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Exploring public perceptions of carbon capture and utilization in the U.S

Kaitlin T. Raimi [a,*], Kimberly S. Wolske [b], P. Sol Hart [a], Soobin Choi [a]

[a] University of Michigan, Ann Arbor, MI, USA
[b] University of Chicago, Chicago, IL, USA

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ABSTRACT

Carbon capture and utilization (CCU) is an emerging climate change mitigation technology. At this early stage of development, there are still major uncertainties about the extent to which CCU can help mitigate climate change due economic and technological challenges. This study focuses on an additional complication in the development and deployment of CCU: how the public perceives its benefits, risks, and acceptability. In a nationally representative study of U.S. adults ($N = 1200$), we examined (1) overall support for CCU; (2) public expectations about CCU's effects on health, the economy, and climate change; and (3) whether perceptions vary depending on which aspects of CCU are discussed (general overview of CCU, proposed local facility, or using CCU-derived products). Using an oversample of Black, Hispanic/Latino, and Asian American participants ($n = 471$, total $N = 1671$), we also explored how beliefs differed across race/ethnicity and gender as well as the influence of psychological traits of environmentalist identity and aversion to tampering with nature. We found that the U.S. public had moderately positive views of CCU overall, with important nuances. First, people were less positive about CCU facilities in their home communities than they were about the idea of CCU in general or about products made with CCU. Second, people believed CCU would benefit the economy more than health or climate change. Third, individual differences in demographics and psychological traits matter for perceptions: (1) women were more wary of CCU than men, and (2) while White participants had more positive views about CCU the more they identified as environmentalists, the same was not always true for Hispanic or Black respondents. The study, thus, reveals the nuanced ways in which different American audiences may respond to CCU proposals.

1. Introduction

Climate change is already causing significant harm worldwide, with scientists (IPCC, 2023) and global leaders (Guterres, 2021) calling for urgent action to limit the worst impacts. According to the most recent report by the Intergovernmental Panel on Climate Change (IPCC), deep reductions in greenhouse gas emissions are needed within the next 5 to 15 years to reduce the risk of overshooting warming limits (IPCC, 2023). There is not a single mitigative solution; addressing climate change will require a diverse range of efforts across societal sectors. Understanding public perceptions of different strategies is critical, as perceptions can influence which climate measures are pursued, prioritized, or abandoned – regardless of their relative mitigative potential. Here, we focus on carbon capture and utilization (CCU), which has been identified as a critical technology for keeping global warming below 2 °C (Wei et al., 2021), even if the impacts may be modest compared to other technologies (Mac Dowell et al., 2017).

CCU refers to a variety of technologies that pull carbon dioxide (CO_2) from the atmosphere or industrial sources and use the captured carbon to produce commercial products, such as fuels, concrete, and plastics (Al-Mamoori et al., 2017). This differs from carbon capture and storage (CCS) in which captured carbon is stored permanently in geologic formations underground (National Academies of Sciences, Engineering, and Medicine, 2022). By creating new commercial industries, CCU may spur economic growth and create new job opportunities. There are also potential environmental benefits. For some CCU products, the captured carbon replaces traditional hydrocarbon-based feedstocks used in manufacturing; this reduces the carbon footprint associated with extracting and processing new fossil fuel resources (Garcia-Garcia et al., 2021; Hepburn et al., 2019). For other products, captured carbon is used as an additive or enhancer, improving the performance, durability, or environmental footprint of the end product without completely replacing conventional materials. By recycling carbon, CCU has the potential to build a so-called "circular carbon economy," which means that carbon-based products could continue to be produced without adding to the net CO_2 in the atmosphere (National Academies of Sciences,

* Corresponding author.
E-mail address: kraimi@umich.edu (K.T. Raimi).

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Engineering, and Medicine, 2022). While carbon emission reductions are seen as the main benefit of CCU, there is also the potential to reduce other environmental damages like eutrophication and ozone depletion. Researchers caution, though, that this varies with the specific CCU process used and in some cases these outcomes may be exacerbated (Garcia-Garcia et al., 2021).

The degree to which CCU can help mitigate climate change is a topic of active debate (Garcia-Garcia et al., 2021; Thonemann, 2020). The IPCC estimates that using CCU for chemical feedstocks currently removes only 1–2 $GTCO_2$ per year but could reach 20 $GTCO_2$/yr by midcentury (IPCC, 2023). Whether this comes to fruition will depend on the scalability of different CCU pathways. Though a few CCU technologies have been commercialized, most are in early stages of development and face significant economic and technological challenges to cost-effective deployment (Hepburn et al., 2019; IPCC, 2023). Some estimates suggest, for example, that large-scale CCU has the potential to decarbonize the chemical industry by 2030, but doing so would require 18.1 PWh of low-carbon energy, equivalent to >55 % of global projected electricity consumption (Kätelhön et al., 2019). There is also the question of market demand: will CCU-manufactured products be competitive with the traditional products they are intended to replace?

Another critical factor is public acceptance. Whether and to what extent CCU is adopted as part of emission-reduction efforts will partly depend on how the public perceives and supports these technologies. Current research on this topic is largely confined to Western Europe. Some studies have examined overarching perceptions of CCU technology and associated industrial development (e.g., Arning et al., 2020; Jones et al., 2017; Perdan et al., 2017), while others have explored attitudes toward specific CCU products (e.g., Arning et al., 2021; Lutzke and Árvai, 2021; Simons et al., 2021). Scholars suggest that social acceptance of emergent technologies depends on multiple factors, including socio-political acceptance by the public and policymakers, community acceptance of specific projects at the local level, and market acceptance by consumers, firms, and investors (Huijts et al., 2012; Jones et al., 2017; Wüstenhagen et al., 2007). Individual differences also matter. Growing evidence points to the importance of attributes such as race/ethnicity and gender in shaping perceptions of environmental problems (Lazri and Konisky, 2019; Pearson et al., 2018). Likewise, traits such as environmentalism (Shrum et al., 2020) and attitudes toward human interference with nature (Sweet et al., 2021; Wolske et al., 2019) can influence support for proposed emergent technologies. Importantly, public perceptions of climate change actions and technologies are powerful predictors of behavior, regardless of their accuracy (Truelove and Parks, 2012). Research shows that public perceptions of climate change solutions often differ from experts: despite increasing public education about climate change over the past several decades, the lay public continues to systematically misestimate the technical potential of a wide range of climate change technologies and actions (Johnson et al., 2024). Thus, whether or not experts believe that CCU is a promising approach to climate change, public perceptions of this technology could affect its development and use.

The aim of this study is to provide a first look at how the U.S. public perceives CCU across these dimensions. The U.S. presents a unique context for studying public perceptions of CCU. It has the highest per capita CO_2 emissions and the second highest CO_2 emissions by region in the world (IEA, 2024), yet lags behind many European countries in its efforts to mitigate it. This is partly due to the fact that, compared to Europeans, Americans are less concerned about climate change and more polarized, with the ideological right in the U.S. less willing to change how they live and work to help address climate change compared to the ideological right in Europe (Pew Research Center, 2021). Research also shows that U.S. conservatives and liberals are divided on climate change solutions (Pew Research Center, 2024), which may translate into perceptions of CCU that may differ from European populations.

