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Carbon Capture
And Storage Using MgO Aerogels

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Introduction

The earth’s climate is dependent upon the radiative balance of the atmosphere, which depends on the input of solar radiation and the atmospheric abundance of radiatively active trace gases (greenhouse gases), clouds and aerosols.\(^1\) Since the onset of the industrial revolution in the 1800’s, the amount of carbon dioxide gas (CO\(_2\)) in the atmosphere has increased dramatically.\(^1\) In 1990, the concentration of carbon dioxide in the atmosphere was calculated to be about 353 ppmv, the highest concentration than any other time in the last 160,000 years and about 25% higher than the concentration of carbon dioxide before the industrial revolution began (280 ppmv).\(^1\) The burning of fossil fuels has resulted in an increase in the CO\(_2\), a by-product of combustion, into the environment. This poses a serious problem in terms of global warming and climate change as carbon dioxide gas is widely regarded as a major contributing factor to global warming.

The greenhouse effect is one of the most well-established theories in atmospheric science: greenhouse gases are gases that allow solar radiation to filter through to the surface of the earth, but trap infrared radiation from escaping.\(^2\) This creates a situation similar to glass on a greenhouse—heat can enter but cannot exit—resulting in the Greenhouse Effect.\(^2,3\) Therefore, increasing the concentration of greenhouse gases increases a planet's surface temperature by increasing the amount of heat that is trapped in the lowest part of the atmosphere.\(^2\) For example, although Mars is much closer to the sun than Venus, the temperature on Venus is about 700K while the temperature on Mars is about 220K.\(^2\) This discrepancy in the temperature can be explained with knowledge about the atmospheric conditions of both planets: the concentration of CO\(_2\) on the Martian atmosphere is much greater than the concentration of CO\(_2\) on Venus.\(^2\)

Climate change has been linked to an increase in atmospheric temperatures. It has been estimated that within the next 50 years, atmospheric temperatures could rise between 0.6 and 2.5°C, and that by the year 2100, atmospheric temperatures could rise between 1.4 and 5.8°C.\(^3\) This change in atmospheric temperature, coupled with the melting of the polar caps would result in an increase of the sea levels. According to the Environmental Protection Agency (EPA), the sea level has increased about 6 inches to 8 inches globally, and rainfall has increased about
The EPA also noted that there has been a 5 to 10% increase in the rainfall over the U.S. with a 10 to 15% increase in the rainfall over the northern tier states and southern Canada over the last century. Climate change is expected to have many effects on our daily life. First and foremost, the melting of ice in the Arctic regions, coupled with thermal expansion from higher temperatures will result in an increase in the sea levels. This in turn will lead to a loss of coastal land and the flooding of coastal cities. As dictated by the Clausius-Clapeyron relation (provided that relative humidity stays the same), warm water is able to hold more water vapor, which condenses as rain. These effects are already evident in Nunavut, Canada, where Inuit hunters are facing survival challenges as a resulting of thinning ice.

Climate change has also been predicted to have an impact on food production worldwide. According to Kasnis and Nettleman, the “main direct effects of global warming will be through changes in temperature, precipitation, length of growing season, and timing of extreme or critical events relative to crop development, as well as through changes in atmospheric CO\textsubscript{2} concentration (which may have a beneficial effect on the growth of many crop types). Middle to high latitudes may experience increased productivity, whereas the tropics and subtropics are likely to face decline in yields.” Climate change is also expected to reduce the amount of land available for agriculture, causing an overall reduction in the production of food. For countries where food insecurity already exists, this would lead to an even lesser availability of food and severe cases of malnutrition.

To counteract all these problems highlighted above, scientists have turned their attention towards reducing the amount of CO\textsubscript{2} being emitted into the environment. With the US population projected to be between 399 and 458 million by 2050, reducing CO\textsubscript{2} through a reduction in the amount of fossil fuels consumed is not a feasible plan. According to the Environmental Protection Agency, about 28% of the CO\textsubscript{2} released into the atmosphere comes from industrial sources (factories, oil refineries cement-producing facilities, etc.) and so most Carbon Capture and Storage (CCS) technologies are focused on the factory level. In light of this, our project seeks to develop ways of capturing CO\textsubscript{2}, produced in energy production, using adsorbents—materials that react can remove CO\textsubscript{2} from the air through by reacting with the
CO₂. Through our research, we hope to help slow down the rise of CO₂ levels worldwide and make an impact in the fight against global warming and climate change.

