

Public Perception of Carbon Capture and Sequestration

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ABSTRACT

While most Americans have heard of the idea of “clean coal,” very few are well-acquainted with the actual processes behind the concept. When polled about Carbon Capture Sequestration (CCS), the main “clean coal” technology, approval ratings are drastically lower than approval ratings for CCS. The causes of this difference in approval have not been thoroughly investigated previously. In order to determine why Americans tend to disapprove of CCS the more they know about it, I conducted an invention-based survey online via Amazon Mechanical Turk (n=156). Respondents answered a pre-test survey with likert-scale items registering their approval and a short answer section to measure their level of knowledge of CCS. Following the pre-test, the respondents read a 300-word explanation of the goals and methods involved in CCS. The respondents then answered the same survey questions in the pre-test again. This intervention revealed distinct increases in both self-rated knowledge of the technology and actual knowledge of CCS ($p < .01$) and decreases in overall acceptance ($p < .05$). Multi-way variance analysis showed that gender and political belief accounted for the majority of differences between respondents. Women tended to alter their acceptance of CCS based upon perceived affordability, conservatives tended to base their opinions mostly upon affordability, and men tended to focus on safety.

KEYWORDS

climate change, public opinion, energy, intervention, de-biasing

INTRODUCTION

Environmental policy analysis usually involves identification of a problem, using theoretical analyses to find solutions to the problem, and then implementing the corresponding policies. In terms of climate change, these solutions include a wide array of alternative energy sources and processes. While each new source technology has its flaws, the fates of these new technologies are often tied not to their scientific or economic viability, but to how they are perceived by the public (Addams 2000). Often the perceived risk does not align with actual quantitative measures of risk by the scientists, engineers, and policymakers who create and promote these new technologies (Renn 1998). Instead, people tend to consider risk in a cost-benefit analysis, where both the costs and benefits are in part determined by individual and societal values (Slovic 2001). When evaluating new information and technologies, people tend to rely upon preconceived beliefs about similar topics and the source of the new information (Lewandowsky 2005). Subconsciously, people evaluate new information based on its compatibility with their beliefs (Schwarz et al. 2007).

This trend holds true for Carbon Capture and Sequestration (CCS) in not only America, but many European nations (Miller et al. 2007). Carbon Capture and Sequestration is a process by which 90% of the carbon dioxide emitted at large coal or natural gas power plants can be contained, transported, and stored for hundreds of years (Oldenburg 2009). The benefit of being able to continue to use fossil fuel sources without emitting carbon dioxide has been perceived to be outweighed by economic expense and safety concerns in many nations. In the early 2000s, in Sweden and Norway, two countries cited by scientists as ideal for ocean storage of captured carbon dioxide, large-scale protests by concerned citizens about safety severely delayed and in some cases, completely halted demonstration plants. More recently, in 2009, projects in

Germany, the leading country in CCS implementation, were denied permits due to safety concerns by the municipal government in a province with the best geologic storage capability, despite previous permission from the national government. As a result, the three German power plants that had already been retrofitted to capture carbon dioxide now have no possible storage locations and are left to simply release all of the CO₂ they capture back into the atmosphere. While there are no demonstration plants in the US yet, many projects have been proposed (Middleton & Bielicki 2009).

American politicians have been using the term “clean coal” for the past few election cycles, yet most Americans are not familiar with the mechanism behind “clean coal.” Currently, there is a huge discrepancy between US polls showing support of “clean coal” (>75%) and surveys which directly ask about approval of CCS (<20%). This data seems to show that Americans like the idea of a technology that can allow the US to continue using fossil fuels while limiting harms but are afraid of how this would actually occur. If Americans knew and understood how CCS works, we would be able to get a more accurate picture of why Americans like clean coal but not CCS. Splitting overall approval into separate categories could help distinguish which types of people have which types of reservations (i.e. conservatives may like the idea, but don’t think it’s economically viable). If projects are going to even be allowed into the demonstration stage in America, we need to know how different communities in the US will react to CCS and the reasons behind their reactions.

My study analyzed whether increasing a person’s knowledge of the goals and processes involved in CCS would decrease that person’s approval. In order to determine what Americans were concerned about when they reported their disapproval, I broke the idea of overall approval into three categories: human safety, sustainability, and economic viability. This enabled me to

determine why certain people disliked CCS and how this related to their individual beliefs and background.

METHODS

Data collection

To gather data about changes in understanding and opinion regarding CCS, I surveyed respondents using an intervention format. Two-thirds of respondents received a survey format I referred to as “sandwich format,” where respondents answered a series of questions in a pre-test, read an explanation of the goals and mechanism by which CCS functions, and then answered the same series of questions in a post-test (Figure 1). The pre- and post-tests consisted of two open-ended questions testing level of knowledge and fourteen likert-scale items each (Figure 2). The explanation intervention was 350 words in length. I designed the survey to be completed in 10-15 minutes. I chose to conduct this study using interventions due to the success the Ranney Lab has had using interventions to increase knowledge and understanding of other environmental behavior related topics, such as anthropogenic climate change. Their research consistently shows that the formula of pre-test, mechanism, and post-test has been successful in raising respondents understanding of climate change and increasing their overall acceptance (Ranney et al. 2011). In order to test whether the intervention method was successful in respect to learning about CCS, I also distributed a control survey with only the CCS explanation and a post-test. I called this type of survey the “open-face” format (Figure 1).

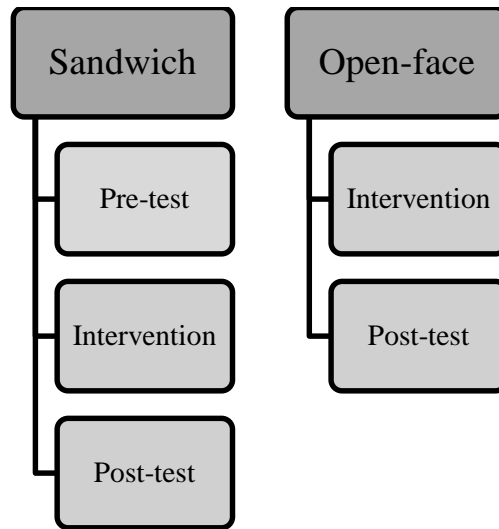


Figure 1. Difference in survey format. I gave the sandwich group a pre-test, intervention, and post-test, while the open-face group only received the intervention and post-test.