Using a nationally representative survey of the U.S. public, we assess perceived risks, benefits, and support for CCU at three distinct scales: CCU technology in general, local CCU facility development, and CCU products. This comparative analysis offers insights into how the American public may respond to proposals to implement CCU. Past research has shown, for example, that while the public broadly supports wind power in the abstract, there is often opposition from those who are affected by wind farms at the local level (Bell et al., 2013). Similar differences may emerge for CCU, depending on what aspects of the technology are under consideration. Critically, our study is also the first to explore how these perceptions vary with gender, race/ethnicity, environmentalist identity, and aversion to tampering with nature. Understanding these nuances can yield important insights as to how accepting different American communities may be of CCU efforts.

2. Literature review

2.1. Public perceptions of CCU

Most research on CCU perceptions has been conducted with German or U.K. samples. Across studies, people report very low awareness of the technology (Arning et al., 2018; Jones et al., 2017; Perdan et al., 2017). This low awareness may explain why support for CCU tends to hover at or slightly above the neutral point of rating scales (Arning et al., 2020, 2019; Linzenich et al., 2019). Though perceptions of CCU tend to be modestly favorable, some evidence suggests that acceptance of CCU decreases when the technology is proposed for nearby development (Arning et al., 2019). Similar patterns of behavior have been observed for other energy-related technologies including wind and nuclear (Bell et al., 2013; Pidgeon and Demski, 2012). Jones et al. (2017) suggest that objections to local CCU facilities may be rooted more in general concerns about industrial development, rather than specific risks posed by the technology.

Reservations around CCU facilities may be amplified in the U.S. context, where there is growing concern about the environmental justice implications of related technologies such as CCS and carbon dioxide removal (Batres et al., 2021). Compared to CCS, which uses similar processes to capture and transport CO_2, acceptance of CCU tends be slightly higher, as people perceive it to be less risky (Arning et al., 2019; Dallo et al., 2024; Jones et al., 2015; Whitmarsh et al., 2019). Concerns about CCS tend to revolve around potential CO_2 leakage during transportation or storage (Arning et al., 2019; Fikru and Nguyen, 2024; L'Orange Seigo et al., 2014), some of which are not relevant to CCU (which does not involve long-term storage). Instead, acceptance of CCU appears to be more strongly related to beliefs about product usage and disposal (Arning et al., 2019), although questions of where to site facilities and the potential for localized effects of any leakage are still relevant.

An added complexity of CCU is that the resulting products must have commercial viability. Though many end uses are industrial, captured carbon may also be used to produce consumer products such as foam mattresses, cosmetics, or textiles used in clothing. Studies, including one focused on American participants, find that people are generally open to the idea of CCU products (Arning et al., 2018; Lutzke and Árvai, 2021; Simons et al., 2023). However, numerous German studies reveal public fears that CO_2 could leak from products in ways that would be detrimental to health or local environments (Arning et al., 2019, 2021; van Heek et al., 2017a). Trust in the industries producing these items also influences public perceptions (Dallo et al., 2024; Offermann-van Heek et al., 2018). In the U.S., people are less accepting of products intended for ingestion (like carbonated beverages), especially if the captured carbon comes from industrial point sources rather than direct air capture (Lutzke and Árvai, 2021).

Beyond health concerns, other perceived benefits and risks can factor into CCU acceptance. For example, in a U.K. study, participants recognized the potential economic benefits of CCU, but remained skeptical of the technology's effectiveness in addressing environmental issues (Jones

et al., 2014). German research respondents shared these doubts, questioning the role of CCU in addressing climate change, since captured CO_2 would eventually be released after product disposal (Arning et al., 2020; van Heek et al., 2017b). They also worried that investing in CCU would distract from other sustainability measures long term. A German survey found that perceptions of environmental impacts are key: CCU acceptance was higher among those who (1) perceived greater benefits to the environment and climate change and (2) perceived fewer health and environmental risks from product usage and disposal (Arning et al., 2019).

Based on this existing literature, we investigate the following preregistered research questions to understand CCU perceptions and support in the U.S.:

RQ1: How supportive is the U.S. public of CCU?

RQ2: Do perceptions of CCU differ among different aspects of the technology (general technology, local facility development, and product use)?

RQ3: To what extent do people see CCU as beneficial or risky to health, the economy, and climate change; is CCU seen as more beneficial for some outcomes than others?

2.2. Individual differences in CCU perceptions

People's perception of CCU may also depend on individual characteristics, including demographic differences and psychological traits or beliefs.

2.2.1. Demographic differences

One relevant factor in the U.S. context may be race and ethnicity. For decades, researchers have documented racial and ethnic differences in U.S. perceptions of environmental issues, including climate change. Much of this work has found that racial and ethnic minorities in the U.S. are more concerned about these topics than White respondents (Lazri and Konisky, 2019; Medina et al., 2019). For example, Latino and Hispanic respondents are more likely to report environmental concern, are more engaged on climate change, and are more willing to take political and personal action on climate change than non-Hispanic White respondents (Goldberg et al., 2020; Leiserowitz et al., 2017; Whittaker et al., 2005). Similarly, Black and Asian respondents report higher levels of environmental concern than White respondents (Mohai, 2003; Pearson et al., 2018), although other evidence on Black respondents has shown a messier pattern (Whittaker et al., 2005). This heightened concern among minorities in the U.S. is hypothesized to be due to their greater exposure to the consequences of environmental degradation (Mohai, 2003; Whittaker et al., 2005). Thus, to the extent that support for CCU reflects concern about climate change and its attendant risks, we might expect that racial and ethnic minorities would be more supportive of these technologies than their White counterparts.

Yet environmental concern among non-White Americans does not always translate into self-identification as an environmentalist. Despite their relatively high levels of environmental concern, non-White respondents are less likely than Whites to identify as environmentalists (Schuldt and Pearson, 2016), perhaps reflecting stereotypes of environmentalists as wealthy, White men (Pearson et al., 2018). What counts as an environmental issue may also differ across demographic categories; non-White (vs. White) respondents more likely to consider health or social outcomes as a form of environmental issue (Jones, 1998; Song et al., 2020). Thus, environmental and social justice concerns about CCU (including questions about where such industries will be built and possibilities for economic or health consequences of these endeavors), may be seen differently by different racial or ethnic groups in the U.S. Whereas members of minority groups may be more concerned about climate change than White participants (which may increase their support of CCU), they may also be more concerned about possible side effects of CCU (dampening support).

Gender can also influence perceptions of climate change and willingness to support actions to address it. In the U.S., while men and women have similar levels of beliefs in anthropogenic climate change, more women than men believe that global warming is currently harming the U.S. and them personally (Ballew et al., 2018). Gender differences in policy preferences depend on the specific policy in question; for example, men and women are similarly supportive of requiring utilities to produce electricity from renewables but women show more support for regulating carbon dioxide as a pollutant (Ballew et al., 2018). Only three studies have examined gender effects on CCU perceptions, finding either no effect (Arning et al., 2019) or that men are more supportive of CCU than women (Perdan et al., 2017; Whitmarsh et al., 2019). Evidence from a multi-national sample (U.K., Netherlands, Norway, Canada, and U.S.) suggests this might be because men are more supportive of capturing carbon in general (regardless of its end use) (Whitmarsh et al., 2019), while evidence from the U.K. finds that men are more familiar with the technology (Perdan et al., 2017). It remains to be seen whether gender is a contributing factor to CCU perceptions in the U.S.

