CYSF Science Fair Logbook
2024-2025

Name: Hanish Dokuparti
Grade: 10
Type of Project: Experimental
Project Title: Comparing the efficiencies of different hydroxides in carbon dioxide capture and determining the most efficient based on the mass of carbon dioxide captured, affordability, and reusability of resulting products: sodium, calcium, and lithium hydroxide.

<table>
<tr><th>Date/Time</th><th>Notes</th></tr>
<tr><td>November 17, 2024</td><td>Choosing science fair topic idea:
Project type: Experimental
Project topic: Chemistry, Environmental Science
Project title: Comparing the efficiencies of different hydroxides in carbon capture: sodium, calcium, and lithium hydroxide.
Sources:
https://www.worldatlas.com/articles/5-major-fields-of-environmental-science.html#:~:text=There%20are%20five%20major%20fields,%2C%20geosciences%2C%20and%20social%20sciences</td></tr>
<tr><td>November 24, 2024</td><td>Finalized project declaration and registered on the CYSF platform. Researched different compounds and made sure they were on Amazon.
➔ Hydroxide compounds were mainly chosen due to:
◆ Strong tendency to readily react with carbon dioxide, effectively “capturing,” it.
◆ Main compounds chosen: (due to their availability)
Potassium hydroxide
Calcium hydroxide
Sodium hydroxide
Magnesium hydroxide
Sources:
https://www.chemguide.co.uk/mechanisms/elim/elimvsubst.html#:~:text=Hydroxide%20ions%20have%20a%20very,group%20and%20pulls%20it%20off.</td></tr>
<tr><td>December 27, 2024</td><td>Revisited science fair project. Basic research on fundamentals of the project and the beginning of choice of hydroxides. More in-depth research is planned for tomorrow.

Fundamentals research:</td></tr>
</table>

	● Carbon emissions into our atmosphere are a major issue, especially lately, as car industries, human settlements, deforestation, and industrialization continue to become prevalent. ● Although this gas only makes up around 0.04% of our atmosphere, it exists in huge concentration as a layer at the very top of the atmosphere. In comparison to all the other gases in the atmosphere, the CO_2 present is very low, but individually, is very high. ● Carbon dioxide, being one of the largest concentrated greenhouse gases (GHGs), acts as a barrier for outgoing radiations bouncing back from the Earth's surface. As these concentrations increase, the light gets trapped within the planet, increasing global temperatures. This is environmentally detrimental because: ○ It raises global temperatures. This melts glaciers at the poles, which destroys many habitats of the polar creatures and increases sea levels. This leads to the sinking of many coastal human settlements. ○ Leads to more natural disasters. More trapped heat heats ocean currents, and as the warmer hits the colder currents move towards the equator, which can lead to more hurricanes. The same applies to warmer air currents, leading to stronger wind-based storms. ● Therefore, given many of these problems created by increasing carbon emissions, it is important to search for alternatives to efficient, cheap, and simple large-scale capture. Sources: ● https://www.un.org/en/climatechange/science/causes-effects-climate-change
December 28, 2024	*Today, research into more of the hydroxide compound choice and the chemistry of it. How they react with carbon dioxide in air and byproducts.* Research of hydroxide choice: ● Simply, hydroxides were first chosen to be experimented on for carbon capture because of acid-base chemistry. Let's start with defining acids and bases: ○ Acids: according to the Lewis definition of an acid, it is a substance that takes in pairs of electrons, and when in water, dissociates into H+ ions and the other parts that make it up due to the positive and negative attractions of water to the compound. ○ Bases: on the other hand, it is a substance that lets go of electrons, and when in water, dissociates into hydroxide ions what makes it up is due to the attraction of water molecules. ○ When these acids and bases come into contact, they neutralize one another and form a salt. This contrast between donating

<table>
<tr>
<td></td>
<td>
        electron pairs of the bases and then taking in electron pairs of the acids makes this an important property of carbon dioxide capture.
    ○ Therefore, carbon dioxide is “captured,” and stored in a stable solid form which may be reused at a later time.
● In the context of carbon dioxide, several reactions take place. Firstly beginning with its relation to being an acid regardless of not having hydrogen.
    ○

Sources:
● https://www.scientificamerican.com/article/washing-carbon-out-of-the-air/#:~:text=Both%20solid%20and%20liquid%20sorbents,sodium%20carbonate%20(soda%20ash).
● https://chem.libretexts.org/Bookshelves/Physical_and_Theoretical_Chemistry_Textbook_Maps/Supplemental_Modules_(Physical_and_Theoretical_Chemistry)/Acids_and_Bases/Acid/Lewis_Concept_of_Acids_and_Bases
</td>
</tr>
<tr>
<td>December 30, 2023</td>
<td>
Finish unexpected pause in previous research on hydroxide compound research and possibly get into individual elements apart from hydroxides that may have a better chance of getting hydroxides.