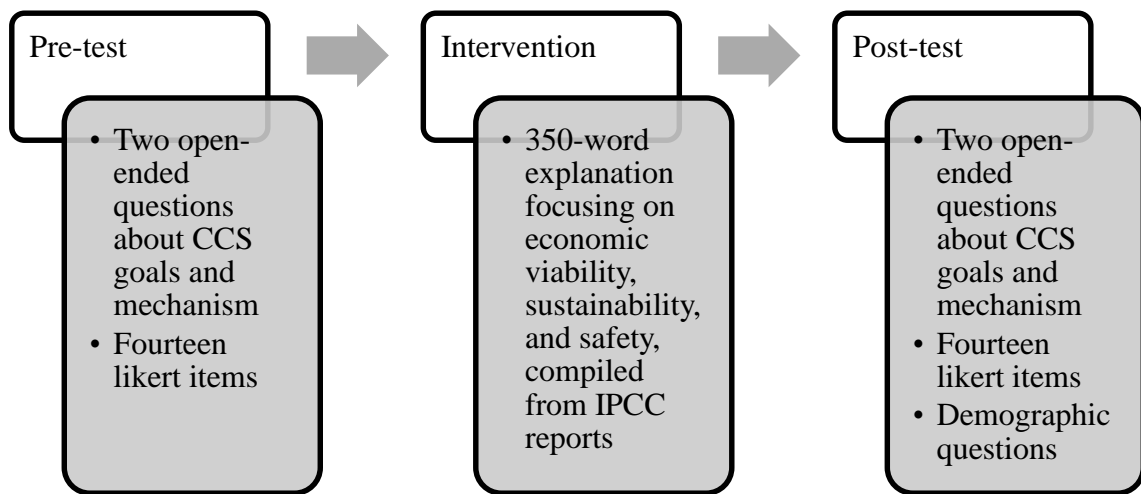


Figure 2. Sandwich intervention format. The pre-test and post-test consisted of open-ended questions and likert-scale items, with an additional demographic question component in the post-test. The intervention was a 350-word explanation of CCS.

In the pre-test survey, I asked the respondents to write 2-4 sentences explaining the goals and purposes of CCS and 1-3 sentences explaining how the technology works, followed by the likert-scale items in random order (Appendix A). The likert-scale items consisted of four categories of questions: perceived economic viability, safety, and sustainability of CCS, as well

as four items measuring concern about the environment. These questions all had likert-scales with ranks from one to five.

To determine whether exposure to the explanation of CCS would alter the respondents' pre-test answers, I gave the respondents a 350-word informational component explaining the goals of CCS and how it works (Appendix B). This explanation was compiled from several IPCC reports for policymakers considering CCS. I chose this method of creating the description instead of personally writing it, because I did not want my description of the possible harms to be a reflection of my own opinions. I shortened the IPCC description to a 350-word intervention and edited it for readability in order to keep the survey time short and avoid overloading the respondent with new information.

To assess whether there were changes in the respondents understanding and attitude, the respondents took the post-test survey, which asked them to once again explain the goals of CCS and give their opinion of the technology. The only difference between the pre- and post-test was question order within the likert-scale items, which were randomized, and the addition of a brief section asking for basic demographic information at the end of the survey (Appendix C). In terms of demographics, the respondents were asked to give their: age, gender, religion, location (US state), political ideology and political party. I chose these specific traits based upon relationships that have previously been shown in studies regarding opinions of alternative energy sources, as well as studies specific to CCS (Miller et al. 2007). Unlike some intervention studies, I chose to give the respondents the post-test immediately after they read the mechanism explanation. I did this, first of all, out of convenience, since I did not have access to these respondents for very long. I also thought that giving respondents the immediate opportunity to reassess the decisions they made in the pre-test would yield more significant results. Current

research in de-biasing via interventions shows that effects of interventions are most drastic immediately after a person receives the new information. Over time, the changes between pre-test and post-test likert-scale results tend to decrease (Lewandowsky et al. 2010).

I made the survey available online in an effort to receive more diverse respondents than I would receive if I had only surveyed in the San Francisco Bay Area. I also felt that I would be more likely to reach my goal of 100 respondents if the survey were online instead of in person. I hosted the survey via Qualtrics, since other studies associated with the UC Berkeley Graduate School of Psychology have used Qualtrics successfully online surveys. I distributed the online survey using Amazon Mechanical Turk (MTurk) and paid MTurk workers \$1.00 for completing the sandwich survey and \$.50 for the open-face survey. After several sessions of MTurk data collection, I closed my survey with 100 sandwich responses and 49 open-face responses ($n=149$). All of my respondents were American, and both genders were represented equally.

Data analysis

To compare all post-test data, I combined the post-test data for both the sandwich and open-face groups and conducted multi-way factor analysis for each of the likert-scale items. If I encountered a specific likert item that showed an interaction with a demographic factor, I compared variance, distribution, and means across that factor (e.g. comparing differences by gender on an economic item). I used t-tests to determine whether the differences in means across demographic groups were significant.

To compare the pre- and post-test survey datasets, I analyzed the likert-scale questions using paired t-tests. The paired t-tests served to distinguish whether there was a statistically significant difference in likert-scale item means before and after the mechanism intervention. In

addition, I also conducted paired t-tests within certain demographic populations to see whether there were alternate trends for these specific groups. Prior research on the public perception of CCS shows that women tend to be more skeptical of the technology (Miller et al. 2007), so I chose to compare pre- and post-tests for women and men to determine whether this trend held true for the my sample population. I also isolated data by political ideology for all items. In terms of approval of CCS, I thought that there would be differences in which aspects conservatives and liberals focused on. Conservatives tend to disapprove of CCS due to economic concerns (Curry et. al 2007), while liberals tend to disapprove of CCS because they do not think it is sustainable or preferable to alternative energy sources (de Best-Waldholber 2009). I was also interested in how conservatives responded to the environmental concern items, specifically the items asking about belief in and worry about global warming. Climate change studies conducted before my research revealed an increase in acceptance of and concern about climate change among conservative respondents if those respondents were given an intervention explaining a climate change mitigation technique, like CCS (Kahan et al. 2011, Upham et al. 2011).

RESULTS

Combined post-test analysis

I found that demographic differences in religion and political ideology were strong predictors of opinion in the areas of economic viability and environmental concern (Appendix D). The multi-way factor analysis performed on all post-test data showed that the interaction between political ideology and opinion of the economic viability of CCS was significant ($p=.02$). Conservatives tended to agree more strongly with the statement that CCS “is affordable,” while liberals tended to disagree (Figure 3).

Additionally, multi-way factor analysis showed a strong interaction between religion and perception of sustainability ($p < .05$). Individual analysis of the three most popular religions reported (agnosticism, atheism, Christianity) revealed that agnostics and Christians were more likely to think that CCS would be “good for the planet overall” ($\mu_{agnostic}=3.9$, $\mu_{Christian}=3.7$). Atheists were more likely to disagree that CCS would be environmentally beneficial ($\mu_{atheist}=3.3$). Christians and agnostic had relatively similar distributions, with roughly 70% of respondents agreeing on some level (Figure 4).