Based on the possible role of race/ethnicity and gender in beliefs about CCU, we tested whether these demographic factors affected the perceptions detailed above.

RQ1a: Do race/ethnicity and gender affect overall support for CCU?

RQ2a: Do race/ethnicity and gender affect perceptions regarding different aspects of CCU (general technology, local facility development, and product use)?

RQ3a: Do race/ethnicity and gender affect perceptions that CCU is beneficial or risky to health, the economy, and climate change?

2.2.2. Psychological traits

In addition to demographic differences, some psychological traits have emerged as key predictors of a range of climate change related technologies and policies and may therefore serve as a psychological foundation for perception of CCU as well. Firstly, people differ in their aversion to tampering with the natural world (Raimi et al., 2020b). In general, people prefer natural processes, products, and outcomes to those that are human-caused (Rozin, 2005; Rozin et al., 2004; Siegrist and Sütterlin, 2014). This preference for naturalness has emerged as perhaps the most robust factor in the public's perceptions of carbon removal techniques, with people generally supporting processes that they see as more natural than those that they perceive as less natural (Braun et al., 2017; Jobin and Siegrist, 2020; Thomas et al., 2018). In addition to this general preference for all things natural, some people are particularly averse to actions that they see as tampering with the natural world (Raimi et al., 2020b); both this individual level of concern about tampering and the belief that any given technology tampers with nature affect public support for carbon removal strategies (Raimi, 2021; Wolske et al., 2019). This aversion to tampering with nature is not limited to carbon removal—it also predicts support for a wide range of climate- and environment-related technologies including sustainable meat, genetically modified organisms, and pesticides (Gonzalez Coffin et al., 2024; Raimi et al., 2020b). While no research has yet examined how much CCU is seen to tamper with nature, the tendency for aversion to tampering with nature to predict support for a wide range of climate technologies suggest that this aversion may also play a key role in perceptions of CCU.

We also examine how environmentalist identity may affect perceptions of CCU. People with a stronger environmentalist identity are generally more concerned about climate change, more likely to believe that climate change is real, and more willing to take action to address climate change (Brick and Lai, 2018; Ziegler, 2017). When looking at specific actions to address climate change, however, the relationship between environmental orientations and support for action can be complex. For example, people with greater concern about climate change and stronger environmental values generally have less support for the adoption of nuclear power, a low-carbon energy source that can help address climate change (Corner et al., 2011). This may be due in part due to the potential environmental consequences of this particular

technology. CCU may offer similar complexities. While CCU can help address climate change, people may worry about its environmental side effects. For example, the infrastructure needed to establish a robust CCU system will alter land use and have the potential for significant environmental damage through associated infrastructure hazards (Xi et al., 2023). Thus, we investigate how participant identification as an environmentalist may affect support for CCU given the complexities in CCU's overall environmental impact.

Given that environmentalist identity and aversion to tampering with nature affect support for climate change and other related technologies, we included a set of exploratory analyses to assess whether individual differences in these psychological constructs would also affect perceptions of and support for CCU. In addition, as noted earlier, whether one considers themselves an environmentalist is inextricably tied to other social identities in the U.S., including gender and race. Thus, our analyses explore whether these psychological traits interact with these social identifies to predict CCU beliefs.

3. Methods

To inform survey development, we conducted six focus groups with 41 adults from Southeast Michigan in the summer and fall of 2020. Participants were shown a short video explaining the basic process of CCU and example products (textiles, fuel, concrete) before being asked about their thoughts on these processes and products. Participants raised concerns that (1) CCU could serve as an excuse for continued greenhouse gas emissions; (2) CCU production could threaten the health of workers, nearby residents, or local environments; and (3) CCU products could damage the health of users. Perceived benefits included that (1) CCU could help address climate change; (2) CCU filters might also help prevent particulate matter from polluting the air; (3) CCU could create new jobs; and (4) CCU could be used to create new or improved products. These themes, along with prior research, informed the specific benefits and risks that were included in the questionnaire. To identify which items formed cohesive scales, we first piloted the draft survey with Amazon Mechanical Turk workers recruited through CloudResearch (see Supplementary Information Section S2).

The research plan, including power analyses and exclusion criteria, research questions and data analyses, were all preregistered on OSF. Details on the preregistration and deviations from the preregistration plan are included in the Supplementary Information Section S1. The survey was determined to be exempt from review by the [redacted] IRB board. Informed consent was obtained on the first page of the survey, and no identifiable data were collected from participants (who were anonymous to the researchers). The authors declare no conflicts of interest regarding this research.

3.1. Sample

To address RQ1 through RQ3—where we wanted to be able to generalize to the U.S. public as a whole, we recruited a nationally representative sample of 1200 U.S. adults from a YouGov survey panel from August – October 2022. YouGov is a top-ranked survey panel firm that provides representative non-probability samples for research that approximate (or outperform) probability samples (see Pew Research Center, 2016, YouGov is Vendor 1). This representative sample was 62.9 % (non-Hispanic) White (n = 755), 12.1 % Black (n = 146), 16.2 % Hispanic (n = 195), and 2 % Asian (n = 24), with 50.4 % identifying as female. Mean age was 47.76 (SD = 18.21), median level of education was attaining "some college," and the median level of household income was "$40,000 to $49,000." For analyses run on this sample, we used YouGov-provided sample weights to ensure our data closely matched the U.S. population.

To ensure adequate power to test race/ethnicity effects (RQ1a-RQ3a), we oversampled race and ethnicity subgroups, resulting in an additional 129 Black, 192 Hispanic/Latino, and 255 Asian American respondents (total n = 1776). For analyses run using this sample we did not use sample weights as we were no longer using a representative sample.

3.2. Procedure

After consenting to participate, participants read a brief informational vignette (222 words) that explained the general process and implications of CCU. This was accompanied by an infographic, shown in Fig. 1a, adapted from a previous study (Arning et al., 2019). Participants were asked to rate their perceptions about CCU in general. The survey then instructed participants to "Imagine there is a proposal to build a carbon capture facility in your community. This would be a carbon capture facility that is added to an existing industrial area." The questions that followed asked participants' perceptions of such a facility. Finally, participants saw another short vignette and infographic (Fig. 1b) explaining potential products manufactured from CCU (102 words) before indicating their perceptions of CCU products. This included example products such as plastics, construction materials, and fuels. Both vignettes can be found as part of the full survey bank in the Supplementary Information (Section S3).

3.3. Measures

The full survey bank can be found in Supplementary Information Section S3. Descriptive statistics for CCU perceptions using the weighted means from the representative sample are shown in Figs. 2 and 3. All descriptive statistics reported in this section are from the unweighted, full sample (n = 1776) rather than the smaller representative sample (n = 1200).

