more sodium bicarbonate into sodium carbonate. However, because of the wide variety of combinations of components used in the trials, it is difficult to see how each individual component affects the temperature of the sodium bicarbonate. Weather, which was an uncontrollable variable, also affected the temperature of the sodium bicarbonate. It does not appear as though that during the testing period, there was a strong correlation between the measurable aspects of the weather and the amount of conversion (See Figure **[xx]** in Appendix B); however, clouds were an aspect of the weather that affected percent conversion but could not be measured. As clouds covered the sun, the amount of direct sunlight decreased, lowering the amount of energy that could concentrate under the lens. For example, in Trial 7, the sodium bicarbonate reached about 120°C just as the sky became overcast, dropping the temperature of the sodium bicarbonate to 65°C.

In the future, percent sodium bicarbonate conversion rate could be improved through better insulation. Future trials could also include changing the location of the trial to a place with higher sun intensity. More trials isolating each separate component could be done to determine the effectiveness of each component in insulating heat. If a high amount of conversion can be achieved while remaining clean and efficient, the apparatus could be connected to the rest of the carbon capture cycle. The ultimate goal would be to spread the apparatus around the globe to help remove carbon dioxide from the air.

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Appendix A: Limitations and Assumptions

Assumptions

- The infrared thermometer, balances, pH meter, weather data, and solar data are accurate.
- The sodium bicarbonate bought contains pure sodium bicarbonate.
- Heat causes sodium bicarbonate to react and form sodium carbonate, carbon dioxide, and water vapor.
- The trials done in this project represent an average trial done in similar conditions.

Limitations

- The sodium bicarbonate only heated up when in direct sunlight. Clouds that covered the sun did not allow for the sodium bicarbonate to increase in temperature. Different trials had different amounts of cloud cover. Some trials also experienced high winds, which may have had an effect on the temperature of the sodium bicarbonate.
- The testing was done during a Massachusetts winter. The intensity of the sunlight was at its lowest level during the testing period. Testing in more intense sunlight could not be done.
- There was not enough time to conduct many trials. Testing could only be done on sunny days when school was not in session in order for there to be enough sunlight.
- A linear Fresnel lens was used instead of a spot Fresnel lens because of the high price of the spot Fresnel lens. The size of the lens used in the experiment was also limited by cost.

Appendix B: Data

Table 4. This table shows the raw temperatures. Bluer cells signify a cooler temperature, while redder cells signify a warmer temperature.

Trial #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Time (min)	Temperature (°C)																							
0	15.4	15.2	17.8	9.8	13.2	11.6	8.1	14.2	5.2	6.1	6.6	-5.1	-0.8	-1.7	11.6	0.0	12.1	10.8	7.2	17.2	7.7	-4.8	6.4	-0.7
1	29.3	17.6	40.0	16.0	52.3	32.4	48.6	28.9	39.1	46.1	36.9	13.9	20.8	24.4	29.1	20.5	35.2	41.6	15.6	57.8	25.8	20.9	33.7	30.4
2	35.7	17.5	45.3	21.1	51.4	60.0	60.7	41.8	64.7	70.6	50.6	37.9	38.2	53.4	46.9	39.0	60.3	72.5	37.4	87.5	45.8	45.2	87.8	60.2
3	39.0	21.6	36.5	29.4	67.0	78.3	80.7	48.0	81.4	94.3	63.8	70.9	49.7	84.2	66.4	40.8	92.8	103.5	65.2	104.0	63.7	65.8	92.5	74.7
4	45.2	22.6	53.2	30.5	83.0	105.1	102.8	57.3	109.4	113.8	88.8	77.7	70.0	109.3	72.2	47.2	110.5	127.4	92.0	118.9	86.3	96.5	112.5	89.6
5	61.2	27.7	55.8	34.6	89.8	113.8	102.1	85.1	121.1	132.6	104.7	100.4	97.1	128.0	91.1	64.2	123.9	142.4	103.2	132.8	103.4	117.3	123.4	93.3
6	61.9	29.0	56.1	37.6	96.8	122.4	112.8	107.3	134.7	143.4	116.1	130.1	116.2	142.3	103.2	73.5	128.5	154.7	129.6	154.4	115.4	122.8	128.4	102.2
7	63.4	33.8	56.1	36.7	101.7	131.6	118.7	104.8	148.5	153.0	130.3	131.2	129.4	149.2	110.0	94.2	139.0	159.8	137.8	163.0	119.4	141.5	126.8	113.6
8	62.8	37.1	53.8	40.0	108.0	137.6	98.3	125.8	152.4	158.5	139.0	137.1	146.1	153.8	116.9	102.8	150.0	158.5	149.4	173.0	136.6	144.6	133.6	116.2
9	61.2	36.0	53.5	43.3	115.4	162.2	110.0	133.2	164.1	160.8	142.7	148.7	149.6	160.6	127.8	103.2	151.1	165.5	159.4	173.6	136.9	141.5	133.5	137.6
10	61.9	33.3	51.8	49.6	118.0	156.3	106.5	128.3	158.4	163.2	143.6	154.2	156.4	161.9	129.2	110.7	154.2	166.8	175.0	175.6	142.0	142.6	133.4	147.8
11	65.0	34.2	59.2	55.7	125.4	156.7	102.6	117.9	159.6	170.5	150.9	156.7	166.0	168.5	135.9	109.3	152.2	169.1	175.9	173.3	141.0	148.1	140.7	153.9
12	67.2	37.1	53.2	50.1	136.2	159.8	97.4	131.7	158.4	171.2	163.4	158.7	172.5	170.6	152.3	113.6	155.8	169.8	179.1	175.3	137.2	150.1	141.2	154.6
13	64.0	42.8	48.9	49.5	129.4	145.1	95.2	128.3	157.3	172.0	163.4	159.1	169.0	171.5	160.2	111.0	156.8	168.3	181.5	178.5	139.2	153.3	135.7	159.3
14	72.6	45.5	55.4	51.0	137.5	139.6	84.4	137.5	163.6	176.3	161.2	162.7	171.1	178.3	162.2	116.3	166.1	177.7	173.8	181.4	145.3	159.1	137.2	159.6
15	69.2	39.0	55.6	53.2	141.7	152.7	90.3	135.2	158.2	180.3	159.7	164.4	181.3	183.3	155.0	116.6	166.3	185.3	178.4	180.6	150.8	156.8	143.3	163.9
16	67.5	35.4	57.1	55.2	143.2	151.9	78.4	144.6	159.3	192.1	160.8	165.4	188.0	186.5	158.0	110.5	167.6	181.2	185.6	185.6	153.3	157.9	148.2	169.8
17	77.0	39.7	55.2	54.1	146.2	161.5	73.2	138.1	165.5	190.6	160.6	168.0	186.1	190.9	158.3	106.9	172.0	182.8	190.8	182.8	161.8	166.5	149.6	172.3
18	76.3	31.7	55.7	58.3	148.5	157.2	74.9	143.9	165.9	198.5	162.4	169.3	189.6	195.0	155.8	103.7	175.2	180.8	197.8	181.7	160.4	169.6	154.2	176.4
19	81.0	36.1	53.9	59.8	146.7	151.9	73.3	140.7	174.5	197.4	163.0	166.5	191.2	198.0	160.6		177.3	183.5	193.0	185.4	159.8	171.7	152.9	181.5
20	73.2	41.8	57.1	60.4	150.2	143.3	66.9	147.4	173.9	193.5	161.5	171.1	192.3	199.2	162.3		181.8	183.6	198.5	182.4	160.9	173.3	158.6	183.3
21			59.6		148.6					204.1		175.5					182.0	181.8		183.2				184.4
22			54.3		148.6					210.7		179.4					181.6	177.0		187.7				185.5
23			56.7		145.4					213.1		187.7					191.6	176.9		189.9				179.5
24			51.0		140.1					215.9		193.1					189.8	173.3		195.8				188.2
25			49.6		140.1					216.8		198.4					190.8	173.5		193.7				187.4
26			47.9		135.4					219.8		201.4					194.3	175.8		196.8				194.0
27			51.1		135.5					221.4		206.6					195.2	179.2		205.6				195.9
28			57.8		133.6					221.6		206.2					194.2	179.8		203.2				198.8
29			44.4		130.0					220.6		206.7					197.3	180.1		204.6				199.5
30			46.9		130.0					221.7		207.2					195.0	179.3		205.3				200.6
31					132.2					219.7		209.1					196.8	180.5		208.7				200.8
32					131.1					228.3		212.9					198.2	181.8		208.2				203.2
33					128.6					235.3		214.5					198.6	185.3		202.3				202.8
34					129.7					230.4		215.3					196.1	186.8		215.4				198.6
35					127.2					231.0		217.8					198.4	186.0		217.8				198.2
36					125.4					229.8							200.6	186.4		216.3				200.5
37					128.7					231.8							199.2	187.8		217.6				199.1
38					124.4					232.1							200.9	185.2		218.6				194.2
39					123.4					233.0							199.6	182.6		220.3				197.1
40					122.9					237.2							200.3	187.2		223.0				200.4

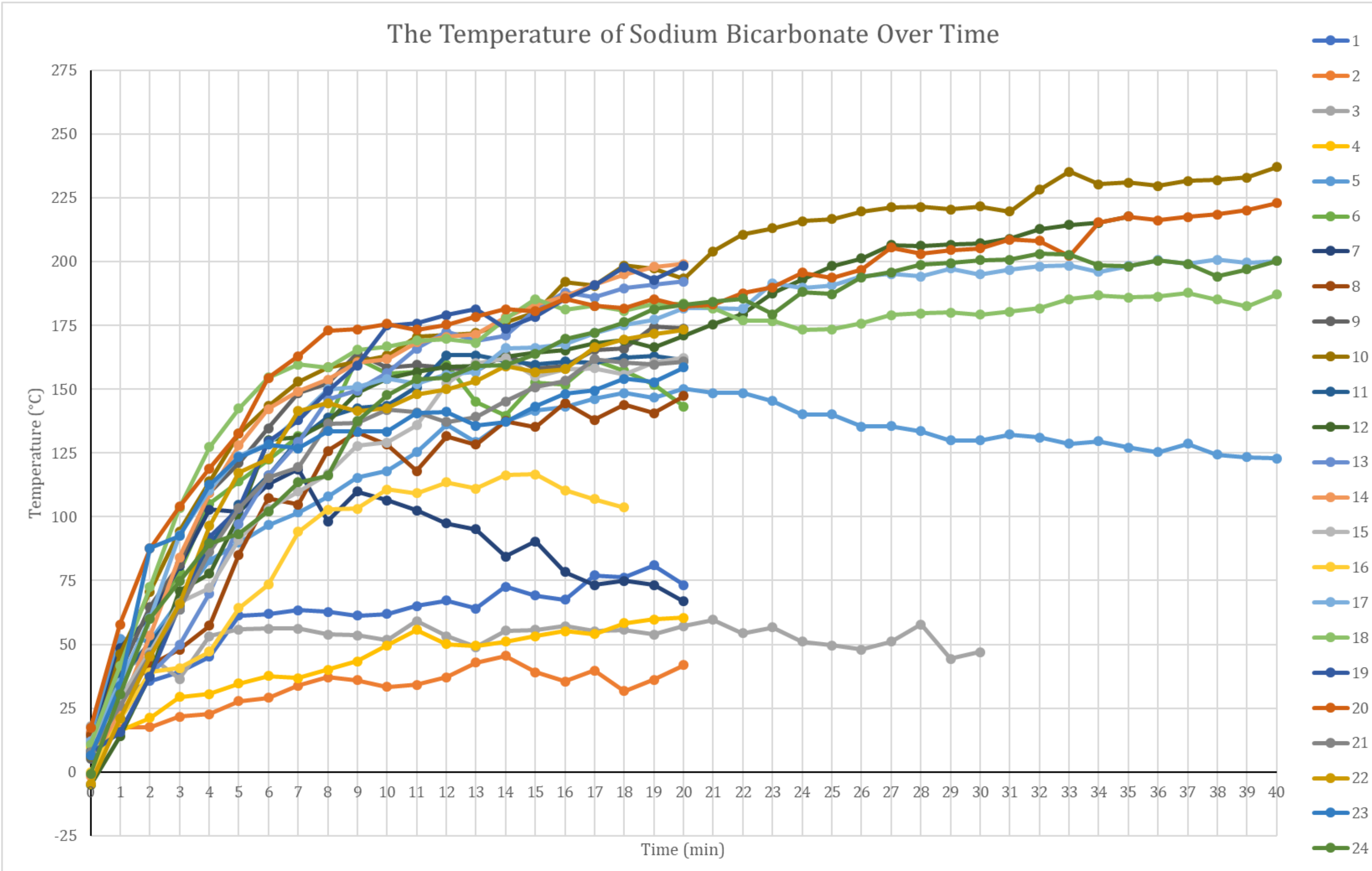


Figure 13. This graph shows each of the raw temperature measurements for each trial.

Table 5. The table shows the data summary for each trial, including sample data, weather data, and component data.