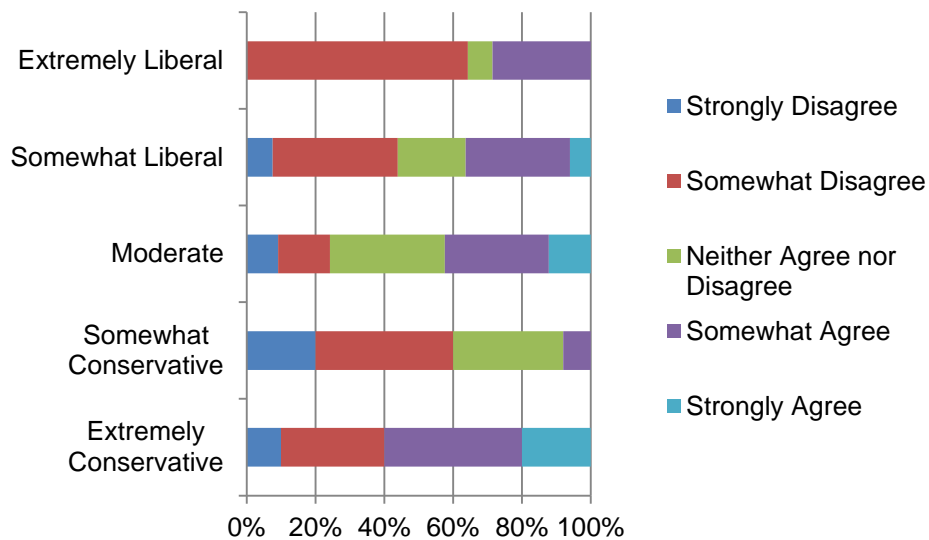


Figure 3. “Carbon Capture and Sequestration is affordable” responses. I sorted all post-test responses by self-identified political ideology ($n=149$).

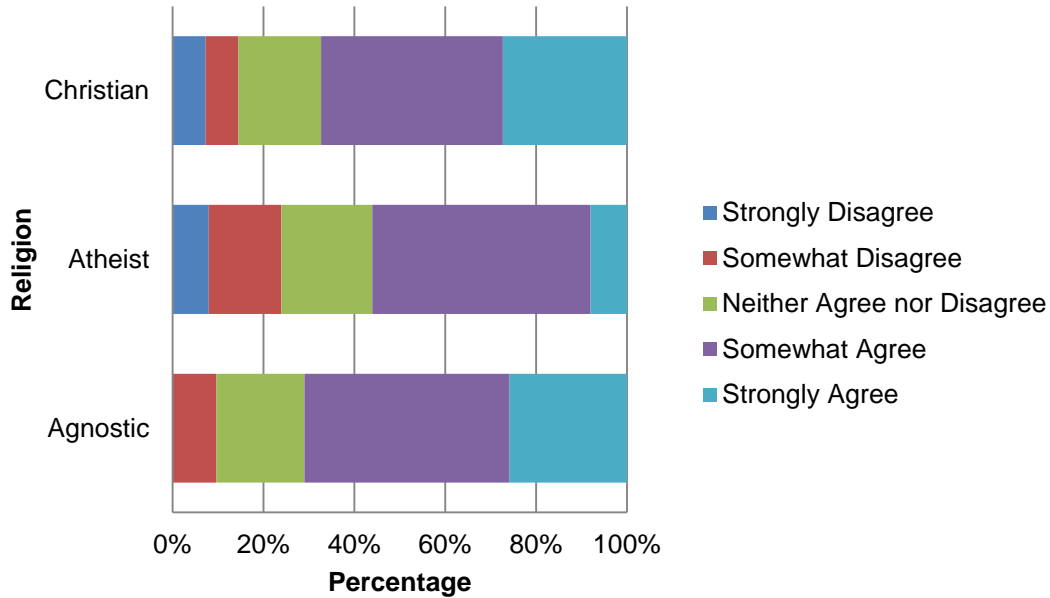


Figure 4. “Carbon Capture and Sequestration will be good for the planet overall” responses. I sorted all post-test responses by religion and presented data for the top three most common religions ($n=123$).

Differences in post-test data

I found that sandwich group and open-face respondents showed significant differences in self-rated knowledge ($p<.01$) and environmental concern ($p=.02$) during the post-test (Appendix NUM). On average, the open-face group rated their knowledge lower than those in the sandwich group by 11% ($\mu_{open}=2.56$, $\mu_{sand}=3.11$). The open-face group also had more evenly distributed responses with the majority of respondents indicating that they “Strongly Disagree” that they are knowledgeable about CCS. The sandwich group answers were less variable and concentrated at “Somewhat Agree” when rating their knowledge (Figure 5).

When evaluating their environmental concern in response to question C1, respondents who had received a pre-test scored 8% higher than those with only a post-test ($\mu_{open}=3.53$, $\mu_{sand}=3.96$). 46% of sandwich group respondents chose “Somewhat Agree” and 28% chose

“Strongly Agree,” whereas open-face respondents only chose “Somewhat Agree” and “Strongly Agree” 40% and 23% of the time respectively (Figure 6).

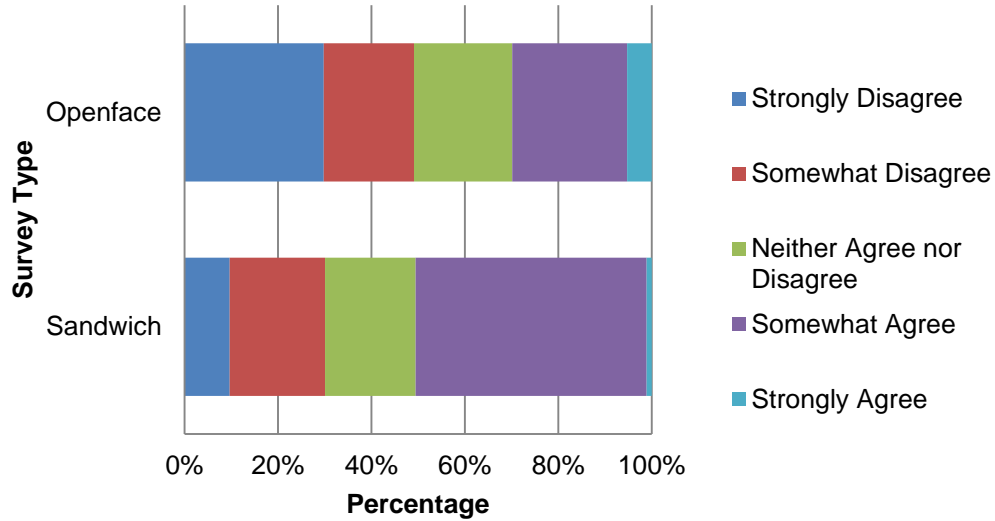


Figure 5. Self-rated knowledge responses. I sorted post-test self-rated knowledge by survey type ($n=149$).