Hydroxide choice continued:
● In the context of carbon dioxide, several reactions take place with the hydroxides. Firstly beginning with its relation to being an acid regardless of not having hydrogen.
    ○ Although carbon dioxide does not have hydrogen ions to dissociate when placed in water, it undergoes a reaction when it first contacts water before it does with the hydroxides!
        ■ Firstly, when carbon dioxide comes into contact with water, the two react and form carbonic acid, a relatively weak acid.
            ● $CO_2(g) + H_2O(l) \longleftrightarrow H_2CO_3(aq)$
        ■ Then, the newly formed acid quickly dissociates as more water molecules are attracted, making bicarbonates and leftover hydrogen.
            ● $H_2CO_3(aq) \longleftrightarrow H + HCO_3$
        ■ The bicarbonate then loses another hydrogen atom due to water molecules, forming carbonates.
            ● $HCO_3 \longleftrightarrow H + CO_3$
        ■ The leftover hydrogens react with the disassociated hydroxides, reforming water.
        ■ The carbonate then reacts with the leftover element from the original hydroxide base compound, forming the final compound, essentially “capturing,” or storing
</td>
</tr>
</table>

	this substance. ■ You may wonder, might they all not just react the same with the final element left over? No, different elements have different electronegativities and empty valence shells, explained later, which affect how much carbonate they react with. That's why it is important to test this. Sources: ● https://chem.libretexts.org/Courses/University_of_Arkansas_Little_Rock/Chem_1402%3A_General_Chemistry_1_(Belford)/Text/11%3A_Intermolecular_Forces_and_Liquids/11.4%3A__NonPolar_Molecules_and_IMF#:~:text=The%20polarizability%20is%20a%20measure,are%20often%20called%20dispersion%20forces ● https://www.merriam-webster.com/dictionary/dipole#:~:text=pole%20%CB%88d%C4%AB%2D%CB%8Cp%C5%8Dl-,1,a%20molecule)%20having%20such%20charges
February 2, 2025	*After consolidation with the science fair coordinator, it was concluded that my project as experimental was not feasible due to microscopic increments in which data could be collected. Today, an alternate, research project idea was met, where instead of 4, 3 hydroxides are researched to compare the efficiencies. After that, the best will be concluded with factors such as the amount of carbon dioxide captured, affordability, and reusability of final products.* Final idea: Comparing the efficiencies of different hydroxides in carbon dioxide capture and determining the most efficient based on the mass of carbon dioxide captured, affordability, and reusability of resulting products: sodium, calcium, and lithium hydroxide. Final project type: Research *Today, I will come up with some questions beforehand so they can guide my research.*
February 8, 2025	*Changed idea to experimental-type project. This way, the workload is less, and the idea is better as an experiment structure.* Plan: ● February 9 - do background research on this topic: ○ What are hydroxides? ○ Why are they better for carbon capture? ○ What kind of products result from this? ○ Why is carbon dioxide capture important? ○ What are some techniques used to do this? ● February 10 - search materials needed to do this project if the project

	were to be done: ◦ What are the materials? ◦ What do each of them do? • February 11/12 - create a procedure if this project were to be done. Make sure to be very detailed. After doing so, also identify the variables if the project was done. • February 14/15 - find the studies with exact data. Make sure to include everything, and try to find more than different sources that are under typical conditions. Save them, and create your graphs based on these numbers. • February 16 - interpret the graphs and analyze the results. • February 17 - conclude. • February 18 - predict some possible limitations to the data collected. • February 19 - what would you do differently next time to the
February 9, 2025	*Today, I will do some background research about the topic to reacquaint myself with the material.* Carbon dioxide capture is more important than ever today. Our carbon footprint increases as our population, human settlement, and car production increase. This increase in carbon dioxide contributes to the enhanced greenhouse gas effect, where the re-emitted radiation that bounces off of the Earth gets trapped. Increased radiation inside the atmosphere then raises global temperatures, which temper the convection currents in the air and water, influencing natural disasters. Furthermore, this melts the glaciers near the poles, which has a few detrimental effects: One, it raises the sea levels from melting glaciers, posing threats to coastal human settlements. Two, it destroys the habitats of the species that rely on ice and glaciers, destroying the species diversity and the food chain, which consequently affects us. An example of such is polar bears role in regulating seal populations. If the polar bears were to go extinct, the seal populations would grow uncontrollably. Seals eat fish, so those would decrease rapidly. The rapid decrease in fish would affect companies that depend on fisheries, and fish stocks, affecting the economy. Everything is interconnected. This is just one branch of the problem. In brief, some major problems may be: Weather, Food Security, Air Quality, and Spread of Disease. There are several techniques in which carbon dioxide is captured. A total of 5 will be listed below, with a brief description of each: 1. Pre-Combustion Capture: hydrocarbons are incompletely combusted in chambers of low oxygen, resulting in the formation of mainly carbon monoxide and water. These are then reacted to form carbon dioxide and hydrogen. The resulting carbon dioxide is captured, while the hydrogen is used as clean-energy fuel. 2. Post-Combustion Capture: After the combustion of hydrocarbons, the flue (waste) gases are collected and carbon dioxide is separated, most

commonly with amines, which in chemistry, are compounds that come from ammonia where the hydrogen atoms are replaced with carbon chains. Heating the amine will release carbon dioxide.

3. Oxy-Fuel Combustion: Instead of combusting in regular air, hydrocarbons are combusted in chambers of pure oxygen, resulting in carbon dioxide and water vapor. The water vapor is condensed, and the high-purity carbon dioxide is captured.
4. Direct-Air Capture (DAC): Involves the use of liquid sorbents to directly capture carbon dioxide from the atmosphere. Such an example can be hydroxides, which absorb carbon dioxide and form carbonate solutions. These can be heated to release carbon dioxide and get the original compound.
5. Bioenergy with carbon capture and storage (BECCS): Involves the hydrocarbon combustion process to get renewable energy, while the produced carbon dioxide is absorbed using post-combustion capture. Simultaneously, while energy is produced, carbon dioxide is captured.