Trial #	Start Mass (g)	End Mass (g)	Mass Lost (g)	Predicted Mass (g)	Percent Converted	Time (min)	Average (°C)	MAX Temp (°C)	pH	Temperature (°C)	Humidity (%)	Pressure (mb)	Wind (kph)	Sun Altitude (°)	Smaller Jar Spray Painted	Inside Larger Jar	Aluminum Foil on Larger Jar	Lid on Smaller Jar	Aluminum Foil Spray Painted
1	50.002	49.848	0.154	31.543	0.834	20	59.5	81.0	8.25	10	48	1005	26.7	26.5	No	No	No	Yes	No
2	50.003	49.933	0.070	31.544	0.379	20	32.1	45.5	8.25	11	44	1004	31.2	26.6	No	No	No	Yes	No
3	50.004	49.993	0.011	31.544	0.060	30	51.3	59.6	8.24	6	55	1007	24.5	25.9	No	No	No	Yes	No
4	50.000	49.656	0.344	31.542	1.864	20	42.7	60.4	8.31	1	88	1023	1.1	19.4	Yes	No	No	Yes	No
5	50.002	44.754	5.248	31.543	28.430	40	121.0	150.2	9.14	4	69	1022	7.4	24.3	Yes	Yes	No	No	No
6	50.001	46.490	3.511	31.542	19.021	20	125.3	162.2	8.87	-2	62	1012	24.9	24.1	Yes	Yes	No	No	No
7	50.000	47.983	2.017	31.542	10.927	20	85.0	118.7	8.60	-2	59	1012	27.2	24.1	Yes	Yes	No	No	No
8	50.00	48.44	1.56	31.54	8.45	20	106.7	147.4	8.55	4	37	1008	21.6	20.5	Yes	Yes	No	No	No
9	49.96	45.86	4.10	31.52	22.23	20	134.1	174.5	8.75	-3	52	1021	7.4	23.8	Yes	Yes	Yes	No	No
10	50.00	39.89	10.11	31.54	54.77	40	184.4	237.2	9.09	-2	45	1021	6.8	24.1	Yes	Yes	Yes	No	No
11	49.99	45.83	4.16	31.54	22.54	20	125.2	163.4	8.99	-10	55	1029	21.1	23.6	Yes	Yes	Yes	No	No
12	49.99	42.05	7.94	31.54	43.02	35	157.5	217.8	9.10	-9	53	1029	18.2	24.2	Yes	Yes	Yes	No	No
13	50.01	45.14	4.87	31.55	26.38	20	132.4	192.3	8.96	-15	48	1027	27.8	24.2	Yes	Yes	Yes	No	No
14	50.00	44.62	5.38	31.54	29.15	20	143.2	199.2	9.08	-14	48	1026	17.5	24.1	Yes	Yes	Yes	No	No
15	50.06	43.83	6.23	31.58	33.71	20	117.4	162.3	9.20	-14	56	1019	25.6	24.3	Yes	Yes	Yes	Yes	No
16	50.02	49.46	0.56	31.55	3.03	20	83.4	116.6	8.29	-14	54	1019	24.9	24.4	No	Yes	Yes	Yes	No
17	49.93	39.33	10.60	31.50	57.51	40	164.1	200.9	9.67	-14	50	1022	19.3	24.4	Yes	Yes	Yes	Yes	No
18	50.01	40.84	9.17	31.55	49.67	40	163.7	187.8	9.52	-13	59	1025	18.2	22.7	Yes	Yes	Yes	Yes	No
19	50.00	44.74	5.26	31.54	28.50	20	139.3	198.5	9.06	-13	55	1025	20.4	24.4	Yes	Yes	Yes	Yes	No
20	49.99	41.54	8.45	31.54	45.79	40	177.5	223.0	9.26	-12	51	1024	17.1	24.5	Yes	Yes	Yes	Yes	Yes
21	25.00	21.96	3.04	15.77	32.94	20	118.7	161.8	9.66	-14	42	1030	7.4	25.2	Yes	Yes	Yes	No	Yes
22	25.00	20.52	4.48	15.77	48.54	20	125.7	173.3	9.31	-12	35	1029	5.1	25.0	Yes	Yes	Yes	No	Yes
23	50.03	46.14	3.89	31.56	21.06	20	122.6	158.6	8.73	-10	40	1035	14.2	25.3	Yes	Yes	Yes	No	Yes
24	50.03	41.20	8.83	31.56	47.81	40	159.7	203.2	9.60	-9	39	1035	17.5	26.1	Yes	Yes	Yes	No	Yes

Table 6. Raw data for the oven trials. Twelve trials were conducted in an oven with three trials done at a time. The temperature of the first three trials were not measured. The tray temperature was the temperature of the surface that the jars of sodium bicarbonate were sitting on inside the oven. The temperatures (except for the initial temperatures) were rounded to the nearest five degrees Celsius.

Trial #	1	2	3	Tray	4	5	6	Tray	7	8	9	Tray	10	11	12	Tray
Time (min)	Temperature (°C)															
0	No Data				21.7	21.5	21.3	250	21.3	21.4	21.1	260	20.9	21.0	21.0	230
5					120	125	120	225	135	140	130	260	145	150	145	255
10					140	140	135	225	155	155	145	270	160	160	160	270
15					140	140	140	230	155	165	155	260	170	170	165	250
20					150	150	150	225	155	165	155	260	170	165	165	265
25													170	170	165	265
30													170	175	170	270
35													170	175	170	270
40													165	175	165	265

Table 7. The table shows a summary of each oven trial.

Trial	Time (min)	Oven Setting (°C)	Start Mass (g)	End Mass (g)	Mass Lost (g)	Predicted Mass (g)	Percent Converted	pH
1	20	100	49.99	49.81	0.18	31.54	0.98	8.34
2			50.04	49.72	0.32	31.57	1.73	8.17
3			50.00	49.87	0.13	31.54	0.73	8.16
4	20	200	50.02	47.98	2.04	31.55	11.05	8.65
5			50.04	47.92	2.12	31.57	11.48	9.06
6			49.98	48.52	1.46	31.53	7.91	8.96
7	20	230	50.03	46.85	3.18	31.56	17.22	8.70
8			50.02	46.89	3.13	31.55	16.95	8.62
9			50.00	47.60	2.40	31.54	13.00	8.59
10	40	230	50.00	43.50	6.50	31.54	35.21	9.46
11			49.99	43.54	6.45	31.54	34.95	9.32
12			50.01	44.44	5.57	31.55	30.17	9.41

Table 8. The complete scoring matrix. Each criterion, which is weighted, has sub-categories. Efficiency is scored by dividing the number of grams converted per minute by the goal rate of conversion, which is 50 grams per 20 minutes, and multiplying by ten. The other sub-categories are rated on a 1-4 scale, where 1 is never/expensive, 2 is some/sometimes/medium expensive, 3 is most/mostly/medium cheap, and 4 is always/cheap. The sub-categories are added to form a weighted subtotal, and the subtotals are added to form the total score.

Criteria	Sub-Category	Max	Trial																																			
			OV1	OV2	OV3	OV4	OV5	OV6	OV7	OV8	OV9	OV10	OV11	OV12	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
High Efficiency	Efficiency	10.0	0.1	0.2	0.1	1.1	1.1	0.8	1.7	1.7	1.3	1.8	1.7	1.5	0.1	0.0	0.0	0.2	1.4	1.9	1.1	0.8	2.2	2.7	2.3	2.5	2.6	2.9	3.4	0.3	2.9	2.5	2.8	2.3	1.6	2.4	2.1	2.4
	High Efficiency subtotal *1	10.0	0.1	0.2	0.1	1.1	1.1	0.8	1.7	1.7	1.3	1.8	1.7	1.5	0.1	0.0	0.0	0.2	1.4	1.9	1.1	0.8	2.2	2.7	2.3	2.5	2.6	2.9	3.4	0.3	2.9	2.5	2.8	2.3	1.6	2.4	2.1	2.4
Low Environmental Impact	Process does not emit greenhouse gas	4.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
	Materials are eco-friendly	4.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	3.5	3.5	3.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
	Low Environmental Impact subtotal *1	8.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	7.5	7.5	7.5	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.5	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
High Feasibility	Easiness to Obtain/ Assemble Materials	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
	Easiness to Operate/ Maintain Apparatus	4.0	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
	High Uptime	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	Efficiency	4.0	0.1	0.2	0.1	1.1	1.1	0.8	1.7	1.7	1.3	1.8	1.7	1.5	0.1	0.0	0.0	0.2	1.4	1.9	1.1	0.8	2.2	2.7	2.3	2.5	2.6	2.9	3.4	0.3	2.9	2.5	2.8	2.3	1.6	2.4	2.1	2.4
	High Feasibility subtotal *0.8	12.8	9.3	9.3	9.3	10.1	10.1	9.8	10.6	10.6	10.2	10.6	10.6	10.4	7.3	7.2	7.2	7.3	8.3	8.7	8.1	7.9	9.0	9.4	9.0	9.2	9.3	9.5	9.9	7.4	9.5	9.2	9.5	9.0	8.5	9.1	8.9	9.1
High Safety	Not Fire Hazard	4.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
	Not General Health Hazard	4.0	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
	High Safety subtotal *0.8	6.4	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	5.2	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
Low Cost	To Run	4.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
	To Maintain/Fix	4.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
	Low Cost subtotal *0.6	4.8	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
Total	Sum of Subtotals	42.0	21.0	21.1	20.9	22.8	22.9	22.2	23.9	23.9	23.1	24.0	23.9	23.5	24.9	24.8	24.7	24.1	26.4	27.2	25.8	25.3	27.8	28.7	27.9	28.2	28.5	29.0	29.9	25.2	29.0	28.3	28.9	27.9	26.8	28.2	27.6	28.1

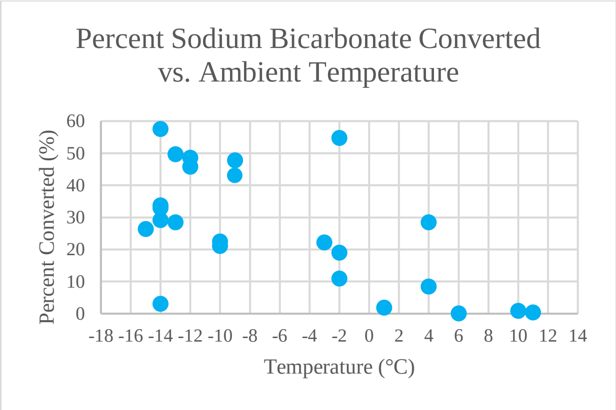


Figure 14a. This graph shows the amount of sodium bicarbonate converted compared to the ambient temperature. Overall, there does not appear to be a strong correlation.

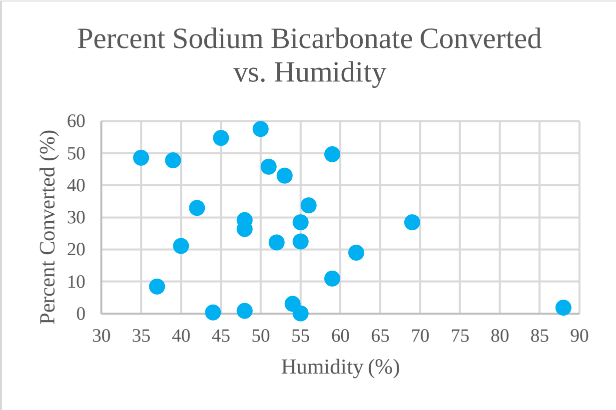


Figure 14b. This graph shows the amount of sodium bicarbonate converted compared to the humidity. There does not appear to be a correlation between the two quantities.

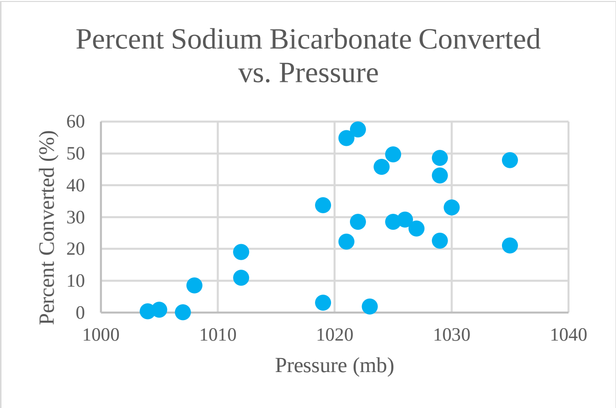


Figure 14c. This graph shows the amount of sodium bicarbonate converted compared to pressure. There does not appear to be a correlation between the two quantities.

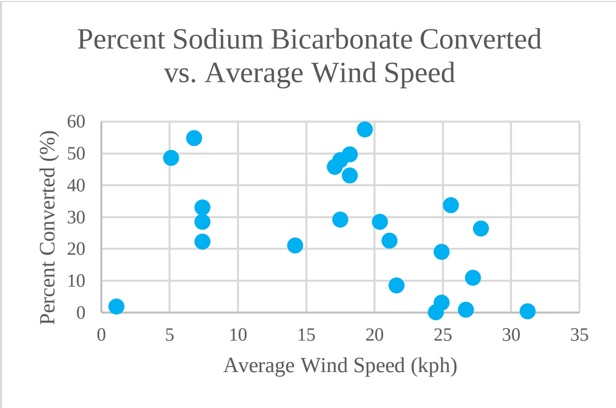


Figure 14d. This graph shows the amount of sodium bicarbonate converted compared to the average wind speed. Overall, there does not appear to be a strong correlation.