3.3.1. CCU support

We measured support for three different dimensions of CCU: (1) CCU technology in general, (2) local CCU facility development, and (3) CCU

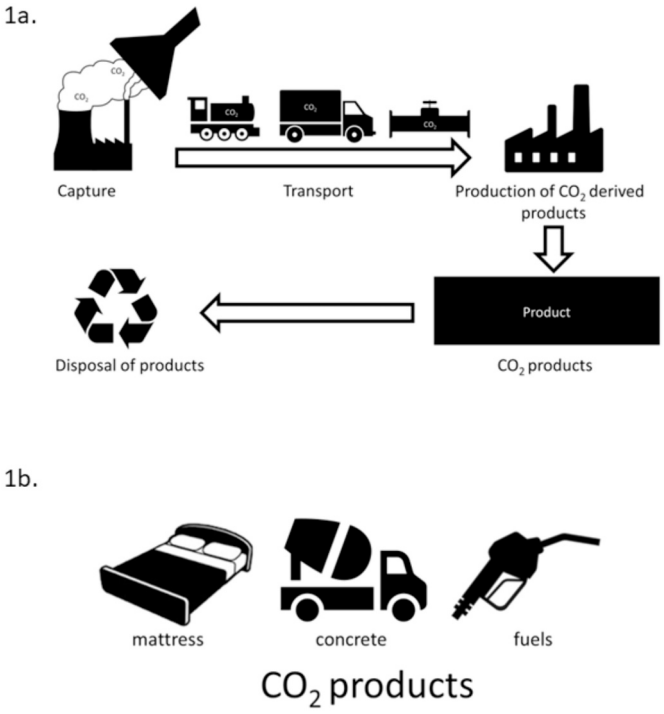

Fig. 1. Infographics shown in vignettes introducing CCU to participants. 1a shows the infographic describing the process of CCU. 1b shows the infographic describing products created by CCU. The written vignettes that accompanied these images are in Supplementary Information Section 3.

Fig. 2. Perceptions of different aspects of CCU using weighted means and standard deviations from the nationally representative sample. Fig. 2a shows overall support for CCU in general, support for the development of a local CCU facility, and support for CCU-derived products. Fig. 2b shows how participants evaluated the relative benefits and risks of each CCU dimension (in general, of local facilities, and of CCU derived products). Fig. 2c shows overall perceived risks of each dimension and Fig. 2d shows overall perceived benefits. Fig. 2a–b are measured on 7-point bipolar scales (1 = "strongly oppose" or "risks greatly outweigh the benefits" to 7 = "strongly support" or "benefits greatly outweigh the risks"). Fig. 2c–d are measured on unipolar 5-point scales (1 = "not at all" to 5 = "extremely").

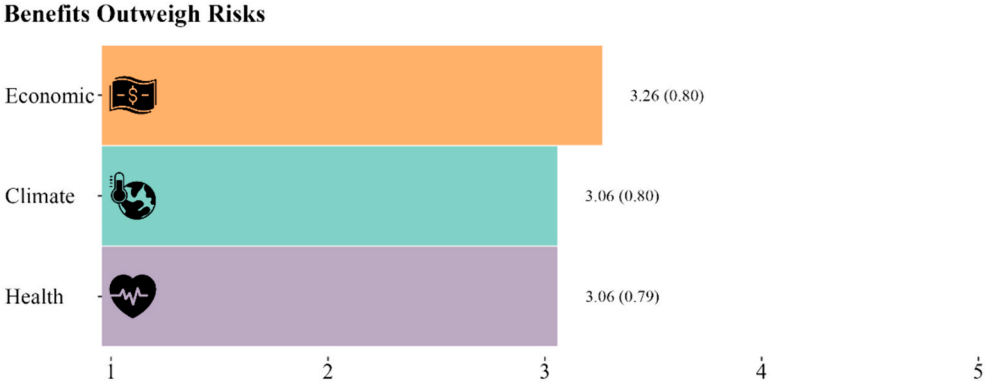

Fig. 3. Perceptions of the effects of CCU on specific domains (economic, climate, and health) using weighted means and standard deviations from the nationally representative sample. Items are measured on a 5-point scale asking how much CCU would have effects in this domain (1 = "not at all" to 5 = "extremely"), with composites of items coded such that higher scores reflect more perceived benefit and less perceived risk.

products. Participants indicated to what extent they would support or oppose "CCU," "having a carbon capture facility in their local community" and "stores selling products made from captured carbon" (1 = strongly oppose to 7 = strongly support).

3.3.2. *Perceived benefits and risks*

Perceived benefits and risks of CCU were assessed with three questions for each dimension of CCU: (1) how beneficial the participant thinks [CCU/having a carbon capture facility in the local community/products made from captured carbon] would be, (2) how risky [CCU/having a carbon capture facility in the local community/products made from captured carbon] would be, and (3) how they would compare the benefits and risks of [CCU/having a carbon capture facility in the local community/products made from captured carbon]. The first two questions were measured on a 5-point scale ranging from "not at all" to "extremely," and the third was measured on a 7-point scale ranging from "risks greatly outweigh the benefits" to "benefits greatly outweigh the risks."

3.3.3. *Domain-specific benefits and risks*

Participants then indicated the extent to which CCU would have effects on specific domains (1 = not at all to 5 = very much). Most items were created for this study, but some were adapted from previous literature (Arning et al., 2020; Jones et al., 2015). Ten items stated potential health benefits and risks of CCU, including: "improve people's health by cleaning the air," "create safe alternatives to existing manufacturing processes that use fossil fuels," "harm human health if CO_2 leaks during the capture, transport, or storage process."

Eight items stated potential benefits and risks of CCU on the economy. Some example statements are: "help the economy by creating new manufacturing items," "provide consumers with new types of products to meet their needs," "threaten the livelihoods of people who make traditional products without captured carbon."

Seven items stated potential benefits and risks of CCU on climate change, including: "Help buy us time to tackle climate change," "reduce overall carbon emissions," "give society an excuse to continue burning fossil fuels." One of the seven items ("discourage policies to reduce fossil fuel emissions") was removed from analyses due to low inter-item correlation with the other six items.

After reverse-coding items that stated potential risks, we created composites for each domain such that higher scores indicated more perceived benefits. These composites had strong internal reliability (Health α = .844; Economy α = .792; Climate α = .719).

3.3.4. *Environmentalist and nature beliefs*

Environmentalist identity was measured with a single item asking to what degree participants considered themselves to be an environmentalist. Response options ranged from 1 = not at all to 5 = very much so (unweighted mean = 2.59, *SD* = 1.11).

Participants completed the five-item Aversion to Tampering with Nature scale using responses 1 = strongly disagree to 7 = strongly agree (Raimi et al., 2020b). Sample items include, "people who push for

technological fixes to environmental problems are underestimating the risks," and "altering nature will be our downfall as a species" ($\alpha = 0.75$, unweighted mean = 4.44, $SD = 1.17$).