Hydroxides are basic compounds, where a polyatomic ion (group of different ions with a charge) called a hydroxide, which contains hydrogen and oxygen, bonds with a metallic element. Simply, hydroxides were first chosen to be experimented on for carbon capture because of acid-base chemistry. Let's start with defining acids and bases:

- Acids: according to the Lewis definition of an acid, it is a substance that takes in pairs of electrons, and when in water, dissociates into H+ ions and the other parts that make it up due to the positive and negative attractions of water to the compound.
- Bases: on the other hand, it is a substance that lets go of electrons, and when in water, dissociates into hydroxide ions what makes it up is due to the attraction of water molecules.
- When these acids and bases come into contact, they neutralize one another and form a salt. This contrast between donating electron pairs of the bases and then taking in electron pairs of the acids makes this an important property of carbon dioxide capture.
- Therefore, carbon dioxide is “captured,” and stored in a stable solid form which may be reused at a later time.

In the end, after the reactions, we get carbonates. In the context of carbon dioxide, several reactions take place with the hydroxides. Firstly beginning with its relation to being an acid regardless of not having hydrogen.

- Although carbon dioxide does not have hydrogen ions to dissociate when placed in water, it undergoes a reaction when it first contacts water before it does with the hydroxides!
    - Firstly, when carbon dioxide comes into contact with water, the two react and form carbonic acid, a relatively weak acid.
        - $CO_2(g) + H_2O(l) \leftrightarrow H_2CO_3(aq)$
    - Then, the newly formed acid quickly dissociates as more water

<table>
<tr>
<td></td>
<td>

molecules are attracted, making bicarbonates and leftover hydrogen.
$H_2CO_3(aq) \leftrightarrow H + HCO_3$
The bicarbonate then loses another hydrogen atom due to water molecules, forming carbonates.
$HCO_3 \leftrightarrow H + CO_3$
The leftover hydrogens react with the disassociated hydroxides, reforming water.
The carbonate then reacts with the leftover element from the original hydroxide base compound, forming the final compound, essentially “capturing,” or storing this substance.
You may wonder, might they all not just react the same with the final element left over? No, different elements have different electronegativities and empty valence shells, explained later, which affect how much carbonate they react with. That’s why it is important to test this.

</td>
</tr>
<tr>
<td>February 10, 2025</td>
<td>
Today, I will be researching the materials for the project, as if I were to do the project.

For the project, the following list of materials is required for noticeable results:

The three hydroxide compounds; each a mass of 30 g. 15 g extra of sodium hydroxide.
A total of 12 Petri dishes - to test the carbon capture. 3 compounds, 3 dishes each, with one control for each hydroxide.
Distilled water - to disassociate the ions from each ionic compound to react with the carbon dioxide. Distilled to get rid of any impurities.
Phenolphthalein - to measure pH changes to track that CO_2 is reacting.
pH paper - to track pH changes as well.
Burette - to help with the titration, helping determine how much CO_2 was released.
Stirring rods - to agitate solution to disassociate.
Graduated cylinder - to precisely measure the volume of water for dissolving the hydroxide compounds.

CO_2 test properties: Combustive properties

Erlenmeyer flask - to collect the final solutions to heat and test for some CO_2 properties.
Rubber stopper - to transfer carbon dioxide in through.
Bunsen burner - to heat the final solution to release CO_2 for testing.
Delivery tube - to direct the released CO_2.
Test tube - collect the released CO_2.
Flexible tubing - completely covers the transferring process to test

</td>
</tr>
</table>

	tube to avoid loss of CO_2 for testing. ● Splint and matchsticks - test combustive properties of captured gas. 2. CO_2 test properties: Limewater test ● Do the same steps above for method 1 until you get the collected gas. ● Erlenmeyer flask ● CO_2 captured solution ● Separate test tube of calcium hydroxide mixed into water to form limewater. ● Bubble quickly, the CO_2 in a way that the test tube is under the solution. Do not touch the solution. ● If a milky precipitate (calcium carbonate) forms, CO_2 is captured. ● *If you keep bubbling for a while, the solution will disappear as the calcium carbonate reacts with both more carbon dioxide and water, forming soluble calcium bicarbonate! 3. CO_2 test properties: Carbonic Acid test ● Do the same steps from method one to collect the CO_2 gas. ● In a separate flash, collect distilled water. ● Test the pH of the distilled water. ● Bubble collected gas into water and test with pH paper again. If the pH drops, most likely carbon dioxide.
March 10, 2025	Factors that affect the ability of a hydroxide to ‘capture’ carbon dioxide: ● Basicity - the more basic a substance is, the better it reacts with an acid (in this case, carbonic acid when carbon dioxide reacts with water). This is especially true with hydroxide compounds, which when dissociated in water, respond quickly to form water with the hydrogen ions from the acid. The more OH ions there are, the faster it can actively neutralize the carbonic acid, resulting in more being ‘captured’ over time. ● Solubility - the more soluble the hydroxide compound is in water, the better it can ‘capture’ carbon dioxide. As more soluble hydroxides can dissociate easier and quicker in water, the reaction rate will increase, allowing more carbon dioxide to be captured within a time frame. ● Surface area - the more surface area contact of the hydroxide compound will result in more of it being reacted at once, allowing for it to react faster. Hypothesis: If the three hydroxide compounds are dissolved in water and left open to the air to capture carbon dioxide, then I think sodium hydroxide will