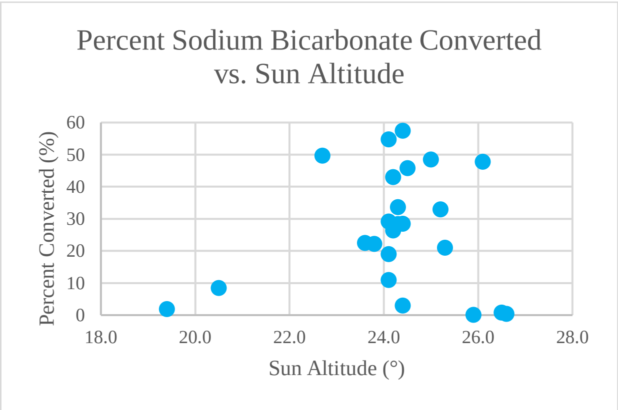


Figure 14e. This graph shows the amount of sodium bicarbonate converted compared to the height of the sun above the horizon. There does not appear to be a strong correlation between the two quantities.

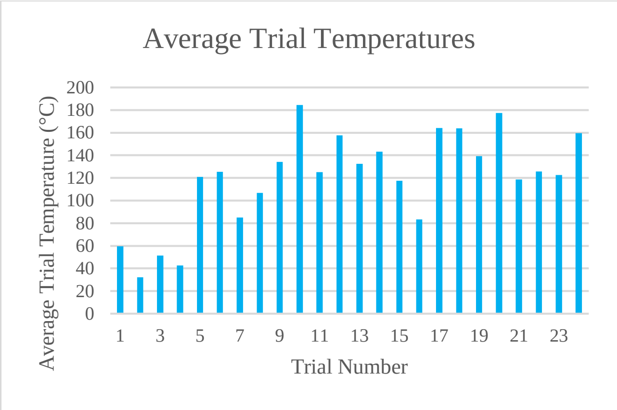


Figure 15a. This graph shows the average temperature of each trial over the course of the project.

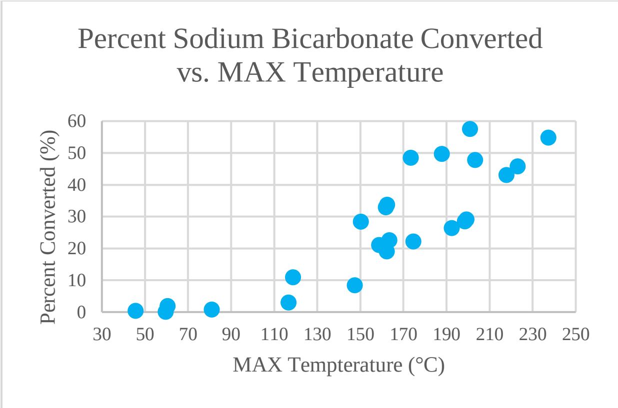


Figure 15b. This graph compares the amount of sodium bicarbonate converted to the maximum temperature of each trial. There appears to be a correlation between the two quantities.

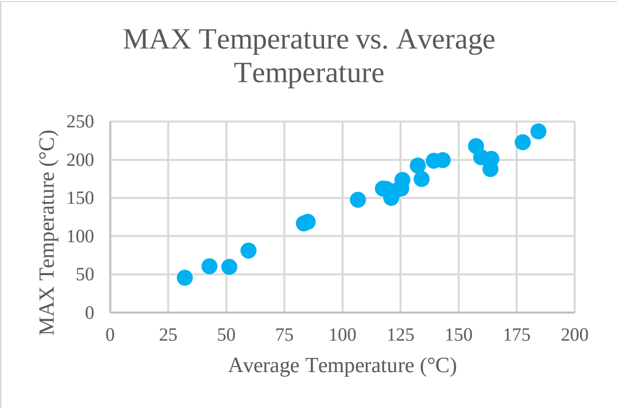


Figure 15c. This graph compares the maximum temperature to the average temperature. There appears to be a strong correlation between the two quantities.

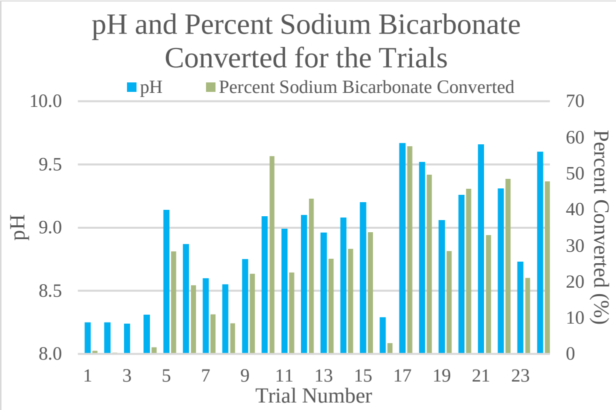


Figure 16a. This graph shows the pH and percent converted for each temperature.

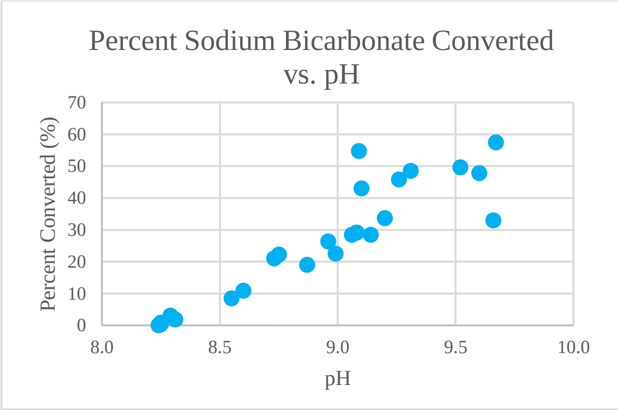


Figure 16b. This graph compares the amount of sodium bicarbonate converted to the pH. There appears to be a correlation between the two quantities.

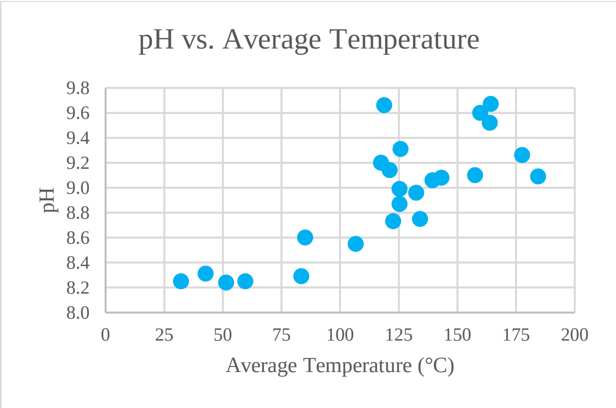


Figure 16c. The graph compares pH to average sample temperature. There appears to be a correlation between the two quantities.

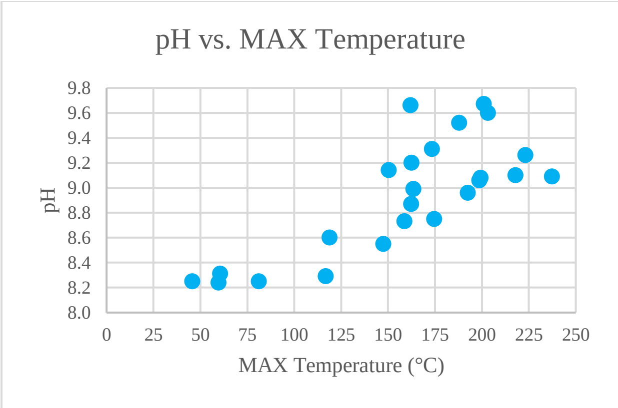


Figure 16d. The graph compares pH to maximum sample temperature. There appears to be a correlation between the two quantities.

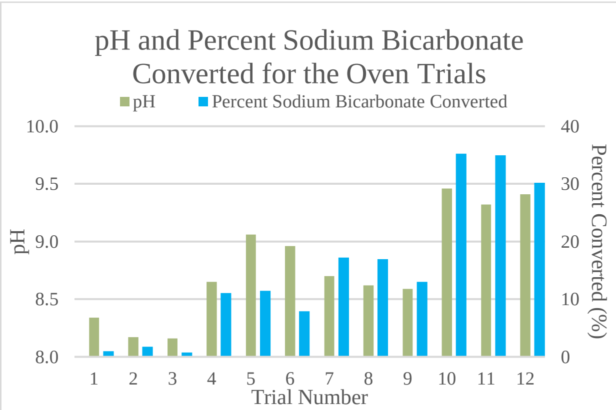


Figure 16e. This graph shows the pH and the amount of sodium bicarbonate converted to sodium carbonate for each oven trial.

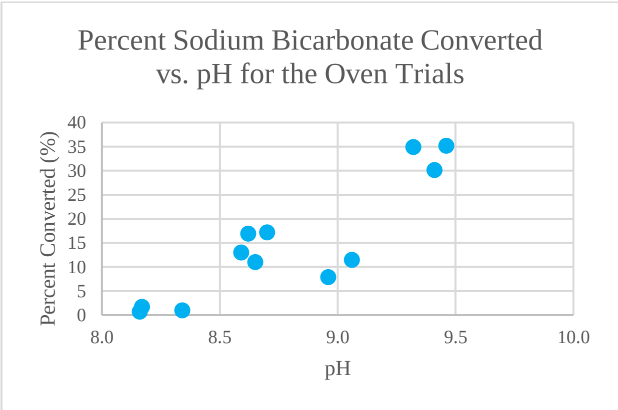


Figure 16f. This graph compares the amount of sodium bicarbonate converted to the pH for each oven trial. There appears to be correlation between the two quantities.

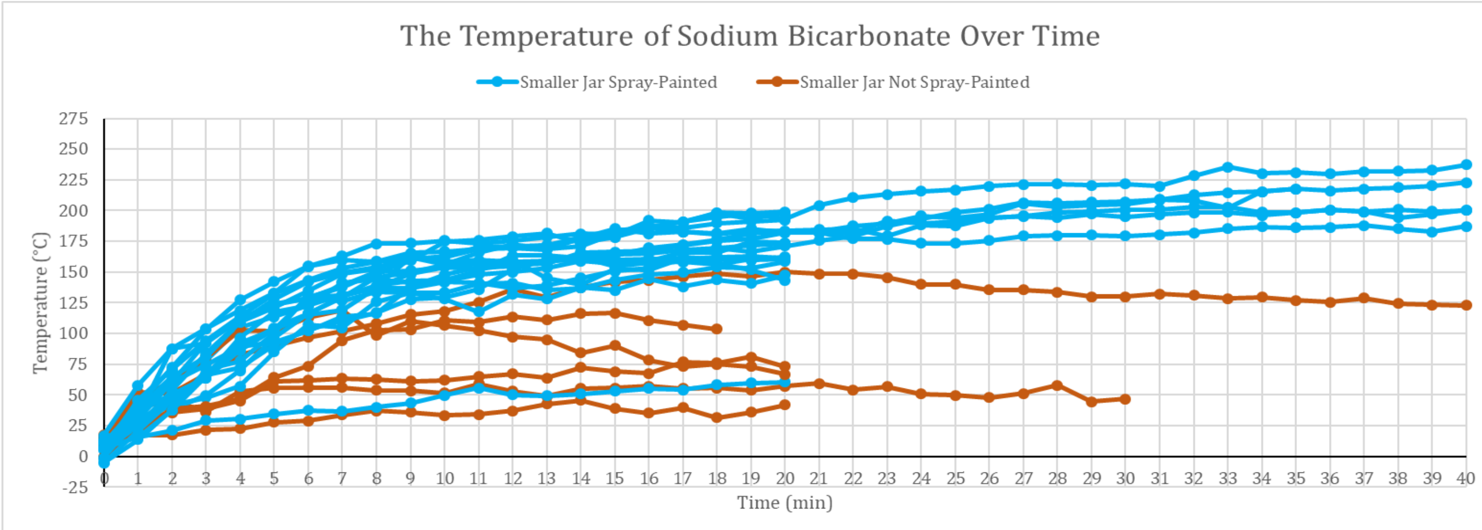


Figure 17a. This graph shows the temperature of each trial in one-minute increments. Trials with the smaller jar spray-painted are in blue while those not spray-painted are in red.

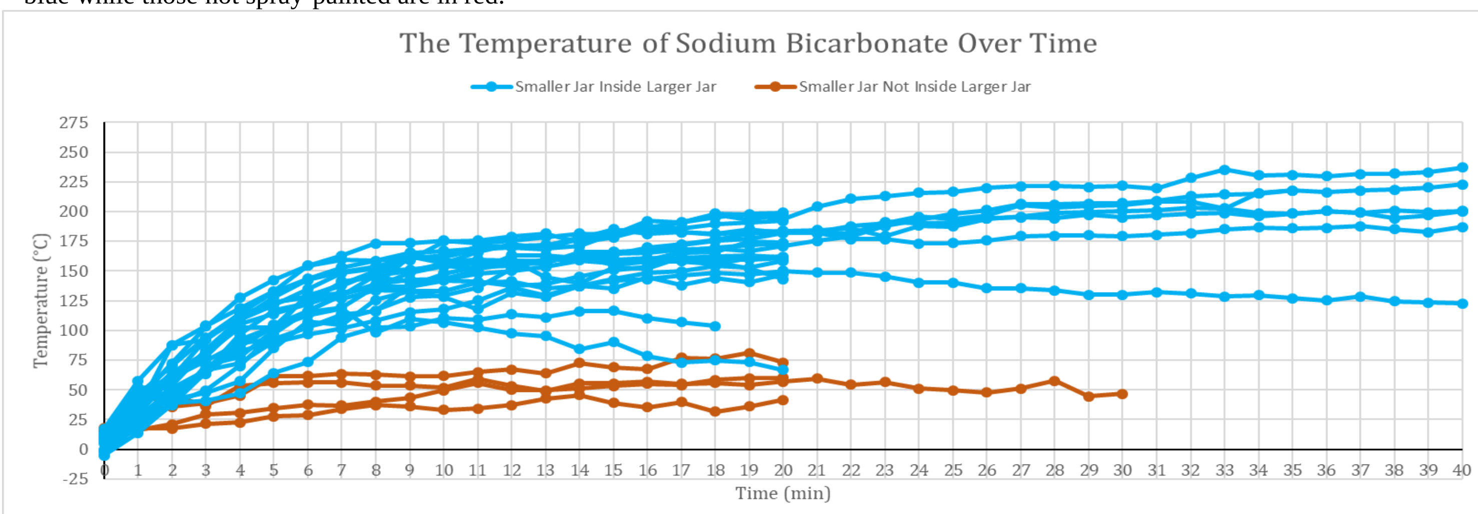


Figure 17b. This graph shows the temperature of each trial in one-minute increments. Trials with the smaller jar inside a larger jar are in blue while those whose jars are not inside a larger jar are in red.