3.3.5. Demographics

Participants indicated their gender identity: man ($n = 772$), woman ($n = 969$), non-binary ($n = 24$), and other ($n = 11$). They reported their race/ethnicity by choosing a single category that best described them: White ($n = 875$), Black ($n = 275$), Hispanic ($n = 275$), Asian ($n = 275$), Native American ($n = 11$), Middle Eastern ($n = 5$), two or more races ($n = 33$), and other ($n = 27$). Political ideology was measured with a single item (1 = very liberal to 5 = very conservative; unweighted mean = 2.94, $SD = 1.14$).

Participants indicated their education level: "No High school," "High school graduate," "Some college," "2-year college degree," "4-year college degree," "Post-graduate degree." These categories were collapsed for analyses into high school or below ($n = 612$), some college or 2-year college degree ($n = 542$), and college degree or higher ($n = 62$). Household income was measured with a single item with 16 response options ranging from "Less than $10,000" to "$500,000 or more." To turn this into a more interpretable continuous measure, income bins were recoded to the midpoint of the bin (e.g., "$40,000–$49,999" was recoded as "$45,000"), with the two endpoints recoded as "$5000" and "$550,000."

4. Results

4.1. Overall perceptions of CCU

For analyses related to RQ1 through RQ3, we used YouGov's weighting scheme to approximate a representative sample of the U.S. population ($n = 1200$).

4.1.1. RQ1: support for CCU

We first estimated overall support for CCU (Fig. 2a). Respondents indicated slight support for CCU as a general concept and for CCU-derived products. They were more neutral about having a CCU facility located in their local community, with the mean slightly above the midpoint of the scale.

4.1.2. RQ2: do perceptions differ across different dimensions of CCU (technology overall, local facility development, and products)?

We next compared perceptions of each CCU dimension (technology in general, local facility development, and CCU products) using repeated-measures ANCOVAs. ANCOVA (Analysis of Covariance) is a statistical technique that combines ANOVA (Analysis of Variance) and linear regression to examine how categorical and continuous predictor variables may be associated with outcome variables of interest. We used this approach so that we could examine our categorical predictors of interest while controlling for demographic variables that were measured as continuous predictors. We looked at four outcome variables: (1) support for CCU, (2) perceived benefits of CCU, (3) perceived risks of CCU, and (4) whether the benefits outweighed the risks (see Fig. 2 for means). For each ANCOVA, we controlled for gender, education, household income, and political ideology (Table 1). Note that while the full ANCOVA models included interactions with our control variables, we did not have research questions about these interactions and so do not discuss them.

Which aspect of CCU was focal (technology overall, local facility development, or CCU-derived products) did not affect the perceived risks of CCU or perceptions that the benefits of CCU outweigh the risks. However, both CCU support and the perceived benefits of CCU were significantly affected by which dimension of CCU was being considered. Pairwise comparisons showed that support for local CCU facilities ($M = 4.37$) was significantly lower than for CCU in general ($M = 4.74$, $p \leq .001$) and for products ($M = 4.82$, $p \leq .001$). Participants also rated the perceived benefits of local facilities ($M = 2.83$) lower than for CCU in general ($M = 3.31$, $p \leq .001$) and for CCU products ($M = 3.38$, $p \leq .001$). CCU products were also seen as having significantly more benefits than CCU in general ($p = .048$).

4.1.3. RQ3: benefits and risk of CCU to health, the economy, and climate change

We next estimated how the U.S. public views the benefits and risks of CCU for the specific outcomes of health, the economy, and climate change. The means for each domain were close to the midpoint, indicating that beliefs about CCU's benefits and risks for these outcomes were moderate overall (Fig. 3). A repeated measures ANCOVA (Table 2) showed that respondents thought that the benefits of CCU would be

Table 1
Repeated measure ANCOVAS testing whether perceptions of CCU differ across levels of CCU.

Predictor	CCU support				Benefits of CCU				Risks of CCU				Benefits outweigh risks of CCU			
	F	*df*	*p*	η_p^2	*F*	*df*	*p*	η_p^2	*F*	*df*	*p*	η_p^2	*F*	*df*	*p*	η_p^2
Between-subjects																
Intercept	794.14	1, 1002	<.001	.442	754.61	1, 1002	<.001	.430	206.70	1, 1002	<.001	.171	734.65	1, 999	<s.001	.424
Gender	5.26	1, 1002	.022	.005	0.29	1, 1002	.588	.000	7.10	1, 1002	.008	.007	7.10	1, 999	.008	.007
Education	5.02	1, 1002	.025	.005	2.10	1, 1002	.148	.002	0.59	1, 1002	.443	.001	4.87	1, 999	.028	.005
Income	0.43	1, 1002	.512	.000	0.07	1, 1002	.793	.000	0.20	1, 1002	.654	.000	0.07	1, 999	.794	.000
Ideo	135.74	1, 1002	<.001	.119	126.71	1, 1002	<.001	.112	42.63	1, 1002	<.001	.041	143.77	1, 999	<.001	.126
Within-subjects																
Aspect	5.79	2, 2004	.003	.006	4.60	2, 2004	.010	.005	0.12	2, 2004	.891	.000	0.17	2, 1998	.845	.000
Aspect * Gender	4.38	2, 2004	.013	.004	6.08	2, 2004	.002	.006	0.11	2, 2004	.900	.000	2.30	2, 1998	.101	.002
Aspect * Education	4.45	2, 2004	.012	.004	0.42	2, 2004	.660	.000	2.35	2, 2004	.096	.002	0.72	2, 1998	.487	.001
Aspect * Income	2.48	2, 2004	.084	.002	0.56	2, 2004	.573	.001	2.49	2, 2004	.084	.002	0.06	2, 1998	.940	.000
Aspect * Ideo	11.93	2, 2004	<.001	.012	3.39	2, 2004	.034	.003	3.35	2, 2004	.035	.003	3.47	2, 1998	.031	.003

Note: Aspect = aspect of CCU (general vs. local facility vs. products). Ideo = political ideology.

Table 2
Repeated measure ANCOVAS testing whether perceptions of benefits and risks of CCU differ across specific outcome domains of health, the economy, and climate change.

Predictor	*F*	*df*	*p*	η_p^2
Between-subjects				
Intercept	1440.60	1, 1002	<.001	.590
Gender	1.95	1, 1002	.163	.002
Education	0.01	1, 1002	.925	.000
Income	0.73	1, 1002	.393	.001
Ideo	124.87	1, 1002	<.001	.111
Within-subjects				
Domain	9.33	2, 2004	<.001	.009
Domain * Gender	3.87	2, 2004	.021	.004
Domain * Education	2.34	2, 2004	.097	.002
Domain * Income	3.57	2, 2004	.028	.004
Domain * Ideo	10.73	2, 2004	<.001	.011

Note: Domain = Specific domain of outcomes (health vs. economic vs. climate). Ideo = political ideology.

more positive for the economy ($M = 3.27$) than for climate change ($M = 3.06$, $p < .001$) or health ($M = 3.09$, $p < .001$).

4.2. Effects of individual differences on CCU perceptions

We next tested whether the research questions above were affected by race/ethnicity and gender. For these analyses, we only included participants who self-identified as either a man or woman and as one of our four categories of race/ethnicity (White, Black, Hispanic, and Asian), $N = 1671$. This sample was therefore no longer representative of the U.S. population, so instead of using weighted means, we used unweighted means and controlled for education, income, and political ideology.