<table>
<tr><td></td><td>capture most carbon dioxide because it has one of the weakest bonds between the three compounds, allowing for it to be easily broken by water molecules, ruling calcium hydroxide out. Additionally, sodium is a larger ion than lithium. Smaller ions have stronger electrostatic attractions as the nucleus of protons is closer to the anions, making it harder to dissolve. Therefore, it is reasonable to assume sodium hydroxide will theoretically capture the most carbon dioxide: because of its weaker attractions, it will dissolve faster within water, allowing better carbon dioxide capture.</td></tr>
<tr><td>March 11, 2025</td><td>Variables:

Manipulated - the type of hydroxide compound used to capture the CO2.
Responding - the mass of carbon dioxide captured in g/g of hydroxide.

<table>
<tr><td rowspan="3">Controlled Variables</td><td>Temperature</td><td>If warmer, will dissolve faster, affecting the rate of CO2 capture. Instead of the type of compound, it will be temp.</td><td>Use a thermometer to check water temperature before dissolving compound.</td></tr>
<tr><td>Surface area</td><td>If one compound has more surface area than the other, it will dissolve faster, affecting the rate of CO2 capture.</td><td>Grind each compound will a mortar and pestle, as fine as possible to have the closest surface area as possible.</td></tr>
<tr><td>Water source</td><td>Some sources of water may have some impurities that will affect or may react with some of the compounds, skewing results.</td><td>Use distilled water for all. Boil all of them before use to get rid of impurities.</td></tr>
</table>
</td></tr>
</table>

Methods:

1. The goal of the experiment is to check how much CO_2 a hydroxide compound will capture. Then, considering the cost and resuability of the compounds, the most efficient will be determined with their unit rates.
2. Getting the same mass of each compound, I will grind each with a mortar and pestle to get the closest surface area equilibrium to each.
3. Using distilled water, I will dissolve the compounds within the petri dishes, and weigh the current mass with ten thousandths place. After, leave them out in the air for carbon dioxide to react. Do this thrice for each compound.
4. After 24 hours, weigh the petri dish again. Find the absolute difference to see how much CO_2 is captured.
5. After doing so, I will do another step called titration, to precisely see how much CO_2 was captured to be sure, and three other tests to see if the captured gas was CO_2; the carbonic acid test, the combustive properties test, and the limewater test.
6. After, I will create graphs on average mass, cost, and analyze reusability factors of resulting compounds, and see the best compound overall.
7. Finally, a possible resuability design for the CO_2 may be thought of to further boost efficiency.

Procedure:

- Preparing hydroxide solutions:
    1. Start with gathering all the materials needed for the experiment and the tests. You will need: 120 g of sodium hydroxide, and 72 g of lithium and 222 g calcium hydroxide, 10 petri dishes, a burette, distilled water, stirring rods, pH paper, phenolphthalein, 2-3 Erlenmeyer flasks, a rubber stopper, a delivery tube, a test tube, a bunsen burner, flexible tubing, splint and mathchsticks, and a waste bucket.
    2. Collect 3 moles of each of the hydroxide compounds; just the masses listed above. With a mortar and pestle, grind each as much as possible into the finest powder it can be.
    3. Dissolve 1 mole of each of the hydroxide compounds (40g/mole NaOH, 24g/mol LiOH, 74g/mol $Ca(OH)_2$) into 150 mm x 25 mm petri dishes, filled with 300 mL of distilled water. Use a weighing scale for the compounds, and a graduated cylinder for the volume of the water.
    4. Add 3 drops of phenolphthalein to the solution. It will turn pink. The goal for it is to turn colorless as the carbon dioxide reacts with water and then the compound. Carbonic acid is acidic. Test with pH paper as well to be sure. Record the pH and color of the phenolphthalein.
    5. With a weighing scale, measure the mass of the entire petri dish in g.

6. Repeat the steps 3 and 4 for each hydroxide in 3 petri dishes; 3 trials. Leave for 24 hours.

- Weighing the mass of CO2 captured:
    1. There are 2 methods for measuring the mass of CO2 captured. It is advised both ways are done.
        a. Electronic scale:
            i. Using the most precise electronic scale, weigh the final compound in solution.
            ii. Record, and find the absolute difference from before and after, to get an idea of how much CO2 was absorbed.
        b. Titration:
            1. Label the conical flask for your titration and place it on a white tile or paper for better visibility.
            2. Fill the burette with 0.1 M HCl, ensuring there are no air bubbles in the burette tip. Record the initial volume of HCl in the burette.
            3. Pipette a known volume of your hydroxide solution into the conical flask. You can use 50 mL or another appropriate volume based on your setup.
            4. Add 3-4 drops of phenolphthalein to the hydroxide solution in the conical flask. Phenolphthalein will turn pink in basic conditions (high pH) and will turn colorless when the solution becomes neutral or slightly acidic.
            5. Slowly add HCl from the burette into the conical flask with the hydroxide solution while continuously swirling the flask to mix.
            6. Watch for the color change from pink to colorless, indicating the endpoint where the solution has reached neutralization. This color change means that all the excess hydroxide and any carbonates/bicarbonates have been neutralized.
            7. Record the final volume of HCl used from the burette.
            8. Determine the volume of HCl used by subtracting the initial volume from the final volume.
            9. Calculate the moles of HCl used: Moles of HCl = Volume (L) × Concentration (mol/L)
            10. Calculate the moles of CO_2 captured based on the stoichiometry of the reaction with HCl:
            11. Repeat the titration for each sample of hydroxide solution (sodium hydroxide, calcium

hydroxide, lithium hydroxide) to determine how much CO_2 was absorbed by each.