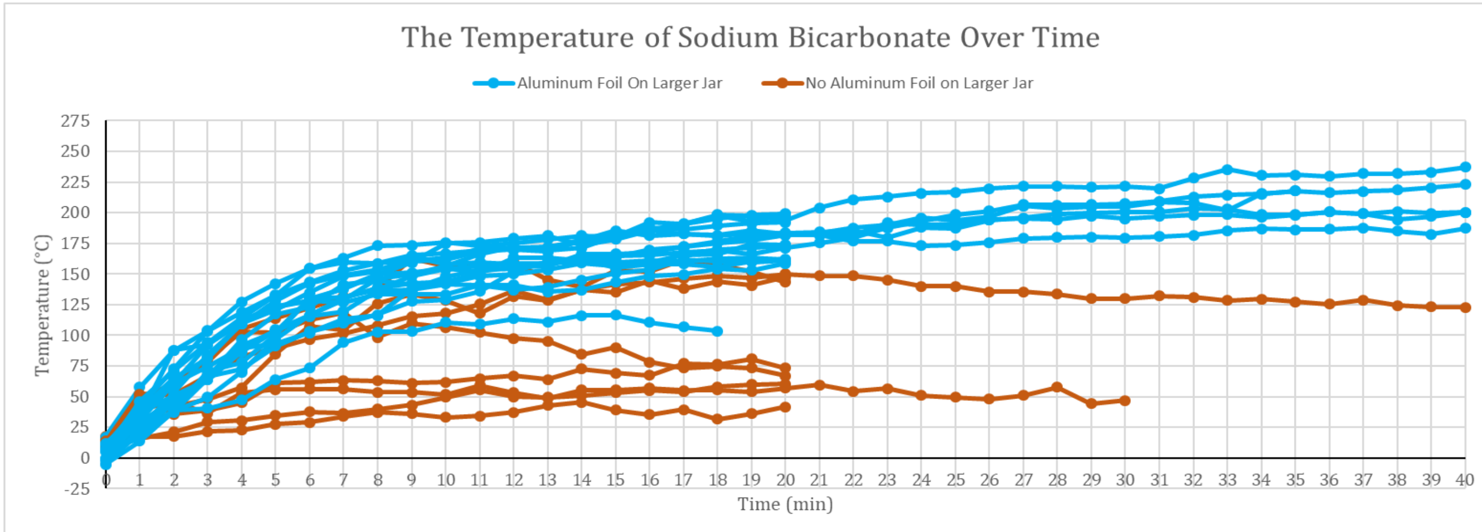


Figure 17c. This graph shows the temperature of each trial in one-minute increments. Trials with aluminum foil around the larger jar are in blue while those without aluminum foil around the larger jar are in red.

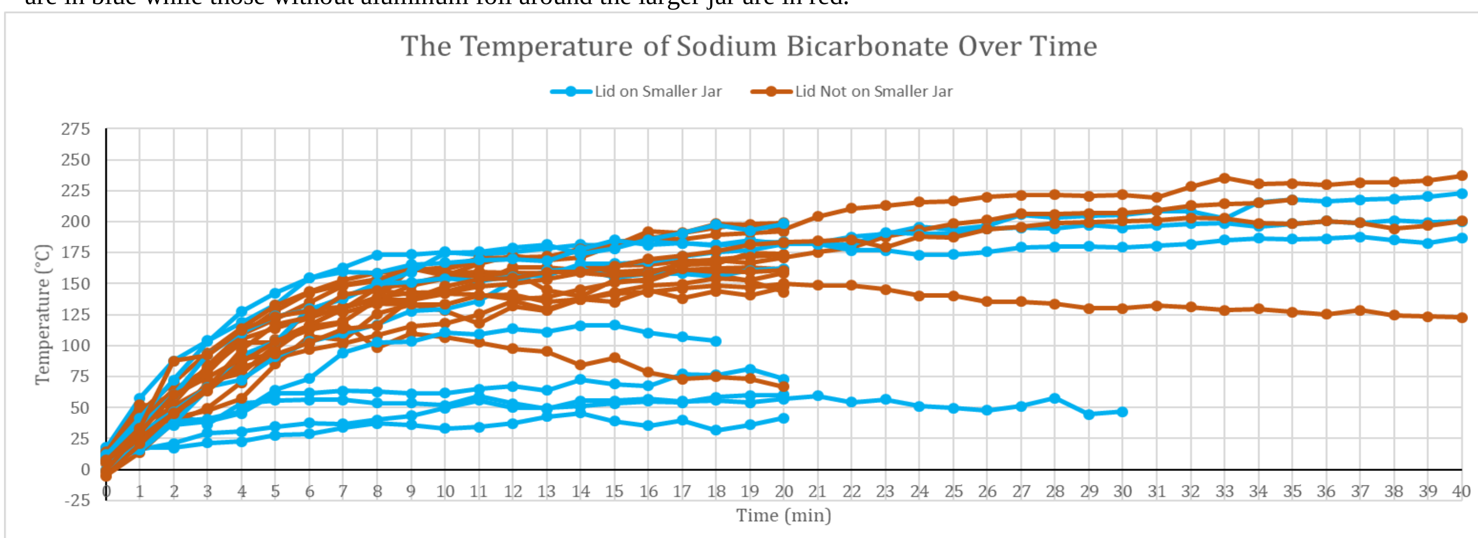


Figure 17d. This graph shows the temperature of each trial in one-minute increments. Trials with a lid on the smaller jar are in blue while those without a lid on the smaller jar are in red.

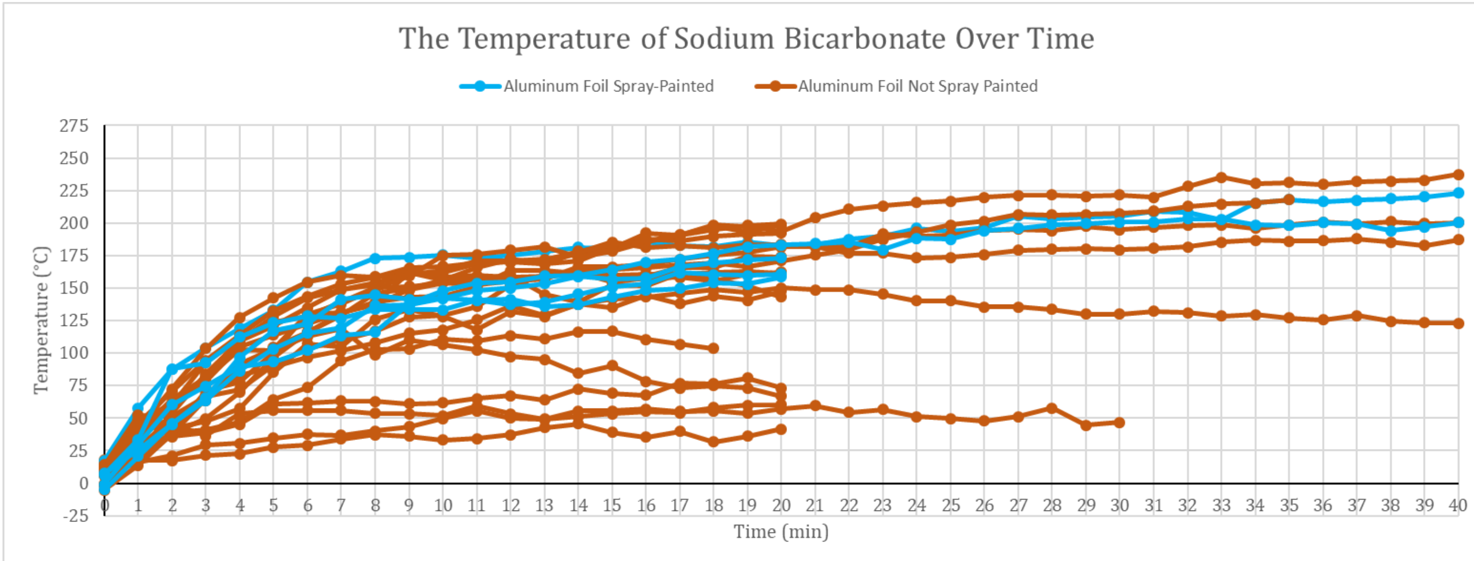


Figure 17e. This graph shows the temperature of each trial in one-minute increments. Trials with the aluminum foil spray-painted are in blue while those without the aluminum foil spray-painted are in red.

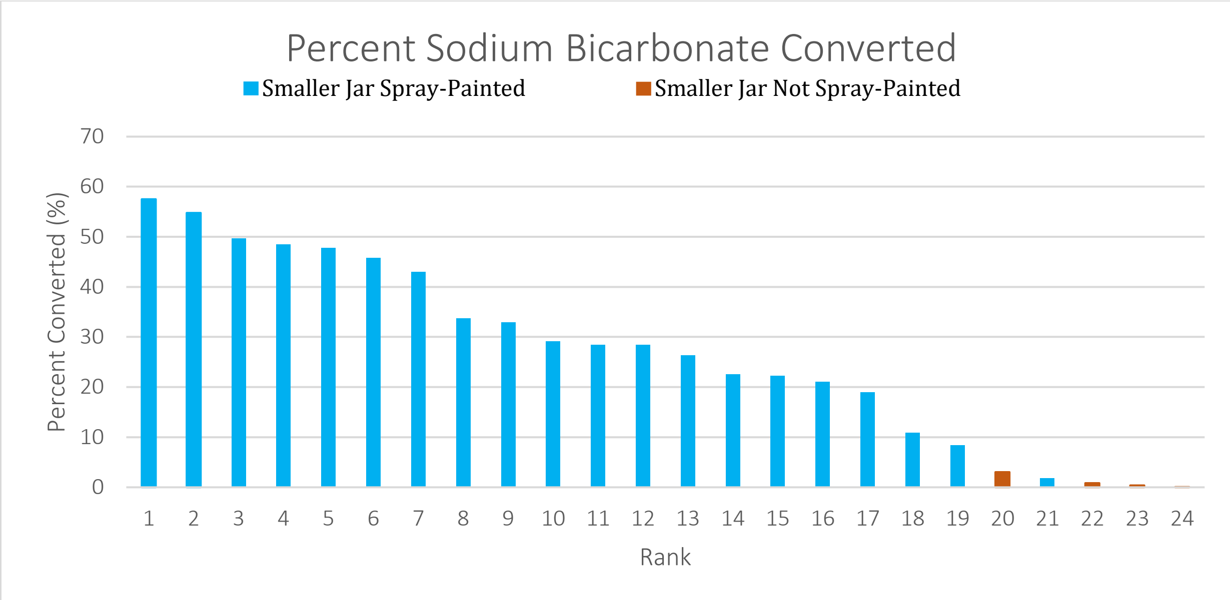


Figure 18a. This graph shows the amount of sodium bicarbonate converted in decreasing order. Trials where the smaller jar was spray-painted are in blue while jars where the smaller jar was not spray-painted are in red.