4.2.1. RQ1a: is support or opposition to CCU affected by race and gender?

ANCOVAs tested whether race/ethnicity, gender, or their interactions affected support for CCU (Table 3). For each dimension of CCU (technology overall, local facility development, or CCU-derived products), we found that men were more supportive than women. Neither race nor the interaction of race and gender were significant predictors.

4.2.2. RQ2a: do race and gender affect differences in the perceived risks and benefits of CCU between the different dimensions of CCU (technology overall, local facility development, and products)?

We next used repeated-measures ANCOVAs to test whether race or gender (between-subject variables) affected support and perceived benefits and risks of CCU across the three aspects of CCU (within-subjects variable; Table 4).

Gender effects emerged for all outcome variables (support of CCU, benefits of CCU, risks of CCU, and the perceptions that benefits outweigh the risks). In all cases, men ($M_{support} = 4.95$, $M_{benefits} = 3.36$, $M_{risks} = 2.53$, $M_{benefits\ vs\ risks} = 4.84$) felt more positively about CCU than women ($M_{support} = 4.53$, $M_{benefits} = 3.18$, $M_{risks} = 2.72$, $M_{\ benefits\ vs\ risks} = 4.37$). For support, there was also an interaction between gender and CCU level, with pairwise comparisons showing that while men supported CCU more than women at every phase, this was strongest when considering local CCU facilities ($F_{overall} = 14.11$, $F_{local} = 32.26$, $F_{products} = 15.44$, all $ps < .001$).

There was only a main effect of race when considering risks of CCU, with White participants ($M = 2.47$) perceiving lower risk than Black ($M = 2.73$, $p < .001$) or Hispanic participants ($M = 2.74$, $p < .001$), but not differing from Asian participants ($M = 2.58$, $p = .443$). The perceived risks of different aspects of CCU also differed by race. Among White participants, CCU products ($M = 2.36$) were seen as significantly less risky than was CCU overall ($M = 2.51$, $p < .001$) or local facilities ($M = 2.52$, $p < .001$). Among Black participants, local CCU facilities ($M = 2.96$) were seen as riskier than CCU overall ($M = 2.59$, $p < .001$) or products ($M = 2.65$, $p < .001$). No such effects emerged for Hispanic or Asian participants.

4.2.3. RQ3a: do race and gender affect perceptions that CCU are beneficial or risky for specific domains?

A repeated measures ANCOVA next tested whether race and gender affected differences in risk/benefit perceptions across each of our three specific domains (health, economy, and climate change; Table 5). There was a main effect of gender, such that—collapsing across domains—men ($M = 3.29$) were more optimistic than women ($M = 3.15$, $p < .001$). There was also an interaction between gender and the domain being considered. Men reported significantly more economic ($M = 3.44$) and health benefits ($M = 3.24$) than women ($M_{economy} = 3.29$, $M_{health} = 3.00$, both $ps < .001$). No such effect emerged for climate benefits ($M_{men} = 3.18$, $M_{women} = 3.14$, $p = .424$).

There were no effects of race or the interaction of race and gender. However, there was an interaction between race and domain outcome. Participants of all races though that economic benefits ($M_{White} = 3.40$, $M_{Black} = 3.44$, $M_{Hispanic} = 3.28$, $M_{Asian} = 3.34$) would be higher than health ($M_{White} = 3.17$, $M_{Black} = 3.12$, $M_{Hispanic} = 3.13$, $M_{Asian} = 3.06$) or climate benefits ($M_{White} = 3.11$, $M_{Black} = 3.25$, $M_{Hispanic} = 3.16$, $M_{Asian} = 3.14$; all $ps < .001$ except for Hispanic estimates of economic vs. climate benefits: $p = .033$). However, while White participants rated health benefits as significantly higher than climate benefits ($p = .026$), Black participants thought the opposite ($p = .009$). Ratings of health vs. climate benefits did not differ among Hispanic or Asian participants.

4.3. Exploratory analysis: do environmentalist identity and aversion to tampering with nature (and their interaction) correlate with perceptions of CCU, and are these relationships moderated by gender or race?

In a non-preregistered analysis, we ran a series of hierarchical regressions testing the effects of environmentalist identity, aversion to tampering with nature, and their interaction on support for CCU, perceived benefits and risks of CCU, and perceptions that the benefits outweigh the risks. Given past research finding gender and race differences in perceptions of environmental concern, we tested whether these demographic factors interacted with these psychological constructs to

Table 3
ANCOVAS testing whether race, gender, or their interaction affect support for CCU.

Predictor	Overall CCU support				Support for local facilities				Support for products			
	F	*df*	*p*	η_p^2	*F*	*df*	*p*	η_p^2	*F*	*df*	*p*	η_p^2
Intercept	1284.30	1, 1396	<.001	.479	1049.03	1, 1397	<.001	.429	1174.75	1, 1397	<.001	.457
Education	7.54	1, 1396	.006	.005	4.89	1, 1397	.027	.003	9.47	1, 1397	.002	.007
Income	1.05	1, 1396	.306	.001	0.04	1, 1397	.844	.000	0.39	1, 1397	.533	.000
Ideology	123.03	1, 1396	<.001	.081	111.57	1, 1397	<.001	.074	76.21	1, 1397	<.001	.052
Race	0.78	3, 1396	.505	.002	0.32	3, 1397	.810	.001	1.24	3, 1397	.293	.003
Gender	14.11	1, 1396	<.001	.010	32.50	1, 1397	<.001	.023	18.84	1, 1397	<.001	.013
Race * Gender	1.48	3, 1396	.220	.003	1.94	3, 1397	.122	.004	1.95	3, 1397	.119	.004

Table 4
Repeated measure ANCOVAS testing whether race and gender affect differences in perceptions of different dimensions of CCU.