12. The moles of CO_2 calculated will give you the total amount of CO_2 absorbed by each hydroxide.

- Test to make sure what was captured was carbon dioxide. There are 3 tests to be absolutely sure it is carbon dioxide that was captured.
  - Carbonic Acid and pH test:
    - Pour the hydroxide solution into an erlenmeyer flask. Seal it with a rubber stopper and a delivery tube.
    - In a separate basin, fill it with water, and insert an inverted test tube with a test tube clamp, with the test tube submerged within the water. The delivery tube must led into the inverted test tube.
    - Gently heat the solution in the petri dish with a busen burner in a visible flame mode. Heat until no more gas is being released.
    - Quickly remove the test tube and seal with your thumb.
    - In a separate basin, test the water for its pH. Then, bubble the captured CO2 into the water, and test its pH. If it increased, most likely carbon dioxide.
  - Combustive Properties test:
    - Repeat the steps above to collect the CO2.
    - With a splint, light it up with a matchstick.
    - Unplug the test tube with your thumb and put the splint into the test tube.
    - If the splint's fire is put out, then it is most likely carbon dioxide captured.
  - Limewater test:
    - Repeat the steps above to capture the carbon dioxide.
    - Dissolve some calcium hydroxide into water. The final solution is called limewater.
    - Insert flexible tubing to the test tube with the captured carbon dioxide, and insert the other end into the limewater.
    - If the CO2 is bubbled, then it forms a precipitate with the calcium hydroxide.
    - If precipitate formed, it is CO2!

March 12, 2025

Observations:

	Mass of Carbon Dioxide Captured g/g of hydroxide

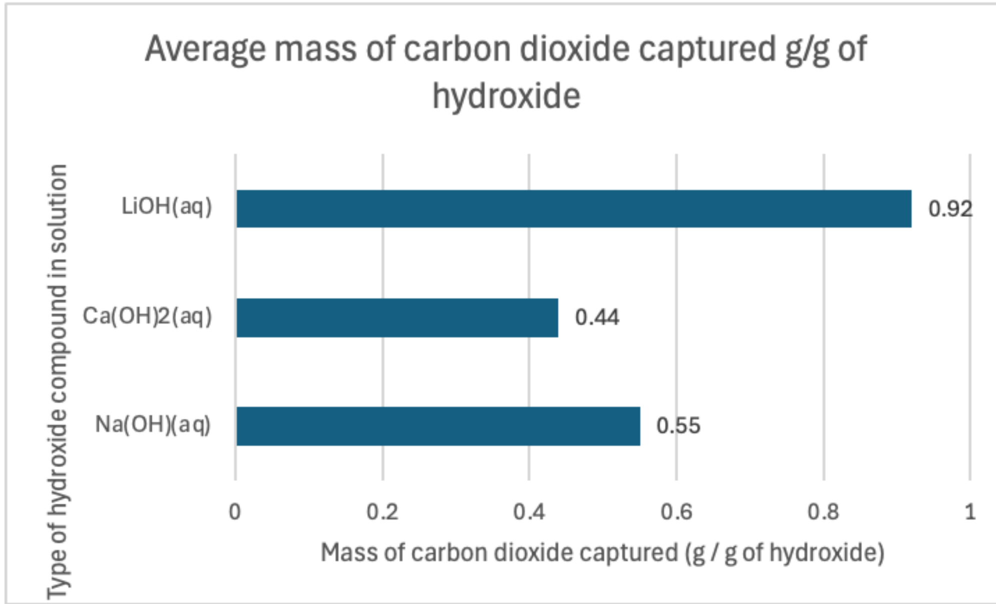
Compound	Trial 1	Trial 2	Trial 3
Na(OH)(aq)	0.52	0.58	0.56
Ca(OH)2(aq)	0.40	0.47	0.42
LiOH(aq)	0.89	0.94	0.91

Compound	**Average mass of carbon dioxide captured g/g of hydroxide**
Na(OH)(aq)	0.55
Ca(OH)2(aq)	0.44
LiOH(aq)	0.92

Compound	**Initial**	**After**
Na(OH)(aq)	• Clear, colorless • Very alkaline	• Slightly cloudy • Slightly sticky/viscous • Lower alkalinity
Ca(OH)2(aq)	• Slightly milky • Few suspended particles • Very alkaline	• Milky white • White precipitate • Less alkaline
LiOH(aq)	• Clear, colorless • Very alkaline	• Slightly cloudy • Less alkaline

Compound	Average Cost per g. $**[CAD]**/g
Na(OH)(aq)	0.167
Ca(OH)2(aq)	5.80
LiOH(aq)	0.014

Analysis:



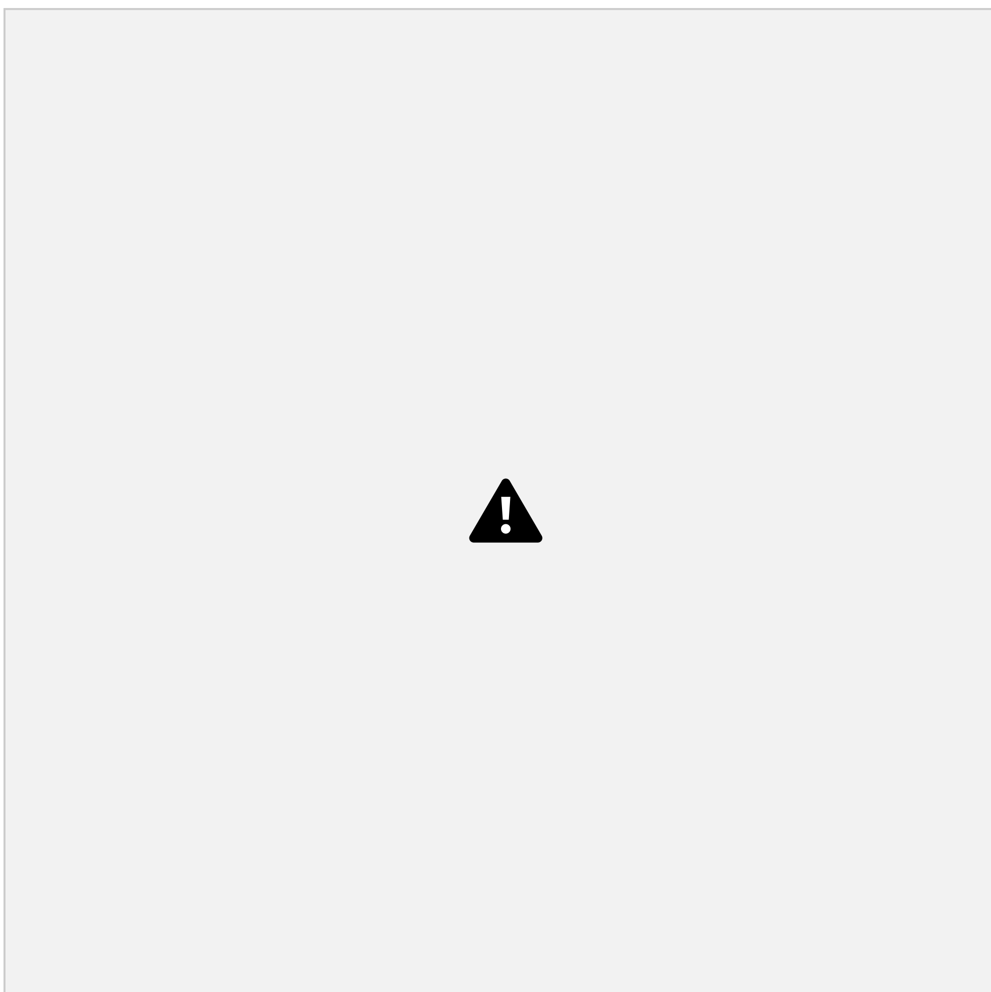
Lithium hydroxide, sodium hydroxide, and calcium hydroxide all capture carbon dioxide (CO_2) through their reactions with the gas, but each does so at different efficiencies. The amount of CO_2 captured per gram of hydroxide varies, and these differences can be attributed to a combination of chemical properties, solubility, and reactivity.

Starting with **sodium hydroxide**, we know it captures **0.55 grams of CO_2 per gram of sodium hydroxide**. This means that, for every gram of sodium hydroxide used, it absorbs 0.55 grams of CO_2 from the surrounding environment. Sodium hydroxide is a relatively strong base that readily reacts with CO_2 in an exothermic reaction, producing sodium carbonate (Na_2CO_3) or sodium bicarbonate ($NaHCO_3$) depending on the conditions. The reactivity of sodium hydroxide, combined with its reasonable solubility in water, makes it a fairly efficient compound for CO_2 absorption. However, its performance in capturing CO_2 is not as high as lithium hydroxide.

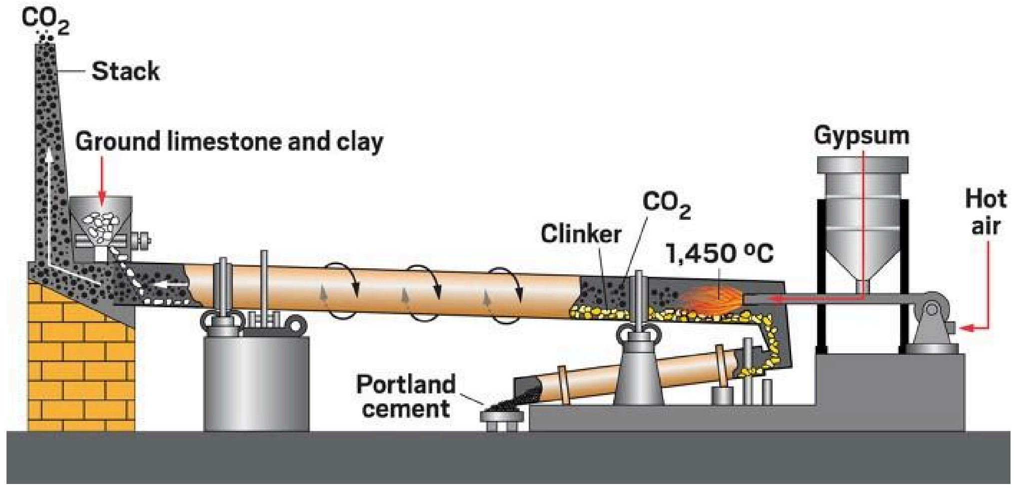
Calcium hydroxide is slightly less efficient than sodium hydroxide in capturing CO_2, with **0.44 grams of CO_2 per gram of calcium hydroxide**. Calcium hydroxide ($Ca(OH)_2$), also known as slaked lime, reacts with CO_2 to form calcium carbonate ($CaCO_3$). Despite being a strong base, calcium hydroxide is less soluble in water than sodium hydroxide, meaning that fewer hydroxide ions are available to react with CO_2. Additionally, calcium carbonate, the product of the reaction, is less soluble in water, which can further limit the reaction efficiency. These factors contribute to its lower CO_2 capture efficiency compared to sodium hydroxide.