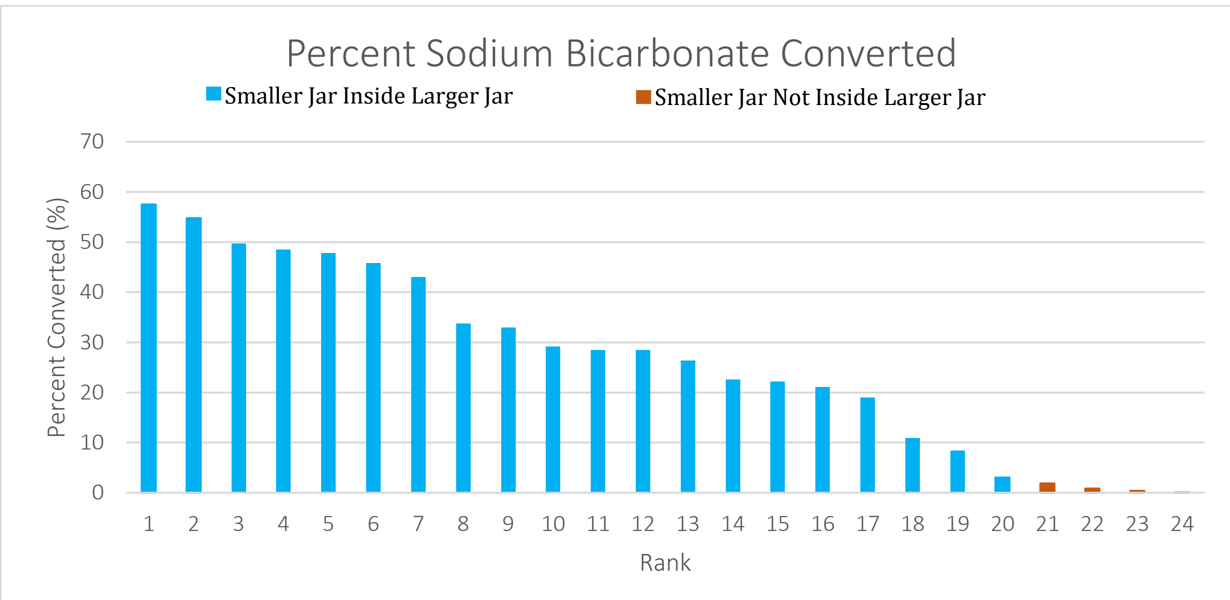


Figure 18b. This graph shows the amount of sodium bicarbonate converted in decreasing order. Trials where the smaller jar was inside a larger jar are in blue while jars where the smaller jar was not inside the larger jar are in red.

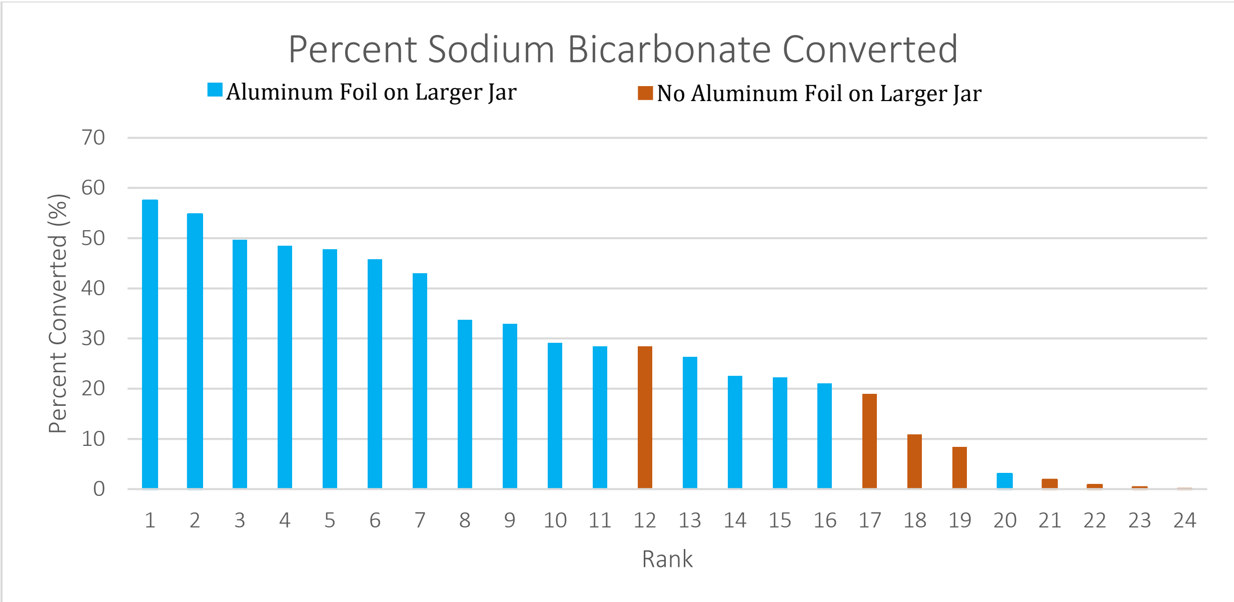


Figure 18c. This graph shows the amount of sodium bicarbonate converted in decreasing order. Trials with aluminum foil on the larger jar are in blue while jars without aluminum foil on the larger jar are in red.

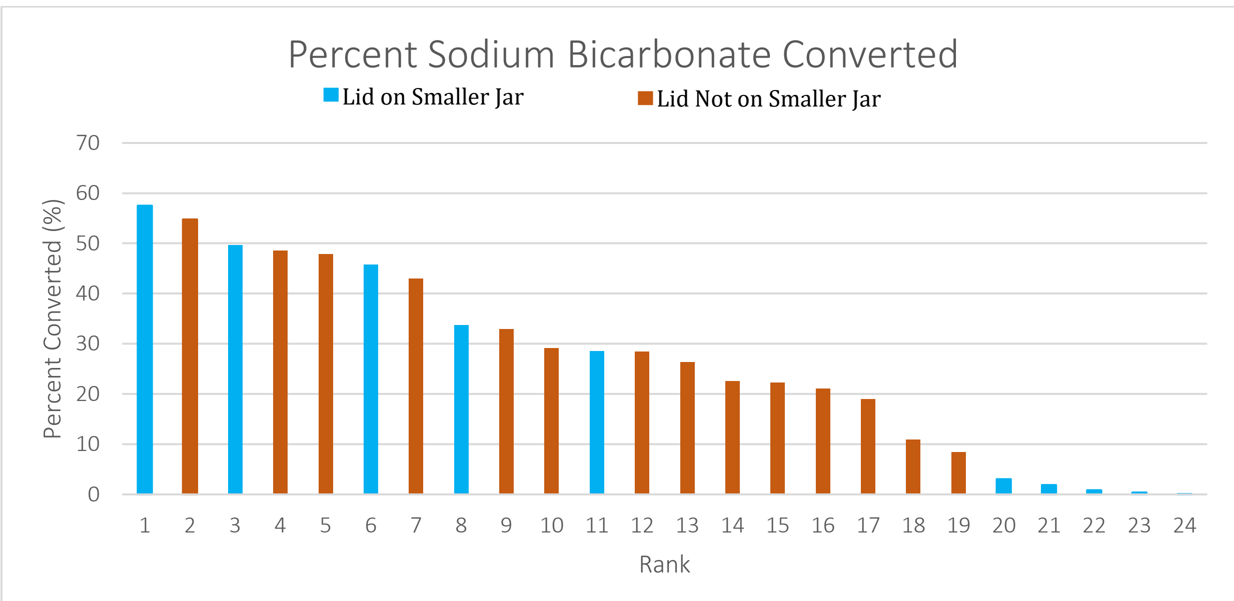


Figure 18d. This graph shows the amount of sodium bicarbonate converted in decreasing order. Trials where there was a lid on the smaller jar are in blue while jars where there was no lid on the smaller jar are in red.

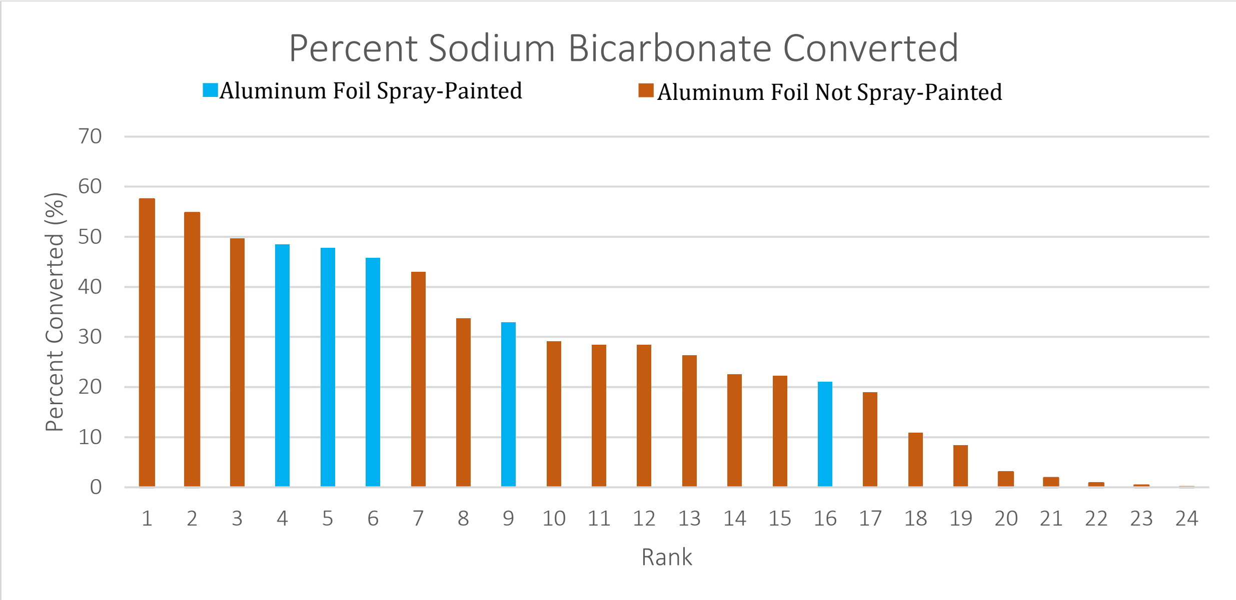


Figure 18e. This graph shows the amount of sodium bicarbonate converted in decreasing order. Trials where the aluminum foil was spray-painted are in blue while jars where the aluminum foil was not spray-painted are in red.

APPENDIX C: NOTES

#1 – Cost analysis of air capture driven by wind energy under different scenarios	
Citation	Geng, Y., Li, C., Cao, Y., Chen, H., Kuang, Y., Ren, X., & Bai, X. (2016). Cost analysis of air capture driven by wind energy under different scenarios. *Journal of Modern Power Systems and Clean Energy*, 4(2), 275-281. Retrieved September 17, 2017, from https://link.springer.com/article/10.1007%2Fs40565-015-0150-y.
Found by	Searching Engineering Village
Source types	Research paper
Keywords	CO_2 capture and storage, Renewable energy, Wind power, Air capture, CO_2 emission
Summary	• Greenhouse gases big problem • Carbon dioxide industries need it • Renewable energy to capture carbon dioxide could reduce emissions • Tries to determine cost and savings of carbon dioxide capture using wind energy under four different scenarios • Found that connecting to grid, but having air capture devices use curtail electricity the best
Reason for Interest	Attempts to calculate savings of carbon capture with renewable energy
Notes	• Calculate costs • Wind energy • "CO_2 capture from air system is composed of contactor, causticizer, slaker, calciner, kiln, and compressor."
Questions	
Link	https://link.springer.com/article/10.1007%2Fs40565-015-0150-y

#2 – A novel process for direct solvent regeneration via solar thermal energy for carbon capture	
Citation	Khalilpour, R., Milani, D., Qadir, A., Chiesa, M., & Abbas, A. (2017). A novel process for direct solvent regeneration via solar thermal energy for carbon capture. *Renewable Energy*, 104, 60-75. doi:https://doi.org/10.1016/j.renene.2016.12.001
Found by	Searching Engineering Village
Source types	Research paper
Keywords	Post-combustion carbon capture, Solar thermal energy, Solvent regeneration, Solvent storage, Process systems, Repowering
Summary	• Proposes a method of using solar energy to heat solvent to perform regeneration reaction • Traditional methods use a desorber column which transfers the heat of a working fluid into the solvent to perform the regeneration reaction • Proposed method takes out the desorber column which simplifies the process and prevents some heat loss • Also proposed process is cheaper
Reason for Interest	Proposes method to regenerate solvent using solar energy
Notes	• Included a part where the authors calculated savings of proposed method – didn't read
Questions	
Link	http://www.sciencedirect.com/science/article/pii/S0960148116310485?via%3Dihub