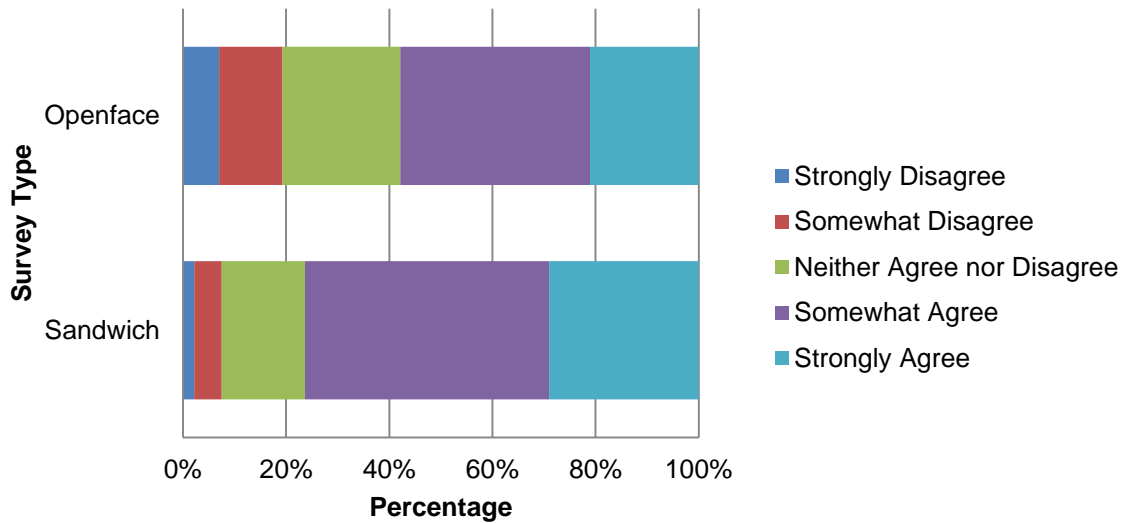


Figure 6. “I intend to engage in a more environmentally-friendly manner in the future” responses. I sorted all post-test responses by survey type ($n=149$).

Changes in self-rated knowledge

I found that during the pre-test survey, respondents showed very little self-rated knowledge of both the goals and operation of CCS ($\mu=2.04$). While scores were low across the board during the pre-test, I found that men tended to rate their knowledge 3.6% higher than women did (Figure 7). Paired t-testing showed this .18 difference in means to be significant ($p=.03$).

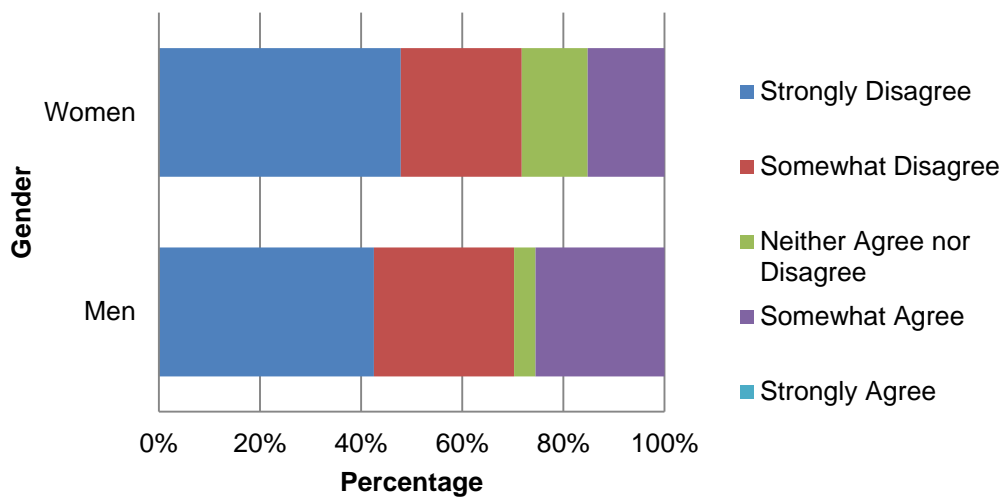


Figure 7. “I am knowledgeable about Carbon Capture and Sequestration” responses. I sorted pre-test responses by gender.

After the intervention, the self-rated knowledge scores of the respondents increased by 21.5%. The mean knowledge score increased by 1.08 points from the pre-test to the post-test ($\mu_{pre}=2.04$, $\mu_{post}=3.12$). This increase between tests was a significant change overall ($t(n)=[amount]$, $p<.0001$), with both men and women showing increases very close to the mean increase. Men maintained the roughly 4% higher mean score over women (Table 3).

Table 1. Pre- and post-test self-rated knowledge. I compared difference in pre- and post-test means within two categories: men and women.

Group	Pre-test μ	Post-test μ	$\Delta\mu$	p-value
Overall	2.0430108	3.11827957	1.08	2.05E-13
Men	2.1276596	3.02727511	0.9	1.37E-07
Women	1.9565217	3	1.04	4.68E-07

Changes in attitude toward CCS

I found that the greatest change in attitude took place in the areas of economic viability and human health and safety (Table 2). Agreement with the statement that CCS was “too expensive to implement” increased by .28 points across all sandwich group respondents (5.6%), showing a decrease in perceived economic viability. Scores for other items about economic feasibility did not increase or decrease significantly. Respondents also showed a 4.3% decrease in perceived safety of CCS ($\Delta\mu=.22$).

Table 2. Changes in mean scores. I compared pre- and post-test means for all items using paired t-tests and reported the two items that showed significant changes.

Variable	Item	$\Delta\mu$	p-value
EC2	<i>Carbon Capture and Sequestration is too expensive to implement.</i>	0.2826087	0.01237
S1	<i>Carbon Capture and Sequestration is safe.</i>	-0.217	0.02829

Among women, I found that the decrease in perception of economic viability was 4.4% larger than among men. Men began with a higher mean level of agreement that CCS is “too expensive to implement,” so the larger increase noticed among women resulted in an evening of the post-test values for men and women (Table 3). After the intervention, the difference in means between men and women was .04 (.8%), which was not large enough to be significant.

Table 3. Changes in economic scores by gender. I sorted pre- and post-test means for the statement “Carbon Capture and Sequestration is too expensive to implement” by gender.

Group	Pre-test μ	Post-test μ	$\Delta\mu$	<i>p</i> -value
Overall	2.9354839	3.215053763	0.2795699	2.05E-13
Men	3.0212766	3.191489362	0.1702128	0.281
Women	2.8478261	3.239130435	0.3913043	0.007

Conversely, men showed a larger decrease in safety approval between the pre- and post-tests (Table 4). In the pre-test, men had lower levels of agreement that CCS “would most likely cause decreases in human health” ($\mu_{\text{men}}=2.5$, $\mu_{\text{women}}=2.6$). Men showed a significant increase in agreement after the intervention (8%), while women showed a small, non-significant decrease in agreement (-3%). As a result, on average men had higher agreement scores than women in the post-test ($\mu_{\text{men}}=2.9$, $\mu_{\text{women}}=2.5$).

Table 4. Changes in safety scores by gender. I sorted pre- and post-test means for the statement “Carbon Capture and Sequestration would most likely cause decreases in human health” by gender.