**Background**

Carbon dioxide capture on solid sorbents is an important technology in the context of greenhouse gas emission reduction in a variety of energy generation and industrial manufacturing processes. Traditional CO₂ adsorbents such as hydrotalcite, alumina and zeolites have been extensively investigated. This project focuses on the study of CO₂ adsorption on sol-gel derived magnesium oxide (MgO) aerogels. To be a commercially viable CO₂ adsorbent in an industrial setting, a material must exhibit the following characteristics:

- Selective reactivity for CO₂
- High CO₂ adsorption capacity
- Adequate adsorption and desorption kinetics
- Good mechanical strength
- Long lasting multi-cycle performance

Common commercially available adsorbents include alumina, MgO, and hydrotalcite, which are reactive in the temperature range of 350–450°C.¹ ² ³ Table 1 shows the operating temperature and the adsorption capacity of a few of the adsorbents.

**Table 1: Operating temperature and adsorption capacity of commercially available adsorbents**

<table>
<thead>
<tr>
<th>Adsorbent</th>
<th>Adsorption Capacity (mmol/g)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrotalcite</td>
<td>0.3 - 0.4</td>
<td>350 - 450</td>
</tr>
<tr>
<td>Alumina</td>
<td>0.2 - 0.4</td>
<td>350 – 450</td>
</tr>
<tr>
<td>Na-doped Alumina</td>
<td>0.5 - 0.7</td>
<td>350 - 450</td>
</tr>
</tbody>
</table>
However, in order to efficiently capture CO\textsubscript{2} emitted as part of the flue gas in industrial settings, the optimum operating temperature needs to be lowered to 250 °C, the average temperature of flue gas. The goal of this project is to develop a material that has high CO\textsubscript{2} adsorption capacity at 250 °C, has high adsorption/desorption kinetics, and can maintain its capacity over multiple cycles.

MgO is a material that is widely studied for its rich surface reactivity. MgO’s surface reactivity is due to the H\textsubscript{2} and D\textsubscript{2} exchange reactions that occur on its surface through acid-base interactions: the protons are adsorbed on unsaturated surface oxide. Thus, the effectiveness of MgO in many applications can be enhanced by increasing the surface area and the coordinative unsaturated anion concentration on the surface. When MgO is used as an adsorbent, the CO\textsubscript{2} is collected onto the surface of the MgO aerogel by bonding with one of the oxygen sites.\textsuperscript{4} (Figure 1) The CO\textsubscript{2} molecule is then said to be physically adsorbed onto the MgO aerogel. Since adsorptions are achieved through weak bonds, the CO\textsubscript{2} molecules can then be desorbed from the MgO material easily.

Since the adsorption reaction occurs on the surface of the MgO material, synthesizing a material with a high surface area or increasing the reactivity of the bonding sites will resulting in an increase of the adsorption potential of the MgO. Synthesizing MgO through the sol-gel method with acetic acid and glycerol has been shown to produce an amorphous aerogel with high surface area.\textsuperscript{5} MgO aerogels are different than most materials used for CO\textsubscript{2} adsorption because of its structure—aerogels have an amorphous structure, which is different from the crystalline structure of most materials used to capture and store CO\textsubscript{2}. (Figure 2) This gives aerogels unique properties including high surface area, low density, and low thermal conductivity.\textsuperscript{6} Increasing the surface area of MgO is a main strategy in developing a new CO\textsubscript{2} adsorbent for industrial applications.
A secondary strategy to develop a new CO$_2$ adsorbent is to dope the MgO aerogels with sodium. Research on similar materials used in the capture and storage of CO$_2$ shows that adsorbents doped with sodium enhance the CO$_2$ adsorption potential of the material. This research focuses on the capture and storage of CO$_2$ released during the pre-combustion phase of energy production; using magnesium oxide aerogels as a CO$_2$ adsorbent. Since the majority of CO$_2$ emissions come from single point factory sources, most carbon capture and
storage technologies are focused at the factory level.\textsuperscript{10} The pre-combustion process of separating CO\textsubscript{2} from the fuel source produces a high concentration of CO\textsubscript{2}, which reduces the monetary cost of the separation process, while also increasing the amount of CO\textsubscript{2} being captured.\textsuperscript{11}