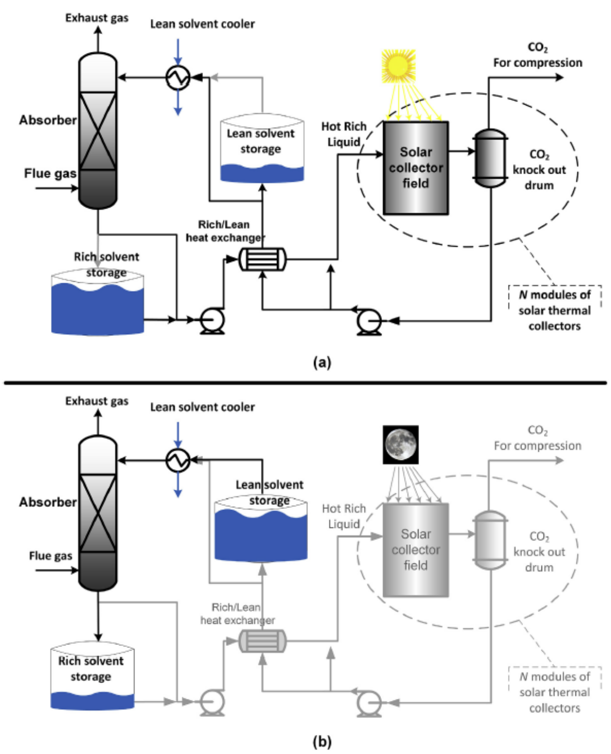
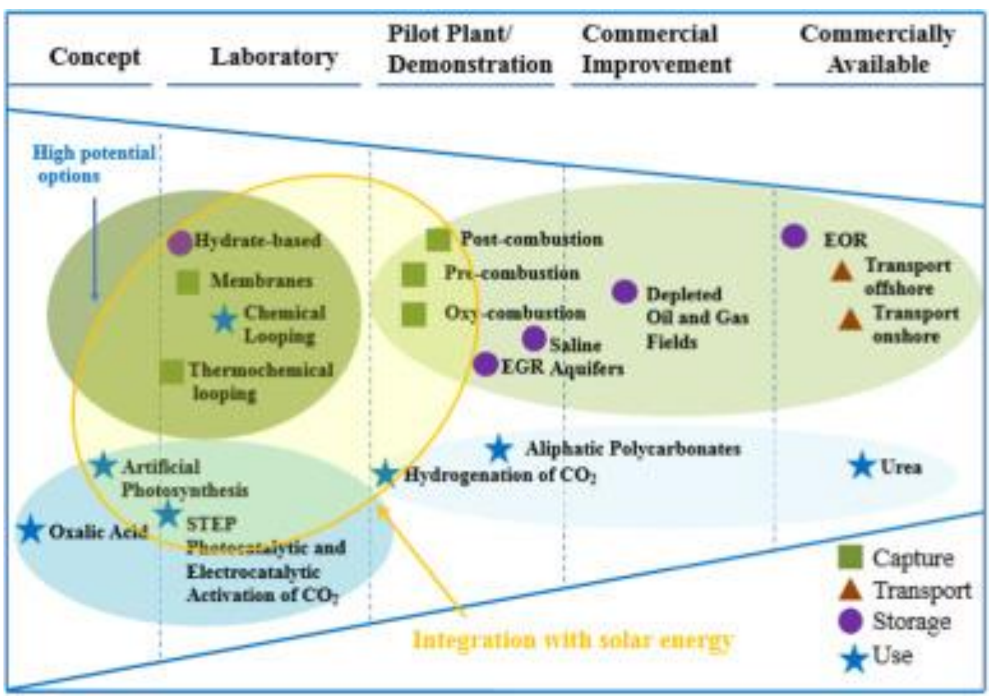


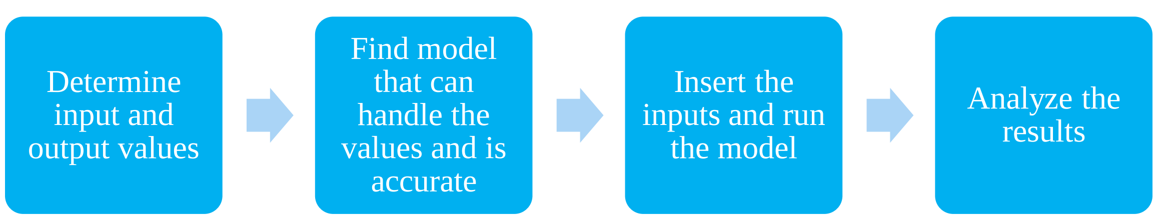
Fig. 10. Schematic of a solar-assisted PCC with storage during a) daytime (sun available), b) night (sun unavailable). Grey color indicates the process inactivity.

#3 – Energy-saving pathway exploration of CCS integrated with solar energy: A review of innovative concepts	
Citation	Liu, Y., Deng, S., Zhao, R., He, J., & Zhao, L. (2017). Energy-saving pathway exploration of CCS integrated with solar energy: A review of innovative concepts. *Renewable and Sustainable Energy Reviews*, 77, 652-669. doi:https://doi.org/10.1016/j.rser.2017.04.031
Found by	Searching Engineering Village
Source types	Research paper
Keywords	CO_2 capture, Solar energy, CCS, Renewable energy
Summary	• Lots of methods to capture carbon dioxide • However not many papers analyzes carbon capture through solar energy • Focuses on cost and efficiency • "The purpose of this review is to summarize and evaluate recent CCS technologies feasible to integrate with solar energy and develop the potential role of solar integration within the next-generation CCS concepts."
Reason for Interest	Carbon capture with solar energy
Notes	• Looks at the current technologies
Questions	
Link	http://www.sciencedirect.com/science/article/pii/S1364032117305336



#4 – The role of Carbon Capture and Storage in a future sustainable energy system	
Citation	Lund, H., & Mathiesen, B. V. (2012). The role of Carbon Capture and Storage in a future sustainable energy system. *Energy*, 44(1), 469-476. doi:https://doi.org/10.1016/j.energy.2012.06.002
Found by	Searching Engineering Village
Source types	Research paper
Keywords	CCS, Carbon Capture and Storage, Sustainable energy systems, Energy system analysis, 100 Percent renewable energy systems
Summary	• Analyzed how introducing CCS to a powerplant in Denmark would affect costs, efficiency, how long the plant needs to run, and how CSS would do in helping turn this powerplant into a sustainable system.
Reason for Interest	Included CCS and sustainable energy
Notes	• Not what I wanted to read about since this article was about CCS in powerplant not in atmosphere • However did provide interesting info • 90% CO_2 can be removed with CCS in powerplant • CCS expensive bc of electricity •
Questions	
Link	http://www.sciencedirect.com/science/article/pii/S0360544212004525?via%3Dihub

Procedure



#5 – Air as the renewable carbon source of the future: an overview of CO_2 capture from the atmosphere	
Citation	Goeppert, A., Czaun, M., Prakash, G., & Olah, G. A. (2012). Air as the renewable carbon source of the future: an overview of CO2 capture from the atmosphere. *Energy and Environmental Science*, (7), 7833-7853. doi:https://doi.org/10.1039/c2ee21586a
Found by	Searching Summon
Source types	Review
Keywords	Carbon capture in the atmosphere
Summary	• Intro talks ab greenhouse gases and why prob
Reason for Interest	Talks about carbon capture in the air, not in a factory

Notes	• Greenhouse gases absorb and emit infrared radiation
	• CO_2 is 25% of greenhouse gases
	• 390ppm co2 in atm – 100 ppm higher than before indust rev
	• Fosil fuel creates > 30Gt/yr
	• CCS three steps: extract, concentrate 2. Pressurize, transport 3. Store
	• Accumulated 600 Gt since indus rev
	• 15 Gt/year
	• Ab half co2 come fm sm things like cars and & homes tht r dif to cap co2
	• Method 1: modified photosynthesis – inefficient
	• Method 2: $2LiOH + CO_2 \longrightarrow Li_2 + H_2O$
	    ○ Needs high heat
	    ○ LiOH hard to regenerate
	    ○ Could also use other bases or hydroxide
	• OH solutions w high pH good at absorbing CO_2
	    ○ Drip liquid through column of packing material and flow gas from opposite side – 99% captured
	• Method 3: Na/Ca cycle – complicated and needs high heat
	    ○ Could add metal oxide or salt to Na_2CO_3 to form CO_2
	• Method 4: Steinberg
	    ○ Use K_2CO_3 – wide temp range that can cap 100% of CO_2
	    ○ Requires less energy (100-200 C) because less water in precipitate
	• Method 5: Zeolites
	    ○ “a high cation content lithium exchanged low silica type X zeolite (Li-LSX)” in low humidity using TSA and VSA at 240 C.
	• Method 6: FS-PEI
	    ○ Does well at 25 C with adsorption of CO_2

Questions	Hybrid absorbents section Does Na/Ca cycle only work for Na and Ca? Can I replace them with other compounds using the same process?
Link	http://pubs.rsc.org/en/content/articlepdf/2012/ee/c2ee21586a

#6 – US Patent US20120003722A1	
Citation	Polak, R. B., & Steinberg, M. (2012). *U.S. Patent No. US20120003722A1*. Washington, DC: U.S. Patent and Trademark Office.
Found by	Reference to article 5
Source types	Patent
Keywords	
Summary	• Method to remove CO_2 using potassium carbonate • Patents an entire process for large scale removal ○ Includes information on how to capture CO_2, regenerate the sorbent, and the what structures are needed • Carbon dioxide goes through process that uses concentrated potassium carbonate to capture it • $K_2CO_3 + CO_2 + H_2O \rightarrow 2KHCO_3$ • Potassium bicarbonate formed – precipitates from solution • Precipitate = less water = less energy for regeneration reaction • Decompose potassium bicarbonate with 100-200°C heat to get CO_2 gas and K_2CO_3 • $2KHCO_3 \rightarrow K_2CO_3 + CO_2 + H_2O$ • Can replace K with Na • Na_2CO_3 solubility – 30g/100mL • $NaHCO_3$ solubility – 7.8g/100mL
Reason for Interest	Potassium carbonate requires the lowest amount of energy to regenerate, the patent describes a method that uses potassium carbonate to remove carbon dioxide
Notes	• Only read parts about the chemical reactions
Questions	Is potassium better than sodium at absorbing CO_2? If so, how much better?
Link	https://patents.google.com/patent/US20120003722A1/en

#7 – Efficient Recovery of Carbon Dioxide from Flue Gases of Coal-Fired Power Plants by Cyclic Fixed-Bed Operations over K_2CO_3-on-Carbon	
Citation	Hayashi, H., Taniuchi, J., Furuyashiki, N., Sugiyama, S., Hirano, S., Shigemoto, N., & Nonaka, T. (1998). Efficient Recovery of Carbon Dioxide from Flue Gases of Coal-Fired Power Plants by Cyclic Fixed-Bed Operations over K2CO3-on-Carbon. *Industrial & Engineering Chemistry Research*, *37*(1), 185-191. doi:http://doi.org/10.1021/ie9704455
Found by	Reference 122 of Source 5
Source types	Article
Keywords	
Summary	• Gives process for carbon capture using potassium carbonate
Reason for Interest	A process to regenerate CO_2 using potassium carbonate
Notes	• Skimmed – only read parts that deals with reaction of potassium carbonate • $K_2CO_3 + CO_2 + H_2O \rightarrow 2KHCO_3$ • Includes graph (fig 7) on temp vs CO_2 uptake on K_2CO_3, Na_2CO_3, and $LiCO_3$ • Could use Na_2CO_3 for experiment
Questions	I didn't really understand what they did to capture the carbon dioxide
Link	http://pubs.acs.org.ezproxy.wpi.edu/doi/pdf/10.1021/ie9704455

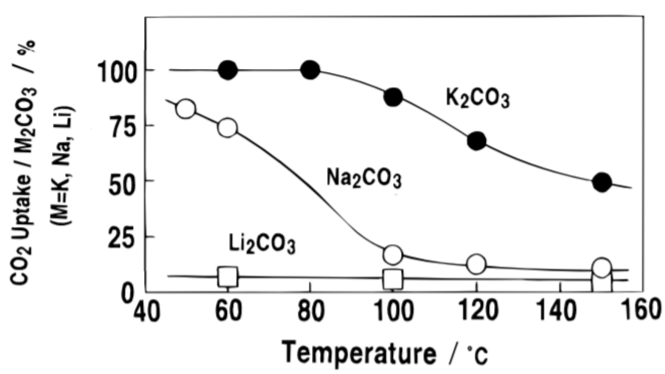


Figure 7. Effect of temperature on the efficiency of CO_2 uptake by alkaline-earth carbonates. Feed gas composition: 13.8% CO_2, 10% H_2O, balance He.

#8 – Energy and Material Balance of CO2 Capture from Ambient Air	
Citation	Zeman, F. (2007). Energy and Material Balance of CO2 Capture from Ambient Air. *Environmental Science & Technology*, *41*(21), 7558-7563. doi:http://doi.org/10.1021/es070874m
Found by	Reference 82 of article #5
Source types	article
Keywords	
Summary	• Gives information about CO_2 capture using the Na/Ca cycle • CO_2 absorbed in NaOH solution to make Na_2CO_3 • Na_2CO_3 then reacted with $Ca(OH)_2$ to form NaOH and $CaCO_3$ precipitate • $CaCO_3$ heated up to 900° to form CaO and CO_2 • CaO then combined with water to form $Ca(OH)_2$
Reason for Interest	An alternative process to capture CO_2 from the air
Notes	• Skimmed – only read parts related to Na/Ca cycle • Table 1 – gives reactions and their heat enthalpies • Fig 2 – equations of the process
Questions	
Link	http://pubs.acs.org.ezproxy.wpi.edu/doi/pdf/10.1021/es070874m

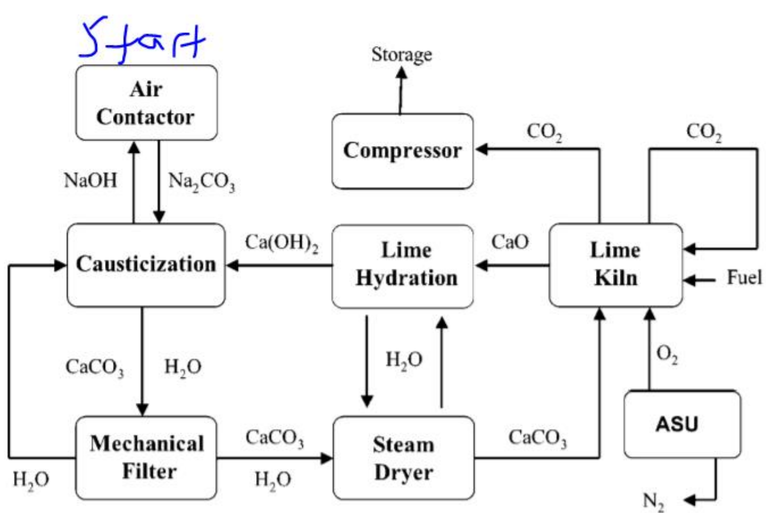


FIGURE 2. Overview of air capture process.