Group	Pre-test μ	Post-test μ	$\Delta\mu$	<i>p</i> -value
Overall	2.591397849	2.720430108	0.129032258	0.1493845
Men	2.510638298	2.914893617	0.404255319	0.013333
Women	2.673913043	2.52173913	-0.152173913	0.4120955

In terms of economic viability, I found that respondents who self-identified as “Moderate” showed the largest change in opinion, followed by “Somewhat Liberal” and “Somewhat Conservative” respondents (Table 5, Figure 8). Post-test means for “Extremely Liberal,” “Somewhat Liberal,” and “Moderate” differed from one another by .2-.4%, a non-significant amount. Respondents who identified as “Somewhat Conservative” had means that were larger the other groups’ by 6%, while “Extreme Conservatives” showed post-test values that were smaller by 16%. “Extreme Conservatives” were the only group to show an increase in

perceived economic viability by decreasing their agreement with the statement that CCS “is too expensive to implement.”

Table 5. Changes in economic viability scores by political ideology. I sorted pre- and post-test means for the statement “Carbon Capture and Sequestration is too expensive to implement” by political ideology.

Group	Pre-test μ	Post-test μ	$\Delta\mu$	<i>p</i> -value
Extremely Liberal	3.285714	3.285714	0	1
Somewhat Liberal	3	3.255814	0.255814	0.09373
Moderate	2.72	3.24	0.52	0.02468
Somewhat Conservative	3	3.5	0.5	0.138185
Extremely Conservative	2.875	2.5	-0.375	0.442266

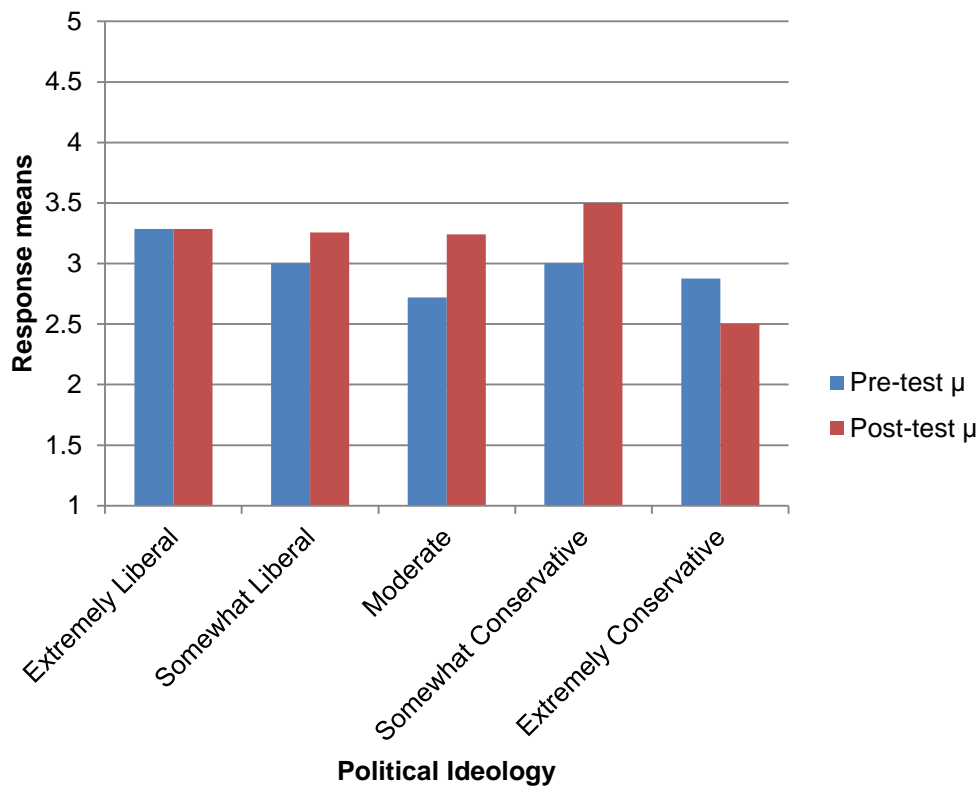


Figure 8. Changes in economic viability scores by political ideology. I sorted pre- and post-test means for the statement “Carbon Capture and Sequestration is too expensive to implement” by political ideology.

Changes in concern

While there were no significant changes overall in global warming belief, I found significant increases in desire to change behavior and worry about global warming (Table 6). There were no significant changes in agreement that “humans are severely abusing the environment,” most likely since the mean was already fairly high in the pre-test ($\mu_{pre}=4.25$).

Table 6. Overall changes in concern item scores. I performed paired t-tests on responses to all items and reported those with significant changes in means.

Item	Pre-test μ	Post-test μ	$\Delta\mu$	p-value
Behavior	3.838709677	3.956989247	0.11827957	0.020209546
GW Worry	3.784946237	3.903225806	0.11827957	0.065767852

In terms of desire to increase environmentally-friendly behavior in the future, “Moderate” respondents showed the largest increase (5.6%), though their post-test mean remained the lowest (Table 7). Respondents on both sides of the spectrum tended to have higher pre- and post-test means than moderates, with only 1-2% non-significant differences between the groups. These higher pre-test means could account for the smaller increases among all groups besides “Moderate” respondents, since the scores were already 3.9 or greater prior to the intervention. There were not significant differences across any other demographic category.

Table 7. Changes in desire to alter behavior by political ideology. I sorted pre- and post-test means for the statement “I expect to personally engage in more environmentally-friendly activities in the future, compared to what I do now” by political ideology.

Group	Pre-test μ	Post-test μ	$\Delta\mu$	p-value
Overall	3.838709677	3.956989247	0.11827957	0.020209546
Extremely Liberal	4.285714286	4.285714286	0	1
Somewhat Liberal	4.023255814	4.139534884	0.11627907	0.168190206
Moderate	3.2	3.48	0.28	0.04997
Somewhat Conservative	3.9	4	0.1	0.343436396
Extremely Conservative	4.375	4.125	-0.25	0.1705

For worry about global warming, no demographic group showed significant changes despite an overall significant (Table 8). The pre- and post- test values did show a strong trend on

the basis of political ideology (Figure 9), with “Extreme Liberals” showing the highest mean global warming worry ($\mu_{\text{post}}=4.7$), and “Extreme Conservatives” showing the least ($\mu_{\text{post}}=3$).

Table 8. Changes in global warming worry by political ideology. I sorted pre- and post-test means for the statement “I am worried about global warming” by political ideology.