The most efficient of the three compounds is **lithium hydroxide**, which

	captures **0.92 grams of CO_2 per gram of lithium hydroxide**. Lithium hydroxide (LiOH) stands out due to its higher solubility in water compared to calcium hydroxide, allowing for a greater number of hydroxide ions to react with CO_2. Additionally, lithium ions are smaller and have a higher charge density than sodium or calcium ions, which leads to stronger interactions with the carbonate ions produced during the reaction with CO_2. These characteristics result in a higher rate of CO_2 absorption and a more efficient capture process. Furthermore, the product of the reaction, lithium carbonate (Li_2CO_3), is stable and less likely to break down, which helps to "lock in" the captured CO_2. In summary, lithium hydroxide's superior performance can be attributed to its greater solubility in water and the high charge density of lithium ions, which enhance the compound's reactivity and the stability of the product formed. Sodium hydroxide, while still effective, captures less CO_2 due to its relatively lower solubility and the characteristics of the sodium carbonate or sodium bicarbonate formed. Calcium hydroxide, although effective in its own right, is the least efficient in this comparison, largely due to its lower solubility and the properties of calcium carbonate. These differences highlight the importance of selecting the appropriate hydroxide for carbon dioxide capture based on the specific requirements of the application, such as the need for efficiency, solubility, or stability of the captured product. Lithium hydroxide is the most efficient, making it the ideal choice for scenarios requiring the highest CO_2 capture rate.
March 12, 2025	Conclusion: In conclusion, the ability of sodium hydroxide, calcium hydroxide, and lithium hydroxide to capture carbon dioxide varies significantly, with lithium hydroxide proving to be the most efficient. The key factors influencing this difference include solubility, reactivity, and the stability of the products formed during the absorption process. Lithium hydroxide, due to its higher solubility in water and the strong interaction of lithium ions with carbonate ions, captures CO_2 more effectively than sodium hydroxide and calcium hydroxide. While sodium hydroxide is effective, its lower solubility and the properties of the resulting sodium carbonate or bicarbonate reduce its overall efficiency. Calcium hydroxide, although still capable of capturing CO_2, is the least efficient of the three, primarily due to its limited solubility and the formation of less soluble calcium carbonate. These findings suggest that for applications requiring the most efficient CO_2 capture, lithium hydroxide should be the preferred choice, while sodium hydroxide and calcium hydroxide may be considered based on other factors like cost, availability, and specific application needs. The differences in

	efficiency also underscore the importance of understanding the chemical and physical properties of the compounds involved when selecting materials for environmental or industrial processes aimed at reducing CO_2 emissions.
March 13, 2025	Applications: ● When the hydroxide solutions "capture" the carbon dioxide, they usually result in carbonates for all, because for bicarbonates to form, there must be excess carbon dioxide, which is not regular for normal circumstances. ● When the solution is heated, it releases carbon dioxide. A closed system can collect this in a tank under high pressure. ● This pressured gas can generate energy within a closed-system power plant. It can also be reused and collected continuously within the closed system. ● A diagram of the closed-system energy capture with carbon dioxide is shown below: 

	Step-by-step explanation of the diagram: ● Controlled Chamber – This is where carbon dioxide (CO_2) gas is stored under high pressure. The gas is contained safely until it is released for energy generation. ● Valve/Nozzle—When the system is ready to generate energy, a valve opens, allowing the pressurized CO_2 gas to escape. The gas is then forced through a nozzle, which increases its velocity and directs it toward the turbine. ● Turbine – The high-speed CO_2 gas hits the turbine blades, making the turbine spin. This is a key part of converting the gas's energy into motion. ● Generator – The spinning turbine is connected to a generator, which converts the mechanical energy from the rotating turbine into electrical energy. This electricity can then be used to power devices or stored for later use. ● Heat Exchanger (Optional) – Sometimes, a heat exchanger is used to regulate the temperature of the CO_2 gas. This can improve efficiency by either cooling down or heating the gas before it reaches the turbine. ● Exhaust or Recapture System – After passing through the turbine, the CO_2 gas either exits the system as waste or is recaptured and stored back in the controlled chamber for reuse. This helps make the system more sustainable by reducing wasted CO_2. **Applications (5b):** ● The "captured" carbon dioxide can be re-utilized for creating stronger concrete, and permanently storing the CO_2 in the building material. ● During cement production, CO_2 can be injected within, where it reacts with it to form stable minerals. This adds more diversity of different-sized minerals, which interlock and create an overall, much more durable structure. ● An example of such is cardboard, when you fill it with basketballs, there is a lot of space between the balls. Now, fill those with baseballs, then ping-pong balls, a few pebbles, or some sort of solution or liquid, and cover all the spaces. With all the space covered, with a diversity in the sizes of objects, the box keeps getting stronger.