TABLE 1. Reaction Cycle for Na/Ca Air Capture

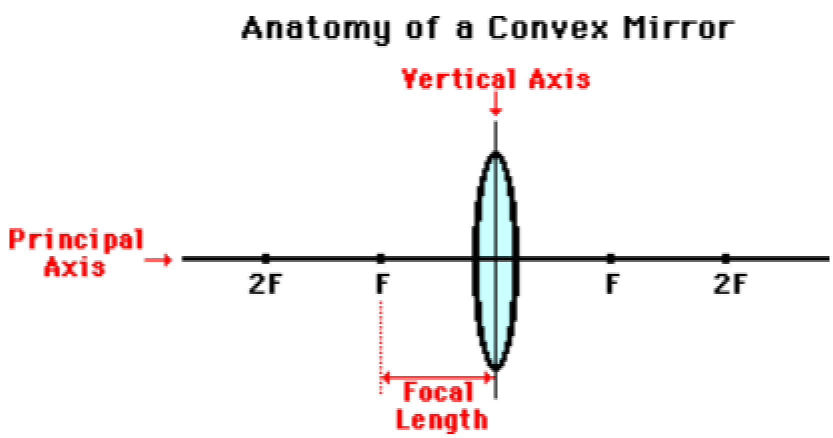
reaction	ΔH° (kJ/mol)	name	type
$2\,NaOH_{(aq)} + CO_{2(g)} \rightarrow Na_2CO_{3(aq)} + H_2O_{(l)}$	−109.4	absorption	gas/liquid
$Na_2CO_{3(aq)} + Ca(OH)_{2(s)} \rightarrow 2\,NaOH_{(aq)} + CaCO_{3(s)}$	−5.3	causticization	aqueous
$CaCO_{3(s)} \rightarrow CaO_{(s)} + CO_{2(g)}$	+179.2	calcination	gas/solid
$CaO_{(s)} + H_2O_{(l)} \rightarrow Ca(OH)_{2(s)}$	−64.5	hydration	liquid/solid

#9 – What happens when sodium bicarbonate is heated?	
Citation	Senese, F. (n.d.). *What happens when sodium bicarbonate is heated?* Retrieved October 21, 2017, from http://antoine.frostburg.edu/chem/senese/101/inorganic/faq/carbonate-decomposition.shtml
Found by	Google
Source types	FAQ question on website
Keywords	decomposition of sodium bicarbonate
Summary	• $2NaHCO_3(s) \rightarrow CO_2(g) + H_2O(g) + Na_2CO_3(s)$ • Reaction begins at ab 100°C, completely changes at 200°C
Reason for Interest	Gives summary of decomposition of sodium bicarbonate
Notes	• Should try to have temperature at or over 200° - from October break observations
Questions	
Link	http://antoine.frostburg.edu/chem/senese/101/inorganic/faq/carbonate-decomposition.shtml

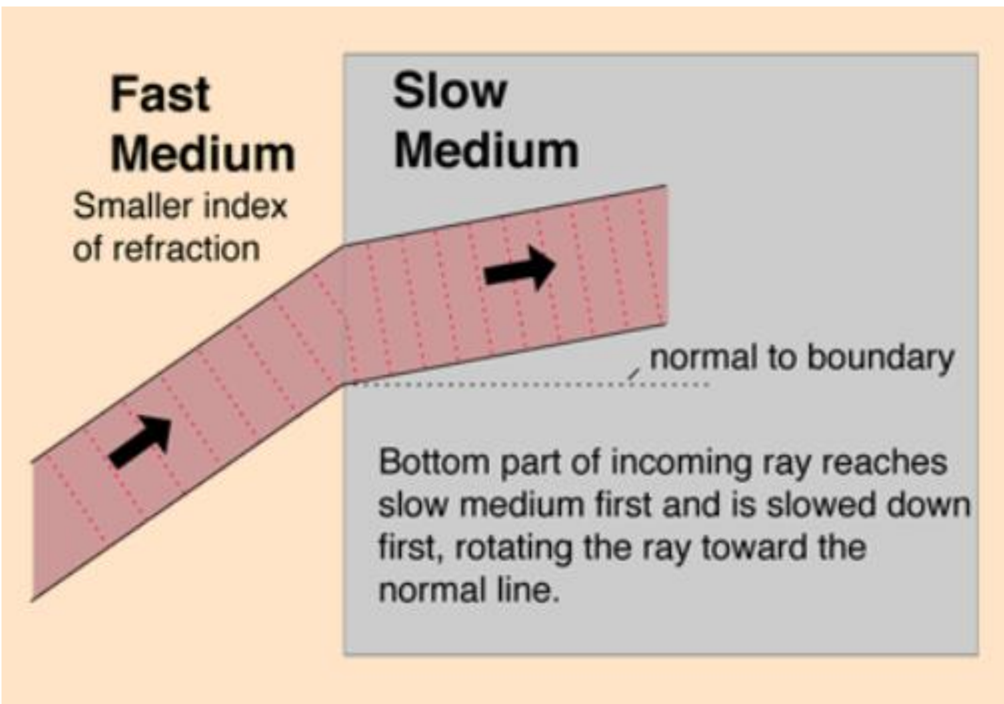
#10 – Refraction and Snell's law	
Citation	Khan, S. (2010b, December 8). *Refraction and Snell's law* [Video file]. Retrieved from https://www.youtube.com/watch?time_continue=754&v=y55tzg_jW9I
Found by	Looking at the available videos on Khan Academy
Source types	video
Keywords	
Summary	• Introduction to refraction • Snell's law • Index of refraction
Reason for Interest	Introduction to refraction
Notes	• Refraction – when light bends when traveling through a different medium • Light travels at different speeds in different media • Light bends because one side of light travels more through a medium than the other side of light. • Snell's law $\frac{v_2}{sin\theta_2} = \frac{v_1}{sin\theta_1}$ or $n_2 sin\theta_2 = n_1 sin\theta_1$ where v is velocity, θ is incident angle, n is index of refraction, c is speed of light • Index of refraction $n = \frac{c}{v}$ • Air index of refraction = 1.00029 • Glass index of refraction = 1.52
Questions	
Link	https://www.youtube.com/watch?time_continue=754&v=y55tzg_jW9I

#11 – Convex lenses	
Citation	Khan, S. (2010a, December 9). *Convex lenses* [Video file]. Retrieved from https://www.youtube.com/watch?time_continue=1&v=K0sjZ5nqQ7g
Found by	Looking at the available videos on Khan Academy
Source types	video
Keywords	
Summary	• Intro to convex lenses • Talks about images created by refraction
Reason for Interest	Introduction to convex lenses
Notes	• Principal axis – axis that goes through the center of the lens • Light will refract toward the principal axis when traveling through the lens • If light rays parallel, light refracted through lens will converge on the other side of lens at a certain point – called the focus • Images will be inverted on the other side of the lens because the lens is symmetric
Questions	
Link	https://www.youtube.com/watch?time_continue=1&v=K0sjZ5nqQ7g

#12 – The Anatomy of a Lens	
Citation	The Physics Classroom. (n.d.). *Refraction by Lenses*. Retrieved from http://www.physicsclassroom.com/class/refrn/Lesson-5/Refraction-by-Lenses
Found by	Google
Source types	website
Keywords	refraction
Summary	• Gives overview of both convex and concave lenses • Basic vocabulary and equations
Reason for Interest	Introduction to lenses
Notes	• Each lens has a principal axis and vertical axis • Each lens has 2 focal points • Focal length is distance from vertical axis to focal point
Questions	
Link	http://www.physicsclassroom.com/class/refrn/Lesson-5/The-Anatomy-of-a-Lens



#13 – Refraction of Light	
Citation	Nave, C. (n.d.). *Refraction of Light*. Retrieved from http://hyperphysics.phy-astr.gsu.edu/hbase/geoopt/refr.html
Found by	Google
Source types	website
Keywords	refraction
Summary	• Describes how light refracts through a surface • Index of refraction • Snell's law
Reason for Interest	Is about the refraction of light
Notes	• Refraction is when light bends as it enters a different medium with a different index of refraction • The light bends toward the normal • Index of refraction $n = \frac{c}{v}$ • Snell's law $\frac{n_1}{n_2} = \frac{sin\theta_2}{sin\theta_1}$
Questions	
Link	http://hyperphysics.phy-astr.gsu.edu/hbase/geoopt/refr.html



#14 – Understanding Solar Concentrators	
Citation	Kaplan, G. M. (1985). *Understanding solar concentrators*. Retrieved October 21, 2017, from http://pdf.usaid.gov/pdf_docs/PNABC955.pdf
Found by	Google
Source types	Book/paper
Keywords	types of solar concentrators
Summary	• 2 types of concentrators – mirrors and lens • Silver or aluminum for mirrors • Lens – fresnel, standard curved lens • Mirrors – parabolic dish, parabolic trough, heliostats • The type of concentrator depends on purpose and size • Lenses limited by size • Sunlight on clear day at sea level about 1000 watts/sq m • Needs to be able to track the sun
Reason for Interest	Gives brief overview of different types of lenses
Notes	• Table 1 is helpful chart of picking a concentrator type
Questions	What is the unit for sun's concentration in Table 1?
Link	http://pdf.usaid.gov/pdf_docs/PNABC955.pdf

Table 1. Classification of Concentrators

Type of Concentrator	Type of Focus	Lens or Mirror	Sun's Concen-tration	Tracking (yes/no)	Tracking Receiver (yes/no)	Capability of Temperature (°C)	(°F)	Typical Applications	Comments
Parabolic dish	point	mirror	> 1000	yes	yes two-axis	>2638	>3000	electricity heat	Small-scale applications
Central receiver	point	mirror	> 1000	yes	no two-axis	>2638	>3000	electricity heat	Large-scale applications
Lens (round)	point	lens	> 1000	yes	yes two-axis	>2638	>3000	electricity heat	Utilized with photovoltaic cells
Parabolic trough	line	mirror	100	yes one-axis	no	538	1000	electricity heat	Can be used for both small and large systems
Fixed mirror moving focus	line	mirror	100	no	yes one-axis	538	1000	electricity heat	Can be used for both small and large systems; not economic in U.S. experience
Lens (linear)	line	lens	100	yes	yes one-axis	538	1000	electricity heat	Little U.S. experience
Sphere	line	mirror	80	no	yes two-axis	538	1000	electricity	Awkward in large size
Cylinder	line	mirror	2	no	no	121	250	heat	
Cusp	line	mirror	1.5–2.5	no	no	121	250	heat	
Winston	line	mirror	3 – 6	no	no	121	250	heat	Concentration decreases as acceptance angle increases
Flat plate with booster	area	mirror booster	> 1 and < 2	no	no	121	250	heat	

#15 – Fresnel Lens	
Citation	Advantages of Fresnel Lenses. (n.d.). Retrieved October 21, 2017, from https://www.edmundoptics.com/resources/application-notes/optics/advantages-of-fresnel-lenses/
Found by	Google
Source types	article
Keywords	Fresnel lens
Summary	• Fresnel lens is a type of lens that is made up of concentric groves • Thin, lightweight, available in small and big sizes, glass or plastic • Fray-NEL • Is condensed version of standard lens • Standard lens cut into rings and flattened • Each ring has a different angle • More grooves = higher quality image • Named after Augustin-Jean Fresnel (1788-1827) who popularized its use in lighthouses • Can be used for light collimation, light collection, and magnifying
Reason for Interest	Gives an overview of fresnel lens
Notes	• Use for project
Questions	What size do I need to have the area under the lens be at 200°
Link	https://www.edmundoptics.com/resources/application-notes/optics/advantages-of-fresnel-lenses/

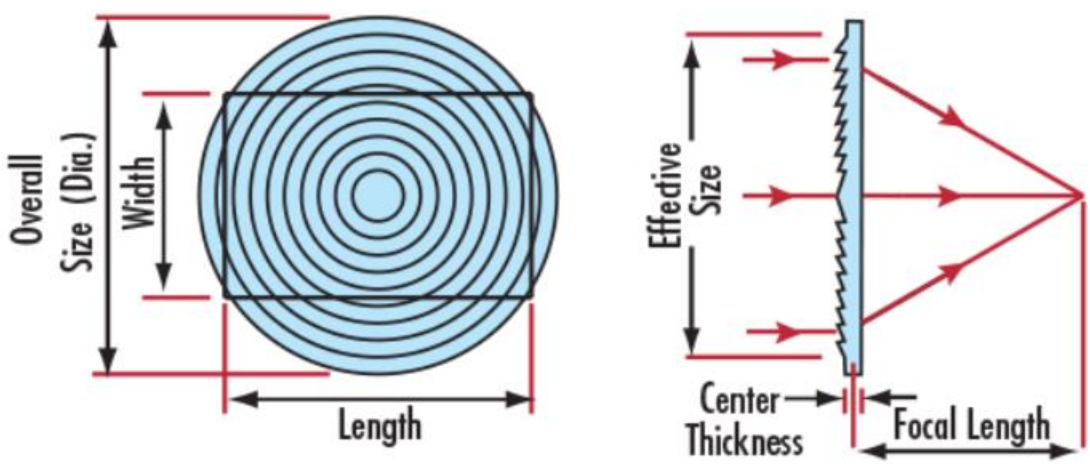
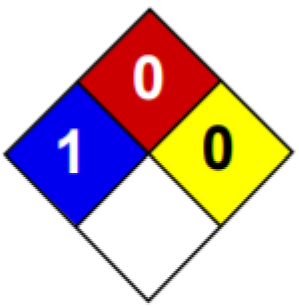
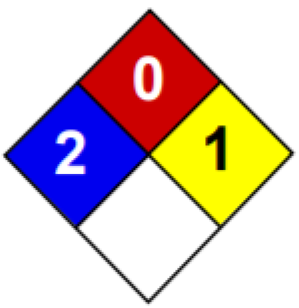