**Experimental Procedure**

*Magnesium Oxide Aerogel Synthesis*

Amorphous MgO aerogels and xerogels were synthesized through the sol-gel method using a modified Pechini process. A schematic of the process is shown below in Figure 3. Magnesium methoxide is mixed with water, ethanol, glycerol and acetic acid. After the solution is allowed to age, it begins to condense to form a gel.\textsuperscript{13} The liquid reaction by-products trapped in the gel is removed in a supercritical dryer to form MgO aerogels or air dried to form MgO xerogel.

![Figure 3: Schematic showing the process of making MgO aerogel](image-url)
From Figure 3, we observe that in the synthesis of MgO aerogels, magnesium methoxide is hydrolyzed by water creating a porous network of magnesium hydroxide. These molecules bond to each other, forming long chains, eventually condensing into the aerogel structure. The amorphous structure of aerogels is highly porous and gives the MgO aerogel its high surface area, essential to its ability to capture CO\textsubscript{2} gas.

In order to further increase the MgO aerogel’s ability to capture CO\textsubscript{2}, we have begun doping the MgO aerogels with sodium. Sodium doping of the MgO aerogel was done by introducing a sodium hydroxide/ethanol solution to the synthesis process. The reaction of sodium hydroxide (NaOH) with ethanol will produce sodium ethoxide and water. The doping of the MgO aerogel should come from the reaction involving sodium ethoxide.

![Figure 4: Proposed doping reaction](image)

Experimentation with different concentrations of the doping solution is used to determine the concentration that produces sodium doped MgO aerogel with the best CO\textsubscript{2} adsorbing capacity.

- **Materials needed**
  1) Beakers: 1-250ml, 3-100ml screw top jar
  2) 4 medium pieces of parafilm
  3) Glycerin, Acetic Acid, Di water, ethanol, Magnesium Methoxide, dopands
  4) Volumetric pipettes: 1-5ml, and 20-200μl, regular pipettes

- **MgO Catalyst preparation**
1) Prevent contamination by thoroughly cleaning a 250mL beaker and a 200ml graduated cylinder and then rinse with de-ionized water. Then dry with Kim wipe and set aside.

2) In a 250ml add:
   a. 0.08g of glycerin (do this using the balance, adding about 1.5 drops)
   b. 105μl of acetic acid using 20-200μl pipette
   c. 670μl of water using 20-200μl
   d. 125.65ml of ethanol using a 200ml graduated cylinder.

3) Place a magnetic stirrer in the above solution and set the entire beaker on top of an automatic stirrer to thoroughly mix the solution, approximately 2-3 minutes.

4) Measure 30g of catalyst solution into a separate screw top jar. The above amount should be able to be separated into three 30g portions.

**Introduction of Magnesium**

1. Quickly measuring 12ml of Magnesium Methoxide into a 25mL beaker using 1-5ml pipette (2x 5ml, 1x 2ml). This step must be done very quickly to prevent the Magnesium Methoxide from oxidizing. It is very important to Parafilm this bottle tightly after each use.

2. Quickly pour the Magnesium Methoxide into the 50mL beaker containing Catalyst Solution and gently rotate the screw top for 2-3 rotations and allow the reaction to occur. This mixing step should not be done with excess force or the gel can break apart. Allow the gel to sit undisturbed for 5 minutes. If reaction occurred properly, a gel with a slight light blue tint should have formed.

3. Place the sample under the hood and allow it to age for at least 24 hours. The aging time ensures complete formation of networks within the gel and thus improving the properties of the ceramic.

**Sodium Doping of MgO (Pre-Acetone Wash)**
1. Measure 40ml of Ethanol and transfer to a 100ml beaker
2. Measure appropriate amount of NaOH for desired doping concentration, and transfer to the beakers containing ethanol. Do this step quickly as NaOH reacts with H₂O in the air.
3. Use stir bars to completely dissolve the NaOH in the Ethanol if needed.
4. Once dissolved, transfer the dopant solution to the aged gels using a transfer pipette.
5. Let the gel age in the doping solution for 24 hours and repeat the doping process 2 more times for a total of 3 sodium doping exposures.