Predictor	CCU support				Benefits of CCU				Risks of CCU				Benefits outweigh risks of CCU			
	F	*df*	*p*	η_p^2	*F*	*df*	*p*	η_p^2	*F*	*df*	*p*	η_p^2	*F*	*df*	*p*	η_p^2
Between-subjects																
Intercept	1396.61	1, 1396	<.001	.500	1467.71	1, 1397	<.001	.512	661.20	1, 1397	<.001	.321	1222.24	1, 1393	<.001	.467
Edu	7.69	1, 1396	.006	.005	1.02	1, 1397	.313	.001	0.21	1, 1397	.645	.000	4.90	1, 1393	.027	.004
Income	0.89	1, 1396	.347	.001	1.07	1, 1397	.301	.001	0.42	1, 1397	.518	.000	1.99	1, 1393	.159	.001
Ideo	133.12	1, 1396	<.001	.087	115.85	1, 1397	<.001	.077	24.92	1, 1397	<.001	.018	115.88	1, 1393	<.001	.077
Gender	24.97	1, 1396	<.001	.018	9.92	1, 1397	.002	.007	13.93	1, 1397	<.001	.010	30.54	1, 1393	<.001	.021
Race	0.45	3, 1396	.719	.001	1.64	3, 1397	.178	.004	8.80	3, 1397	<.001	.019	1.14	3, 1393	.332	.002
Gender * Race	1.73	3, 1396	.159	.004	2.56	3, 1397	.053	.005	0.08	3, 1397	.970	.000	2.38	3, 1393	.068	.005
Within-subjects																
Aspect	2.13	2, 2792	.119	.002	19.55	2, 2794	<.001	.014	1.17	2, 2794	.310	.001	0.39	2, 2786	.675	.000
Aspect * Edu	0.16	2, 2792	.854	.000	0.14	2, 2794	.870	.000	0.56	2, 2794	.571	.000	0.72	2, 2786	.489	.001
Aspect * Income	1.14	2, 2792	.319	.001	1.08	2, 2794	.340	.001	1.26	2, 2794	.283	.001	0.47	2, 2786	.623	.000
Aspect * Ideo	1.13	2, 2792	.324	.001	3.93	2, 2794	.020	.003	3.09	2, 2794	.046	.002	2.29	2, 2786	.102	.002
Aspect * Gender	4.19	2, 2792	.015	.003	7.14	2, 2794	<.001	.005	1.71	2, 2794	.181	.001	2.42	2, 2786	.089	.002
Aspect * Race	1.09	6, 2792	.368	.002	1.81	6, 2794	.093	.004	4.77	6, 2794	<.001	.010	0.55	6, 2786	.770	.001
Aspect * Gender * Race	1.46	6, 2792	.188	.003	0.66	6, 2794	.685	.001	0.61	6, 2794	.719	.001	1.40	6, 2786	.210	.003

Note: Aspect = aspect of CCU (general vs. local facility vs. products). Ideo = political ideology. Edu = education.

Table 5
Repeated measure ANCOVAS testing whether race and gender affect differences in perceptions of CCU across different specific domains.

Predictor	*F*	*df*	*p*	η_p^2
Between-subjects				
Intercept	2607.89	1, 1397	.000	.651
Edu	0.03	1, 1397	.868	.000
Income	0.00	1, 1397	.992	.000
Ideo	108.62	1, 1397	<.001	.072
Gender	12.31	1, 1397	<.001	.009
Race	0.76	3, 1397	.519	.002
Gender * Race	1.92	3, 1397	.125	.004
Within-subjects				
Domain	41.16	2, 2794	<.001	.029
Domain * Edu	1.50	2, 2794	.224	.001
Domain * Income	0.18	2, 2794	.836	.000
Domain * Ideo	20.78	2, 2794	<.001	.015
Domain * Gender	12.73	2, 2794	<.001	.009
Domain * Race	4.64	6, 2794	<.001	.010
Domain * Gender * Race	0.86	6, 2794	.526	.002

Note: Domain = specific outcome domain (health vs. economic vs. climate). Ideo = political ideology. Edu = education.

affect CCU beliefs (using White race and male gender as the reference groups). These regressions were repeated for each dimension of CCU (technology overall, local facility development, and products) and included education, household income, and political ideology as controls (see full regressions in Supplementary Information Section S4, Tables S1–S3). We first examined support for CCU. Regardless of which aspect of CCU was highlighted, environmentalist identity predicted more support for CCU and aversion to tampering predicted less support (with no interactions between these measures). Men also supported CCU more than women. Hispanic ethnicity consistently moderated the effects of environmentalist identity on each aspect of CCU: while White participants supported CCU more when they were higher in environmentalist identity, environmentalist identity did not affect CCU support for Hispanic respondents (see Fig. 4; Supplementary Information Section S4, Table S4). Black race also moderated the effect of environmentalist identity on support of CCU technology overall and support for local facilities (though not for products). For White participants, support for CCU technology went up as environmentalist identity increased (overall: $b = 0.40$, $t = 6.26$, $p < .001$; local facilities: $b = 0.48$, $t = 7.18$, $p < .001$), but this increase was not as strong for Black participants (overall: $b = 0.17$, $t = 1.79$, $p = .074$; local facilities: $b = 0.21$, $t = 2.12$, $p = .034$).

We next examined perceived benefits of CCU. As with support, environmentalist identity predicted more perceived benefits of CCU at all levels, while aversion to tampering with nature predicted lower perceived benefits, with no interaction between them. Women perceived the benefits of local facilities to be lower than men, though unlike with support, this effect did not emerge for overall CCU or products. There was, however, a significant interaction of gender and environmentalist identity when it came to overall CCU benefits. While both genders reported more CCU benefits when higher in environmentalist identity, this effect was stronger for men ($b = 0.35$, $t = 7.71$, $p < .001$) than women ($b = 0.21$, $t = 4.94$, $p < .001$). Black respondents reported more benefits of CCU overall and of local CCU facilities than White respondents. As with support, a consistent interaction emerged between environmentalist identity and Hispanic ethnicity for all three dimensions of CCU, where White respondents' ratings of benefits were tied to environmentalist identity while Hispanic respondents' ratings were not (Fig. 4; Supplementary Information Section S4, Table S4).

We next examined perceived risks. Those high in aversion to tampering with nature perceived more risk from all three dimensions of