Applications (5c):

- Finally, we can reuse carbon dioxide to create carbon-neutral fuels.
- It can be used to create synthetic fuels like methanol by mixing it with hydrogen, produced from the electrolysis of water, using renewable energy.
- This allows for the creation of new synthetic fuels, and this is beneficial because:
  - It is carbon natural! We can stabilize the emissions from planes and jets! Because it is "carbon-neutral," no "new" carbon dioxide is introduced from mining, but is just circled.
  - With continuous capture and other ways of carbon dioxide storage, we can reuse this without introducing more hidden carbon dioxide, allowing effecting usage!
-

<table>
<tr>
<td></td>
<td>
</td>
</tr>
<tr>
<td>March 14, 2025</td>
<td>Sources of error:

Sources of Error for project (4a):

Financial limitations. To conduct the actual experiment, financial limitations impeded the purchase of all of the required materials. As a result of not being able to conduct, but still being passionate about experimental design, I continued with searching the results and concluding.
Research bias. It is important to acknowledge, that when researching, some sources may have biased results, which may produce inaccurate results. Although several sources were used to side-check, it is difficult to eliminate this.
Outdated sources. Some sources, although may seem modern, may not have the most recently discovered results, not producing the most recently discovered results. Although many sources have been checked, it is difficult to maintain every source, making this important to acknowledge for the project.

Sources of Error for experimental design (4b):

Temperature differences: the solution will be left out for 24 hours.

</td>
</tr>
</table>

	This does not account for protected temperature control, as they drop as night falls. This can more or less, impact the reaction rate, not producing the most accurate results. ● Measuring/readings: it is impossible to ever be 100% accurate of a reading done by a machine or read by an analog device. There will always be some degree of uncertainty, including for this project. ● Impruities during project: while leaving the solutions out to react, it will be difficult to control what comes and does not come near. In the air, there may be impurities that may affect the reaction rates of the solutions with the carbon dioxide.

Sources:

- https://www.sciencedirect.com/science/article/abs/pii/S0301479712005737
- https://pubs.acs.org/doi/10.1021/acs.iecr.3c00357
- https://keith.seas.harvard.edu/files/tkg/files/101.mahamoudkhani.low-energysodiumhydrec.e.pdf
- https://pubs.acs.org/doi/10.1021/ef200415p
- https://www.sciencedirect.com/science/article/pii/S2666386423001042
- https://www.nature.com/articles/s41598-022-14235-5
- https://www.nature.com/articles/s41598-023-34360-z
- https://nss.org/settlement/nasa/teacher/course/lioh.html
- https://pubmed.ncbi.nlm.nih.gov/37130879/
- https://chem.libretexts.org/Bookshelves/General_Chemistry/General_Chemistry_Supplement_(Eames)/Chemical_Reactions_and_Interactions/Acid-Base_Reactions
- https://www.britannica.com/science/acid-base-reaction

Citations:

- ScienceDirect. (2012). CO_2 capture by sodium hydroxide: Evaluation of the reactivity and kinetics. *Journal of Environmental Management, 111*, 87-95. https://doi.org/10.1016/j.jenvman.2012.06.019
- American Chemical Society. (2023). Low-temperature CO_2 capture using lithium hydroxide: Insights from molecular dynamics simulations. *Industrial & Engineering Chemistry Research, 62*(3), 548-555. https://doi.org/10.1021/acs.iecr.3c00357

- Harvard University. (2020). Low-energy sodium hydroxide-based carbon capture: A new method for CO_2 sequestration. *Harvard School of Engineering and Applied Sciences*. Retrieved from https://keith.seas.harvard.edu/files/tkg/files/101.mahamoudkhani.low-energysodiumhydrec.e.pdf
- American Chemical Society. (2021). Evaluation of sodium hydroxide as a potential CO_2 scrubber: A study of its efficacy in reducing emissions. *Energy & Fuels, 35*(7), 5728-5735. https://doi.org/10.1021/ef200415p
- ScienceDirect. (2023). A review of novel carbon capture technologies using hydroxides for sustainable energy applications. *Renewable & Sustainable Energy Reviews, 172*, 113541. https://doi.org/10.1016/j.rser.2023.113541
- Nature. (2022). CO_2 capture with calcium and lithium hydroxide: Mechanisms and performance in environmental applications. *Scientific Reports, 12*, 11840. https://doi.org/10.1038/s41598-022-14235-5
- Nature. (2023). Optimizing hydroxide-based materials for efficient CO_2 capture under low energy conditions. *Scientific Reports, 13*, 15463. https://doi.org/10.1038/s41598-023-34360-z
- NASA. (n.d.). Lithium hydroxide: A critical material for CO_2 scrubbing in spacecraft. *National Space Society*. Retrieved from https://nss.org/settlement/nasa/teacher/course/lioh.html
- PubMed. (2023). Evaluation of lithium hydroxide for CO_2 absorption and environmental impact. *PubMed Central*. https://pubmed.ncbi.nlm.nih.gov/37130879/
- LibreTexts. (2023). Acid-Base Reactions. *LibreTexts Chemistry*. Retrieved from https://chem.libretexts.org/Bookshelves/General_Chem