- **Xerogel Formation**
  After aging for a minimum of 24 hours, uncover the sample and allow it to air dry.

- **Aerogel – Acetone Washes**
  1. After 24 hours of aging, or doping, fill the sample in a glass container approximately 80% filled with acetone. The rinsing process allows the acetone solvent to replace the water and ethanol in the sample originated from the catalyst solution.
  2. Pipet out the old acetone and replace with new acetone every 24 hours. This rinsing step should be repeated for 4 times per sample.

- **Aerogel - The Drying Process**
  1. After going through the rinsing process, the sample is ready to be dried. Turn on the Thermo NESLAB RTE Series Refrigerated Bath/Circulators and set the temperature to 4.0˚C. The Thermo NESLAB circulates cold water though the Thermo VG Microtech E3100 Series Critical Point Drying Apparatus until the dryer itself is approximately 4˚C.
  2. Thoroughly clean the inside of the dryer and be sure to remove any particles that may have been left over from the previous use.
  3. As soon as the supercritical dryer reaches 4˚C, fill the inner boat with acetone, remove the sample from the glass container and place it into the boat.
4. Make sure the sample is mostly immersed in the acetone. If not fill the boat with acetone until it is about to overflow.

5. Carefully set the boat inside the supercritical dryer and close the chamber tightly. Refill the boat with acetone if some is lost during the transfer.

6. Turn on the Carbon Dioxide Tank.

7. Very gradually turn on the nozzle on the top of the supercritical dryer connecting to the carbon dioxide tank to fill the inner chamber with carbon dioxide. This step is to be done very slowly and carefully for a sudden opening of the nozzle allows the carbon dioxide in the tank to shoot into the chamber and shatter the sample into pieces.

8. Continue to fill chamber with carbon dioxide until the pressure gage reads approximately 800 psi. At this point, the chamber should be completely filled with liquid carbon dioxide.

9. Allow 40 minutes for the pressure to reach equilibrium, then turn off the nozzle on top of the supercritical dryer and begin to purge out the liquid inside the chamber by opening the nozzle on the bottom right side of the supercritical dryer.

10. Purge slowly until the liquid level drop to approximately 1mm above the boat. Make sure the liquid level does not drop below the 2 notches of the boat.

11. Close the purge nozzle and slowly refill the chamber again with carbon dioxide.

12. Purge every 40 minutes for a total of 6 initial purges.

13. On the 7th and final purge, purge slowly until the liquid level drop to approximately 1mm above the boat, set the temperature on the Thermo NESLAB RTE Series Refrigerated Bath/Circulators to 40.0°C and hot water will begin to circulate until the supercritical dryer reaches the temperature of 35°C, which takes about 35 to 40 minutes.

14. Turn off the carbon dioxide tank. The liquid carbon dioxide in the chamber will begin to evaporate as the temperature in the dryer rises. Remain at the dryer to observe the pressure. If the pressure climbs over 1000psi, vent out some of the gases.
Overpressure of the dryer will cause the safety pressure release to give way causing a loud pop. Good luck fixing it.

15. Turn off the Thermo NESLAB and release the pressure in the chamber by opening the purge nozzle.

16. After the pressure reads 0 psi, open the chamber and remove sample into a labeled vial glass container.

**Thermogravimetric Analysis (TGA)**

The thermogravimetric analyzer (TGA) machine, manufactured by TA Instruments, is a device used to determine the adsorption and desorption potential of adsorbents in a controlled environment. In a TGA, adsorbents are exposed to a set flow rate of Nitrogen gas and CO\(_2\) gas, providing information on exactly how much CO\(_2\) is adsorbed and at what rate and temperature.

1. Open the Nitrogen and CO\(_2\) valves.
2. Use a pair of tongs to carefully place a platinum pan onto the loading dock.
3. Once completed, press the “Furnace” button to bring the furnace down.
4. Once the furnace has been fully lowered, press “Tare” to weigh the pan. After this is complete, the furnace should lower to the bottom again and the pan will be unloaded onto the loading dock.
5. Using a spatula, transfer the sample to be tested onto the pan.
6. From the main console (on the computer), select the “Sample” menu and then click on “Load Sample.” This should cause the pan to be loaded back onto the TGA machine and the furnace to return to the closed/raised position.
7. From the console window, choose the experimental procedure to be run in the TGA test, making changes as needed. Make any necessary notes and be sure to save the procedure file.
8. From the console window (on the computer), click on the green triangle to begin the run.