Group	Pre-test μ	Post-test μ	$\Delta\mu$	<i>p</i> -value
Overall	3.784946237	3.903225806	0.11827957	0.065767852
Extremely Liberal	4.571428571	4.714285714	0.142857143	0.36
Somewhat Liberal	4.023255814	4.372093023	0.348837209	0.5
Moderate	3.36	3.52	0.16	0.33
Somewhat Conservative	2.9	3	0.1	0.34
Extremely Conservative	2.875	3	0.125	0.35

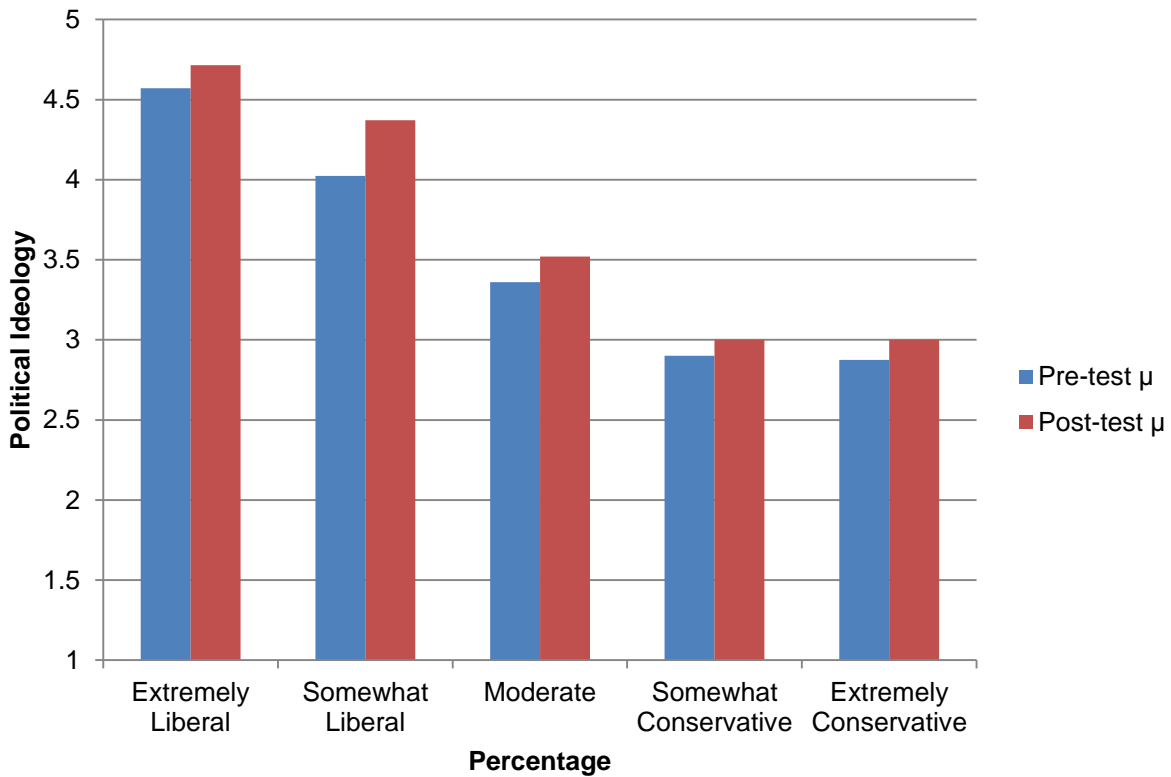


Figure 9. Changes in global warming worry by political ideology. I sorted pre- and post-test means for the statement “I am worried about global warming” by political ideology.

DISCUSSION

The changes in pre- and post-test responses shown in my study show an overall decrease in approval of Carbon Capture and Sequestration similar to previous studies (Ha-Duong 2009, Curry et al. 2007, Reiner et al. 2006), but the differences I found across demographics revealed new trends not apparent in previous studies. Specifically, differences in how groups responded to information on safety and economic viability were clear in my results, where previous studies have relied upon focus groups and interviews with smaller statistical capabilities. These key differences should dictate how advocates of CCS present the technology to new audiences, which could lead to increased approval in the United States.

Changes in self-rated knowledge

The overall increases in scored knowledge between pre- and post-test scores show that the intervention method educated the respondents about CCS in a better manner than simply a post-test alone. While I did not quantify the open-ended responses, I did notice a few differences between the open-face and the sandwich group responses. The sandwich group tended to write more of the keywords, and focused on three branches of survey (economic, environmental, safety), instead of writing tangential information (e.g. personal opinion on climate change). The open-face group tended to write less overall and included more non-relevant information, as was observed in climate change studies conducted in an intervention format (Ranney et al. 2012).

Respondents who were given both the pre- and post-test tended to rate their knowledge lower than those who received only the post-test, indicating that sandwich group felt less confident about their knowledge. While I did not code the open-ended responses, as I originally intended, they did serve the purpose of drawing the sandwich group respondents' attention to the

fact that did not know much about CCS. Since the sandwich group was asked to evaluate their knowledge during the pre-test after attempting to answer the open-ended questions but before having read about CCS, they were harsher in their evaluation of their knowledge. This trend carried over into the post-test, where the sandwich group still had significantly lower self-rated knowledge than the open-face post-test responses. The open-face respondents, having no pre-test, were not forced to evaluate their knowledge before reading the description of CCS, and thus, had an inflated sense of their own knowledge. This aligns other intervention and de-biasing studies, which have shown that people tend to give themselves a false benefit of the doubt after learning new information by subconsciously not admitting that they did not know some of the information before the intervention (Lewandowsky et al. 2010, Ranney et al. 2012).

Changes in acceptance

The overall decrease in acceptance among the sandwich group shows that learning about CCS actually caused respondents to decrease their overall opinion of the technology. This trend mirrors that found in Shackley et al. 2005; the public tends to approve of “clean coal” as an idea but are uncomfortable with the actual processes and repercussions of implementing CCS. On the whole, respondents showed decreases in opinion of safety and affordability. Despite this trend upon learning about the technology, post-test data still reflected a slightly positive view of CCS, with all means on likert-scale items showing slightly above neutral opinions. Like the findings of previous studies conducted in other locations (Ha-Duong 2009, Curry et al. 2007), this ending data shows that while respondents did decrease their overall approval after reading about CCS, they still viewed it more positively than negatively. I initially did not expect to see such a trend in America, since national polls show approval of CCS to be less than 50% (Reiner et al. 2006). This unexpected trend might be a result of the fact that the respondents were able to register their

approval on a scale instead of in a yes/no dichotomy. It is possible that some respondents, while answering that they somewhat agree that CCS is safe, affordable, and environmentally beneficial, still will not approve of the technology overall when asked in a dichotomous format (Curry et al. 2007).

The differences in approval across gender and party line show that, while there was a general decrease in approval, the level of decrease hinged upon different reasons among specific demographic groups (Miller et al. 2007). Women began with higher opinions than men regarding the economic viability of CCS, but decreased their approval after reading about CCS. This decrease was so large that women ended up with a smaller mean economic approval in the post-test. Similarly, women also began with higher opinions regarding the overall safety of CCS, which opposes trends reported in previous studies (Miller et al. 2007, Shackley et al. 2005). From the pre- to post-test, men showed a marked decrease in safety opinion, while women did not increase or decrease their safety opinion significantly. Based on this data, women tended to react more sharply to the economic information, while men tended to respond to information presented about safety rates and regulation of the industry. This contradicts previous studies about both Carbon Capture and Sequestration and energy. In the past, studies have shown that women cared more about safety and health when evaluating new technologies (Ha-Duong 2009) and men tended to care about prices and expense (Miller et al. 2007).