Figure 1: *Profile of a Fresnel Lens*

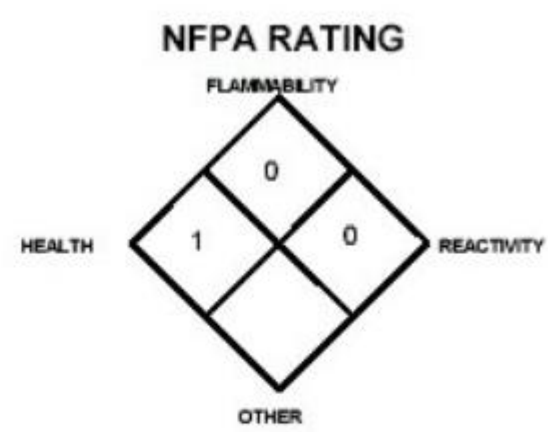
#16 – Material Safety Data Sheet Sodium bicarbonate MSDS	
Citation	Material Safety Data Sheet Sodium bicarbonate MSDS. (2013, May 21). Retrieved October 21, 2017, from http://www.sciencelab.com/msds.php?msdsId=9927258
Found by	Google
Source types	MSDS
Keywords	NaHCO3 safety sheet
Summary	• Safety on sodium bicarbonate
Reason for Interest	Safety and information sheet on sodium bicarbonate
Notes	• Non-flammable • Put spilled material in wastebasket • Do not breathe in • Store in tightly-closed container in cool area • Safety goggles • Molar mass: 84.01 g/mol
Questions	
Link	http://www.sciencelab.com/msds.php?msdsId=9927258



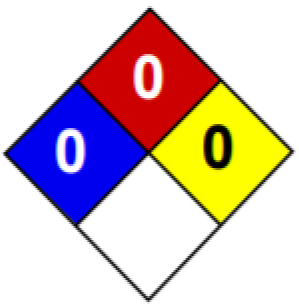
#17 – Material Safety Data Sheet Sodium carbonate MSDS	
Citation	Material Safety Data Sheet Sodium carbonate MSDS. (2013, May 21). Retrieved October 21, 2017, from http://www.sciencelab.com/msds.php?msdsId=9927263
Found by	Google
Source types	MSDS
Keywords	Na2CO3 safety sheet
Summary	• Safety on sodium carbonate
Reason for Interest	Safety and information sheet for sodium carbonate
Notes	• Non-flammable • Put in wastebasket if spilled • Do not breathe in • Safety goggles • Molar mass: 105.99 g/mol • Melting point: 851°C • pH: 11.5
Questions	
Link	http://www.sciencelab.com/msds.php?msdsId=9927263



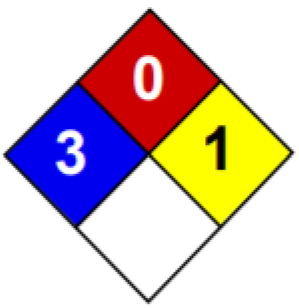
#18 – Material Safety Data Sheet: Gaseous CO_2	
Citation	Material Safety Data Sheet: Gaseous CO_2. (2015, April 25). Retrieved October 21, 2017, from http://www.uigi.com/MSDS_gaseous_CO2.html
Found by	Google
Source types	MSDS
Keywords	CO2 safety sheet
Summary	• Safety sheet for carbon dioxide
Reason for Interest	Safety and information sheet for carbon dioxide
Notes	• Can cause nausea, dizziness, headache, mental confusion, increased blood pressure and respiratory rate between 2 and 10% • Non-combustible
Questions	
Link	http://www.uigi.com/MSDS_gaseous_CO2.html



#19 – Material Safety Data Sheet Water MSDS	
Citation	Material Safety Data Sheet Water MSDS. (2013, May 21). Retrieved October 21, 2017, from http://www.sciencelab.com/msds.php?msdsId=9927321
Found by	Google
Source types	MSDS
Keywords	H2O safety sheet
Summary	• Safety sheet for water
Reason for Interest	Includes safety and other information for water
Notes	• Molar mass: 18.02 g/mol • Boiling point:100°C • pH: 7
Questions	
Link	http://www.sciencelab.com/msds.php?msdsId=9927321



#20 – Material Safety Data Sheet Hydrochloric acid MSDS	
Citation	Material Safety Data Sheet Hydrochloric acid MSDS. (2013, May 21). Retrieved November 4, 2017, from http://www.sciencelab.com/msds.php?msdsId=9924285
Found by	Google
Source types	MSDS
Keywords	hydrochloric acid msds
Summary	• Safety sheet for HCl
Reason for Interest	Includes safety and other information on HCl
Notes	• Very dangerous if skin contact occurs • If spilled, dilute with water and mop up • Keep in dry, tight container in cool place
Questions	
Link	http://www.sciencelab.com/msds.php?msdsId=9924285



#21 – Titration of Sodium Carbonate With Hydrochloric Acid	
Citation	Brubaker, J. (2017, April 25). Titration of Sodium Carbonate With Hydrochloric Acid. Retrieved November 04, 2017, from https://sciencing.com/titration-sodium-carbonate-hydrochloric-acid-6511063.html
Found by	Google
Source types	webpage
Keywords	titration with sodium carbonate
Summary	•
Reason for Interest	Provides and overview on performing a titration with sodium carbonate and hydrochloric acid
Notes	•
Questions	
Link	https://sciencing.com/titration-sodium-carbonate-hydrochloric-acid-6511063.html

#22 – The Sun As A Source Of Energy	
Citation	
Found by	Google
Source types	website
Keywords	solar irradiation, solar panel angle, solar power, solar power calculations
Summary	•
Reason for Interest	Possibly calculate intensity of the sun
Notes	•
Questions	
Link	http://www.itacanet.org/the-sun-as-a-source-of-energy/part-1-solar-astronomy/

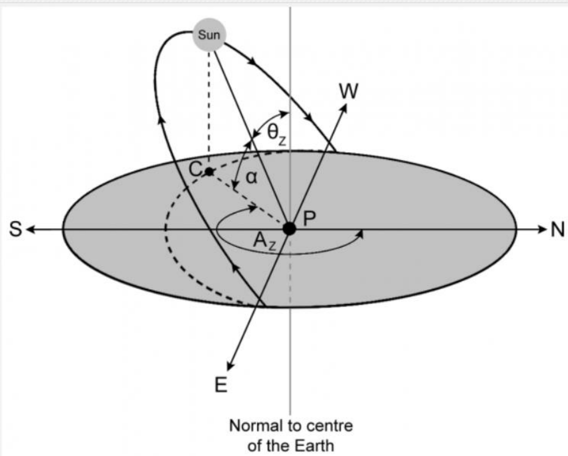


Figure 1.7: The zenith angle (θZ), the altitude angle (α) and the azimuth angle (AZ) of the Sun when viewed from point P.

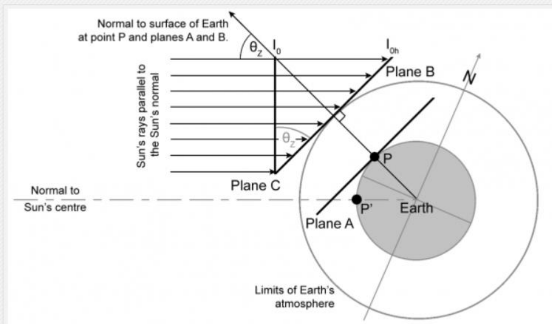
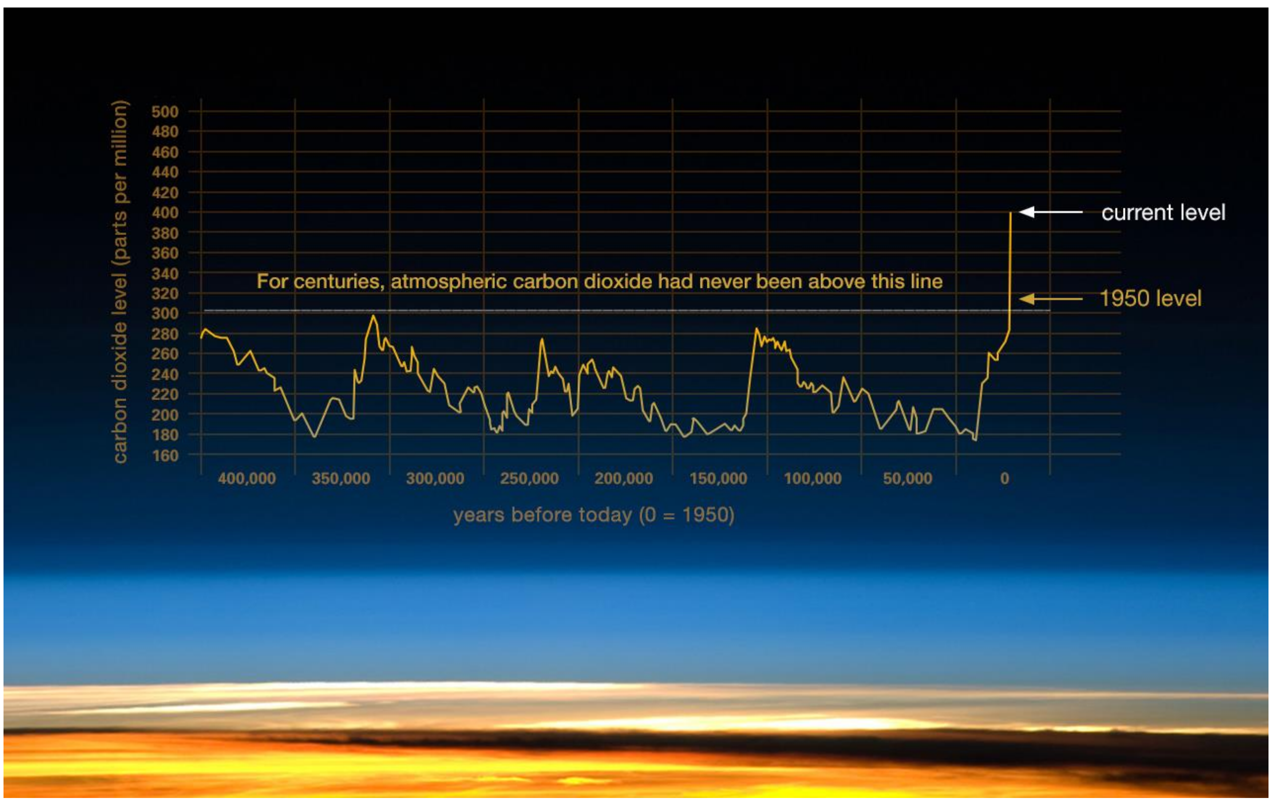


Figure 2.3: The cosine effect.

Figure 2.3 shows three plane surfaces:

- *plane A*, a horizontal plane at the point P on the Earth's surface;
- *plane B*, a surface parallel to plane A but on the edge of the Earth's atmosphere, often referred to as the horizontal plane;
- *plane C*, a surface perpendicular to the Sun's rays, often referred to as the normal plane.

#23 – A blanket around the Earth	
Citation	National Aeronautics and Space Administration. (2017a, August 10). Climate change causes: A blanket around the Earth. Retrieved November 06, 2017, from https://climate.nasa.gov/causes/
Found by	Google
Source types	webpage
Keywords	causes of climate change
Summary	• Heat from sun absorbed by Earth's surface and radiated back up • Greenhouse gases capture the radiated heat and reradiates toward the ground • Carbon dioxide – released through respiration, volcanos, deforestation, land use changes, fossil fuels • CO_2 – 280 ppm to 400 ppm in last 150 yrs
Reason for Interest	Reports why climate change is happening
Notes	•
Questions	
Link	https://climate.nasa.gov/causes/



#24 – Causes of Climate Change	
Citation	Environmental Protection Agency. (2016, December 27). Causes of Climate Change. Retrieved November 06, 2017, from https://19january2017snapshot.epa.gov/climate-change-science/causes-climate-change_.html
Found by	Google
Source types	webpage
Keywords	causes of climate change
Summary	• Climate changes before Industrial Revolution can be explained by natural causes but not recent climate change • Greenhouse effect – carbon dioxide and other chemicals absorb heat energy, preventing their release into space • Currently release over 30 billion tons of carbon dioxide per year
Reason for Interest	Provides overview of the climate change
Notes	•
Questions	
Link	https://19january2017snapshot.epa.gov/climate-change-science/causes-climate-change_.html

#25 - The consequences of climate change	
Citation	National Aeronautics and Space Administration. (2017b, August 03). Global Climate Change: Effects. Retrieved November 06, 2017, from https://climate.nasa.gov/effects/
Found by	Google
Source types	webpage
Keywords	effects of climate change
Summary	• Provides the effects of climate change
Reason for Interest	Gives the effects of climate change
Notes	•
Questions	
Link	https://climate.nasa.gov/effects/