*Figure 5*: Picture of a Thermogravimetric analyzer.
**BET Machine for Determination of Surface Area**

The BET machine, named “BET” after the first initials of the last names of the creators of the machine, is used to analyze the surface area of fine porous substances. The BET machine provides data on the amount of porosity and the surface area of substances. This information is used to create correlations between the physical properties of an adsorbent and its ability to capture CO$_2$. Before beginning, obtain liquid Nitrogen in the tank and place the tank in the BET machine.

1. Load the samples to be tested into round-bottomed flasks and transfer to the BET machine.
2. Open the Tri-Star program from the desktop.
3. From the menu bar, click “File” and then “Open”
4. Name the sample(s) appropriately.
5. From the menu bar, click on “File” and then click “Open.” Choose the filename(s) of the sample(s)
6. A window should appear on the computer screen. Fill out the window appropriately:
a. Choose the “Sample Information” tab and proceed to name the sample as well as the name of the person performing the test and fill out the information on the mass of the sample.

b. Make sure that the information under the “Degas” tab reads “30-10-10”

c. Under “Report Options” change the report type from “5-point” to “Pore Size”

7. Repeat steps 5 and 6 for the remaining round bottomed flasks.

8. From the menu bar, select “Unit 1” and then select “Standard Analysis”

9. From the “View” drop down menu, select “Operations”

10. Under each “port” choose each of the sample names and make sure that the information in each section is correct.

11. To begin the test, select “Start” at the bottom on the screen.

**Extended Heat Treatment**

Since one of the main problems in previous TGA data collection was achieving a solid base line in which total desorption of CO₂ had been achieved, we decided to heat treat a sample of MgO aerogel in the Flow Prep at 300°C for an extended period of time. We did this in hopes of getting most of the degassing done and most and organics burned off, in the Flow Prep before transferring the material into the TGA for testing. After at least 5 days of heat treatment in the flow prep, the MgO aerogel sample was carefully transferred into the TGA for testing. Experiments conducted on the extended samples heat treated samples, detailed below, show that this extended heat treatment period was effective. The time frame of 9 days was chosen to ensure a near total degassing/organic burn off has occurred. Future experiments can be done to determine the minimum time needed for an effective extended heat treatment stage.
**Results and Discussion**

*Cyclic Run (TGA)*

As stated above, in order for a material to be a good adsorbent, it needs to be able to perform well over multiple cycles in the long term. In order to determine whether our material fulfilled this requirement, we put our material to test—the MgO aerogel was put through four cycles of adsorption and desorption in the TGA to test its performance after multiple cycles. The raw data obtained from the test is converted to reflect how the moles of CO$_2$ adsorbed per gram of adsorbent for each cycle. This is shown below Figure 6. From Figure 6, the adsorption phase of each cycle is overlaid in a single graph to allow for better comparison of the performance of MgO aerogel (shown in Figure 7). From Figures 6 and 7, we observe that over the four cycles, the performance of the MgO in terms of its adsorption does not diminish. Although there is less adsorption of CO$_2$ in the first cycle, we attribute this anomaly to the presence of CO$_2$ and also organics on the surface of the adsorbent. In general, looks like it has the potential to be used over multiple cycles without being replaced.
Figure 6: mmol of CO$_2$ adsorbed/grams of adsorbent

Figure 7: Graph showing the adsorption over multiple cycles overlaid

6: mmol of CO$_2$ adsorbed/grams of adsorbent
**Sodium Doping**

Different concentrations of doping solution that were tested to determine the optimum doping concentration for post-gelation doping. The NaOH-ethanol solution was observed to be a cloudy in physical appearance. When the doping solution is poured onto of the MgO aerogel, a clear distinction between the two layers was observed (Figure 8). A few minutes after the doping solution comes into contact with the gel, the cloudiness begins to permeate the gel, giving physical proof that the doping solution is diffusing into the gel. A clear color change is observed in the final gel (seen in Figure 9 and 10). It was discovered that the color of the turn darker with increasing concentrations of NaOH in the doping solution. We hypothesize that this is due to excess sodium ethoxide oxidizing easily with oxygen. This seemed to produce a side reaction, which eventually results in the disassociation of the gels.
The acetone washes, performed after the doping process, also seem to enhance the breakdown of the gels doped in high concentration of solution. Figures 10 and 11 are images of MgO aerogel doped with Na with concentrations of 0.1M, 0.2M and .3M (from right to left) before and after drying respectively. After drying the doped samples, we performed adsorption isotherms on all three samples test our premise that doping the MgO aerogel with sodium increase the adsorption of the aerogel.