Similarly, the trends I observed among respondents with similar political ideology did not completely reflect the simplicity of previous research (Upton et al. 2011). I expected the most conservative respondents to register the lowest economic approval, since conservative ideology usually implies fiscal conservatism. There seemed to be a confusion, though, among conservatives as to how to rate the affordability of CCS. Respondents who were somewhat

conservative did have a lower economic approval than moderates and liberal respondents, but self-identified “extreme” conservatives had the highest post-test approval of all groups. This could be a result of a lurking variable, like income. It is possible that the extreme conservatives in my sample population have higher salaries than the other groups, and thus did not react as negatively to the average increase in household energy bills included in the CCS explanation. Regardless of personal income, though, extreme conservatives complying absolutely with conservative fiscal policy would be focused on keeping market prices at equilibrium, instead of introducing new costs and regulation to industry (Curry et al. 2007). This marked confusion in conservatives shows that there most likely is relatively little consensus on what American conservatives “should” feel about the affordability of CCS, unlike in other nations (de Best-Waldhober 2009).

Limitations and future directions

Due to the fact that I used Amazon’s Mechanical Turk (MTurk) for my survey respondents, I cannot be sure that my sample population is entirely representative of the American population. While studies have shown that MTurk’s sample pool of respondents is representative (Buhrmester et al. 2011, Paolacci et al. 2010), my sample population might not have been completely representative. My population was on the slightly liberal side of the ideological spectrum, but recent polls do show that this is the general trend in America right now (Gross et al. 2011). I still would have liked to have more conservative respondents, especially people who identify as “extreme” conservatives. I could have possibly had more significant results if I had had more conservative data. Similarly, the majority of conservative respondents did not identify as “Republican,” which limited the amount of power political party had in relation to different items. This is most likely indicative of the branding crisis the Republican

Party currently has (Bogard 2011), and made it impossible to determine what effect, if any, political party has on CCS opinions.

In addition, the format of my interventions could be improved upon by issuing a follow-up survey a few weeks after the post-test. Since most educational interventions show a taper over time, where respondents slowly drift back to their pre-test responses if left alone (Lewandowsky et al. 2010, Ranney et al. 2012), I would include a second follow-up post-test in a few days or weeks. It would be helpful to be able to pinpoint which facts stood out in respondents' memories via the open-ended questions and compare likert-scale responses to the initial pre- and post-tests. I was aware of this distinction before designing my study, but I was not able to include a follow-up due to budgetary constraints and limited time.

Broader implications

Since respondents tended to decrease their approval after learning more about Carbon Capture and Sequestration, the industry clearly needs to present data in a way that will appeal to specific demographics (Upham 2011). Since liberals are shying away from the technology due to concerns that it is not as environmentally beneficial as alternative energy sources, advocates for CCS implementation should focus educational materials in liberal communities on the fact that CCS could be used as a bridge technology. While fossil fuels are still relatively cheap, CCS can be used in areas where it is cheaper to employ CCS than to entirely switch fuel sources. Additionally, industry proponents should emphasize that CCS fossil fuel power plants will only be one facet of a variety of methods necessary to combat global climate change (Oldenburg et al. 2009). Alternative energy sources and other mitigation efforts can be used in tandem with CCS. CCS advocates should also focus on pitching the possible economic benefits to conservatives,

since there does not yet appear to be a common narrative involving how conservatives should view CCS, despite the polarization of climate change (McCright et al. 2011). While CCS would involve an increase in energy prices, it might be seen as preferable to conservatives when compared to other options. As shown in Curry et. al 2007, CCS may not have high approval rates, but respondents often choose CCS over other mitigation techniques when offered a comparison. This principle could be even more obvious among conservatives, since CCS holds possible a continuation of the fossil fuel industry, instead of a complete switch to alternate fuel sources.

Along with improving their overall representation of CCS, advocates of CCS should also attempt to improve the technology in the ways that the public finds it lacking. A major part of current research and development is already focused on making CCS more affordable (Hamilton et al. 2009), which is helpful, but increasing safety regulation is not always a main concern for companies hoping to employ the technology (Oldenburg 2009). Despite the fact that increased regulation might increase the cost of CCS, creating clear legislation regarding standards for storage, monitoring, and property rights could help set the public at ease in terms of evaluating safety and accountability (Upham 2011). Additionally, if CCS were able to capture other greenhouse gases that result from combustion, like methane, members of the public who currently feel CCS does not do enough to combat climate change might show an increase in approval (Reiner et al. 2006).

These possible improvements in both advocacy and actual technology are not just limited to Carbon Capture and Sequestration, though. The same principles of highlighting certain concerns among different demographic groups can be applied to other energy sources that are unpopular, such as nuclear energy (Bickerstaff 2008). Newer technologies are consistently held

to a higher standard than technologies already in common use (Oltra 2011). As a result, advocates need to consistently compare new ideas to business as usual, specifically referencing safety and environmental benefit. Tailoring these comparisons based upon knowledge of demographic differences will help new technologies improve in acceptance among the American public.

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APPENDIX A. Pre-test survey

Primary Investigator: Raven McGuane, UC Berkeley

We are currently conducting research about how people use information with regard to base rates or beliefs that involve a great variety of issues, and we would like you to consider aiding us by participating in this study. This form is provided to help you make an informed decision as to whether or not you would like to take part in these investigations. Below is information regarding what you can expect. Please read it carefully. Once you have finished reading the form, if you would like to participate, continue to the survey. Your participation in this research is voluntary. You are free to withdraw your consent and discontinue participation in this study at any time.

Procedures:

If you agree to take part in my research, you will answer several questions on a wide variety of topics. Using the information we provide you and your own knowledge, we would like you to make decisions about the topics or give a response that best reflects your beliefs. The information will be presented on computer and require written responses.

Risks and Benefits:

There are no foreseeable risks associated with this study beyond those encountered in routine examination and testing.

Confidentiality:

All information about you and your responses will be identified only through a randomly assigned identification number.

Questions:

If you have any questions after the survey, you may contact Raven McGuane (ravenmcguane@berkeley.edu). You may also request a copy of any publication describing this study and our findings.

If you agree to take part in this research, please continue to the survey.

General Instructions:

The purpose of this survey is to gain accurate information regarding the opinions and knowledge levels of residents of the United States. If you are not a resident of the United States, please do not respond.

During short answer items, please do not copy and paste from outside sources. If you are unsure of how to answer the questions or do not feel that you have enough knowledge to answer, please attempt to write at least a few words. It does not matter if you do not think you are knowledgeable, your responses are still valuable.

For items that use a 1-5 scale, please respond to them by indicating the degree appropriate—for instance, by circling a number on the 1 to 5 scales below (1 for the least/lowest and 9 for the most/highest).

This study involves NO deceptions. There is NO "trick" involved, and what we are asking about is what we are actually interested in. Further, any information that we provide you is accurate.

Survey Powered By [Qualtrics](#)



Please respond to the following items with a brief textual answer. Do **not** use any sources other than your current knowledge. Answers will be checked for plagiarism.

If you do not feel that you have enough knowledge to answer, please attempt to write at least a few words. Your responses are still valuable.

Please write 1-3 sentences about what the **goals** or **purposes** of Carbon Capture and Sequestration.

Please write 2-4 sentences about how Carbon Capture and Sequestration technology **operates**.



Please respond to the following items by indicating the degree to which you agree with each statement by selecting a number on the 1 (strongly disagree) to 5 (strongly agree) scale below.

Carbon Capture and Sequestration will most likely cause decreases in human health.

Strongly disagree	Somewhat disagree	Neither Agree nor Disagree	Somewhat agree	Strongly Agree
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Carbon Capture and Sequestration is safe.

Strongly disagree	Somewhat disagree	Neither Agree nor Disagree	Somewhat agree	Strongly Agree
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

I am knowledgeable about Carbon Capture and Sequestration.

Strongly disagree	Somewhat disagree	Neither Agree nor Disagree	Somewhat agree	Strongly Agree
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Carbon Capture and Sequestration would be good for the planet overall.

Strongly disagree	Somewhat disagree	Neither Agree nor Disagree	Somewhat agree	Strongly Agree
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Carbon Capture and Sequestration is too risky.

Strongly disagree	Somewhat disagree	Neither Agree nor Disagree	Somewhat agree	Strongly Agree
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

I am certain that global warming is occurring.

Strongly disagree	Somewhat disagree	Neither Agree nor Disagree	Somewhat agree	Strongly Agree
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

I expect to personally engage in more environmentally-friendly activities in the future, compared to what I do now.

Strongly disagree	Somewhat disagree	Neither Agree nor Disagree	Somewhat agree	Strongly Agree
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Humans are severely abusing the environment.

Strongly disagree	Somewhat disagree	Neither Agree nor Disagree	Somewhat agree	Strongly Agree
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Carbon Capture and Sequestration is environmentally friendly

Strongly disagree Somewhat disagree Neither Agree nor Disagree Somewhat agree Strongly Agree

Carbon Capture and Sequestration could become economically viable in the near future.

Strongly disagree Somewhat disagree Neither Agree nor Disagree Somewhat agree Strongly Agree

Carbon Capture and Sequestration is affordable.

Strongly disagree Somewhat disagree Neither Agree nor Disagree Somewhat agree Strongly Agree

Carbon Capture and Sequestration is **not** a sustainable technology.

Strongly disagree Somewhat disagree Neither Agree nor Disagree Somewhat agree Strongly Agree

I am worried about global warming.

Strongly disagree Somewhat disagree Neither Agree nor Disagree Somewhat agree Strongly Agree

Carbon Capture and Sequestration is too expensive to implement.

Strongly disagree Somewhat disagree Neither Agree nor Disagree Somewhat agree Strongly Agree

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APPENDIX B. CCS EXPLANATION

Please read the following explanation carefully.

What is Carbon Capture and Sequestration? How does it work?

Carbon dioxide (CO₂) capture and sequestration (CCS) is a process consisting of (1) the separation of CO₂ from industrial and energy-related sources, (2) transport to a storage location, and (3) long-term isolation of the CO₂ from the atmosphere. Capture of CO₂ can be applied to large producers, like coal and natural gas power plants. CCS technology can prevent about 90% of the CO₂ from entering the atmosphere while still using fossil fuels for electricity generation. A CCS-equipped power plant (with access to necessary geological or ocean storage) uses roughly 25% more energy order to capture and compress the CO₂ than a plant of equal output without CCS. This extra energy required for CCS would increase the average American household's electricity bill by about \$300 per year.

After its capture process, the CO₂ is compressed and transported for storage or for use in industrial processes in geological formations under the ocean or in mineral carbonates. The US already has CO₂ pipelines, mostly located in low-population areas; accident numbers reported per mile pipeline are low and similar to those for oil and gas (i.e. methane) pipelines. A sudden, large release of CO₂ in concentrations greater than 9% by volume in air would pose immediate dangers to human life and health. Pipeline transport of CO₂ through populated areas requires great attention to route selection, overpressure protection, leak detection and other design factors.

Storage of CO₂ in deep, onshore or offshore geological formations uses many of the same technologies that the oil and gas industry have developed. In some cases, the captured CO₂ can be stored in previously-mined oil and gas fields to more quickly regenerate those fossil fuel resources. The local health, safety, and environmental risks of geological storage would be similar to the risks of current activities such as natural gas storage with (a) appropriate site selection based on available subsurface information, (b) a monitoring program to detect problems, (c) a regulatory system and (d) the appropriate use of remediation methods to stop or control CO₂ releases if they arise.

APPENDIX C. DEMOGRAPHIC QUESTIONS

Please respond, as appropriate, regarding your background.

What is your gender?

- Male
- Female

What is your current age?

Is English your first language?

- Yes
- No

What is your strongest political party affiliation?

- None
- Democrat
- Green
- Independent
- Libertarian
- Republican
- Other
- Decline to state

On the following scale, indicate the extent to which you consider yourself to be liberal or conservative on most political and social issues:

- Extremely Liberal
- Somewhat Liberal
- Moderate
- Somewhat Conservative
- Extremely Conservative

What is your main religious faith?

- Atheist
- Agnostic
- Buddhist
- Christian
- Hindu
- Jewish
- Muslim
- Spiritual but not religious
- Other
- Decline to state

In which state do you currently reside?

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APPENDIX D. POST-TEST DATA

Table D. Post-test results by survey type. Means for each post-test likert-scale item and p-values of differences in means

Variable	Item	μ_{open}	μ_{sand}	p-value
C1	<i>I expect to personally engage in more environmentally-friendly activities in the future, compared to what I do now.</i>	3.526316	3.956989	0.02006
C2	<i>I am worried about global warming.</i>	3.736842	3.903226	0.4484
C3	<i>Humans are severely abusing the environment.</i>	4.087719	4.236559	0.3921
E1	<i>Carbon Capture and Sequestration is environmentally beneficial.</i>	3.614035	3.408602	0.2614
E2	<i>Carbon Capture and Sequestration is not a sustainable technology.</i>	2.789474	2.817204	0.8913
E3	<i>Carbon Capture and Sequestration would be good for the planet overall.</i>	3.684211	3.55914	0.4952
EC1	<i>Carbon Capture and Sequestration is affordable.</i>	2.912281	2.870968	0.8283
EC2	<i>Carbon Capture and Sequestration is too expensive to implement.</i>	3.385965	3.215054	0.3434
EC3	<i>Carbon Capture and Sequestration could become economically viable in the future.</i>	3.754386	3.526882	0.1751
S1	<i>Carbon Capture and Sequestration is safe.</i>	3.140351	3.129032	0.9459
S2	<i>Carbon Capture and Sequestration is too risky.</i>	2.894737	3	0.5205
S3	<i>Carbon Capture and Sequestration will most likely cause decreases in human health.</i>	2.45614	2.72043	0.1364
SRK	<i>I am knowledgeable about Carbon Capture and Sequestration.</i>	2.561404	3.11828	7.45E-03
GWB	<i>I am certain that global warming is occurring.</i>	3.842105	4.053763	0.3277