Figure 8: Doping of gels  
Figure 9: Doped gels showing color change

Figure 10: Doped gels showing discoloration  
Figure 11: .1M, .2M, .3M doped gels

In order to test the effects of sodium doping on the adsorption of MgO aerogel, adsorption isotherms were developed with TGA collected data from different concentrations. From Figure 12, we observe that low concentration sodium doped MgO aerogels adsorbs more
CO$_2$ than the undoped MgO aerogel. It is also important to note that although 0.1M concentration of sodium doping has a higher initial adsorption capacity, the optimum sodium doping for highest CO$_2$ adsorption seems to fall in between 0.2M and 0.3M.

**Figure 12: Adsorption Isotherm Comparison of Sodium Doping**

*Kinetics*

The integrated form of the pseudo-first order rate equation was used to determine the rate constant of our samples.
Pseudo-First Order Rate Equation

\[ \frac{dq}{dt} = k_1 (q_e - q) \]  \hspace{1cm} \text{Equation 1} \]

\(q_e\) = mass of CO\(_2\) adsorbed at equilibrium
\(q\) = mass of CO\(_2\) adsorbed at any time
\(k_1\) = first order rate constant

Integrating the pseudo-first order rate equation with (time) \(t=0\) to \(t=t\) and \(q=0\) to \(q=q\), we get;

\[ \ln \left( \frac{q_e - q}{q_e} \right) = -k_1 t \]  \hspace{1cm} \text{Equation 2} \]

Therefore if we plot \(\ln \left( \frac{q_e - q}{q_e} \right)\) vs. \(t\) we get slope = \(-k_1\) or -slope = \(k_1\)

A TGA run with 100% CO\(_2\) adsorption was done with an initial heat treatment period of 480 minutes at 250° (Figure 13). Analysis of the adsorption phase was done in order to determine if the data produced would fit the integrated first order rate equation.

Figure 14 shows the plot of \(\ln \left( \frac{q_e - q}{q_e} \right)\) vs. \(t\) of the data from Figure 13 with \(t=0\) set at the moment of CO\(_2\) adsorption. Two assumptions are made in that \(q\) and \(q_e\) are not taken at total equilibrium points. The mass of the MgO is still decreasing during \(q\), and CO\(_2\) adsorption is still occurring at the defined \(q_e\). With this in mind, we see that parts of the graph (from around \(t=0\) to the \(t=350\) point) in Figure 14 follow the predicted negative slope from the integrated first order rate model. Further data gathering and analysis still needs be conducted to determine if this equation can be used to model the adsorption of CO\(_2\) onto MgO aerogel.
Figure 13: Adsorption at 100% CO₂

Figure 14: Plot relating the change in mass to time.

Conclusion
The increase of CO₂ in our environment has been shown to be related to climate change and needs to be slowed down. Data collected in this research project shows that MgO aerogel is a material that is capable of adsorbing CO₂ and can be implemented in the industry as an adsorbent. Furthermore, doping the MgO aerogel with sodium has been shown to increase the adsorption capacity of MgO aerogel. Since all of these experiments have been performed in the lab on the small scale, tests need to be performed on the large scale to provide more information as to whether MgO aerogel is a viable candidate to replace adsorbents currently being used in the industry today. Also, more experiments need to be performed to investigate how doping the MgO aerogel with sodium changes the structure of the aerogel in order to develop new ways of making the aerogel even more effective.

References


10 Lee, K. B., Beaver, M. G., Caram, H. S., Sircar, S. Performance of Na2O promoted alumina as CO\textsubscript{2} chemisorbent in sorption enhanced reaction process for simultaneous production of fuel-cell grade H2 and compressed CO\textsubscript{2} from synthesis gas. *Journal of Power Sources* 176, 312–319 (2008)