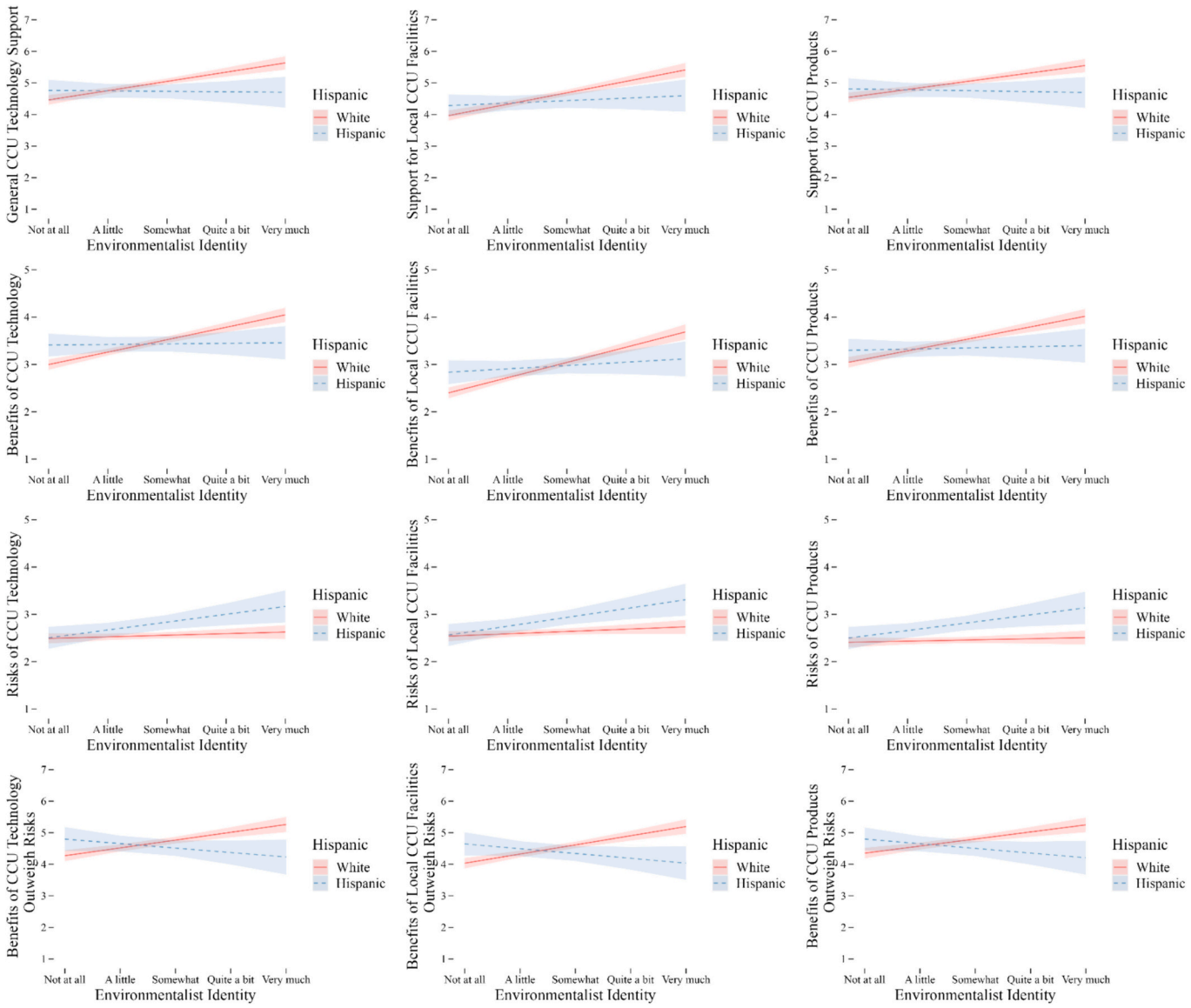

Fig. 4. Interactions of environmentalist identity and Hispanic ethnicity on CCU perceptions. Results for White respondents are shown in red and Hispanic respondents in blue (with shading indicating 95 % CIs). The first column shows the pattern for perceptions of CCU technology overall, the second column shows results for local facilities, and the third column for products.

CCU; however, there were no main effects of environmentalist identity. There was an interaction of aversion to tampering with nature and environmentalist identity when it came to local CCU facilities, but not for other aspects of CCU. Probing the significant interaction revealed that those who were more comfortable with tampering with nature (−1 *SD* of mean) perceived local CCU facilities to be less risky as their environmentalist identity increased ($b = -0.03$, $t = -0.61$, $p = .542$), while those with high aversion to tampering (+1 *SD* of mean) perceived local facilities to be riskier as their environmentalist identity increased ($b = 0.07$, $t = 1.35$, $p = .178$). However, these simple slopes were not significant. Women reported more risks of overall CCU and local CCU facilities than men, but not products. Compared to White respondents, Hispanic respondents perceived all dimensions of CCU to be riskier, while Black respondents saw heightened risk for local facilities and products, and Asian respondents showed heightened risk for products but not for other aspects of CCU. There was an interaction of environmentalist identity and Asian race, but only for local facilities: while there was no effect of environmentalist identity on local CCU facility risk perceptions for White participants ($b = 0.02$, $t = 0.47$, $p = .635$), the more Asian participants identified as environmentalists, the more they rated local facilities as risky ($b = 0.18$, $t = 2.55$, $p = .011$). The interaction that had emerged elsewhere between Hispanic ethnicity and environmentalist identity did not reach significance for any scale of CCU risks.

When it came to whether the benefits of CCU outweighed the risks, we again found that environmentalist identity predicted more perceived benefits (vs. risks) across all dimensions of CCU whereas aversion to tampering with nature predicted less, with no interaction between them. Women (vs. men) reported fewer benefits compared to risks for all three dimensions of CCU. As with support and perceived benefits, a consistent interaction emerged between environmentalist identity and Hispanic ethnicity for all three dimensions of CCU. As with those variables, White respondents were more likely to say that the benefits of CCU outweighed the risks if they were higher in environmentalist identity, but Hispanic respondents were not (Fig. 4; Supplementary Information Section S4, Table S4). There were also interactions of Black race and environmentalist identity when it came to overall CCU and local CCU facilities: while White participants thought that the benefits of CCU outweighed the risks

more when they were high in environmentalist identity (overall: $b = 0.34$, $t = 4.77$, $p < .001$; local facilities: $b = 0.36$, $t = 5.24$, $p < .001$), Black participants were no more likely to when high in environmentalist identity (overall: $b = 0.12$, $t = 1.08$, $p = .279$; local facilities: $b = 0.12$, $t = 1.26$, $p = .247$).

To rule out the possibility that these interactions were caused by differences in levels of environmentalist identity between races, we ran a one-way ANOVA testing whether environmentalist identity differed by race, which was not significant $F(3, 1667) = 2.44$, $p = .063$. The pairwise comparisons between specific race categories were also not significant (all $ps > .05$). Thus, while we did not find that environmentalist identify differed by race, we did find that the way environmentalist identity translated into CCU perceptions differed as a function of race.

5. Discussion

This study was the first to explore how the U.S. public perceives CCU processes and products in a representative survey. While opinions may evolve as this emergent technology becomes more familiar, sites are developed, and more products come on the market, this study offers an initial examination of how the U.S. public is likely to react to efforts to expand CCU initiatives in the U.S. Although there are other major factors that will determine the viability of CCU to mitigate climate change at scale such as cost-effectiveness and technical constraints (IPCC, 2023; Kätelhön et al., 2019; National Academies of Sciences, Engineering, and Medicine, 2022), public perceptions will also play a crucial role in the development and deployment of CCU: both the process of creating CCU products and the success of CCU products in the marketplace will depend on public engagement and support.

We found that the American public feels somewhat positively about CCU, with average support for CCU products and processes hovering above the midpoint of scales and with perceived benefits slightly outweighing risks (RQ1). It remains to be seen whether views will change as the public learns more details about CCU, including its relatively small climate benefits (Mac Dowell et al., 2017) or the prospects of CCU facilities and products become reality.

5.1. Perceptions differ across dimensions of the CCU process and specific domains

In addition to general views about CCU, this work offers insights into how these perceptions may differ depending on what aspects of CCU are highlighted (CCU technology overall, proposed facilities in respondents' local communities, and CCU-derived products). Specifically, respondents perceived fewer benefits and were less supportive of local CCU facilities than of the technology overall or CCU-derived products (RQ2). However, the level of perceived risk did not differ with the dimension of CCU being considered. These results suggest that differences in support for local facilities are not driven by fears that such facilities will damage the local community, as might be expected if environmental justice concerns were top of mind. Rather, people seem to believe that their local community would not be able to benefit from the addition of CCU facilities. Whatever the cause for this difference, this finding highlights the need to study perceptions about all dimensions in the CCU process so that scholars can identify sticking points where public preferences will need to be addressed.

When considering benefits and risks to specific domains, participants were particularly optimistic about the benefits of CCU for the economy, even more so than benefits to health or climate outcomes (RQ3). Yet even the effects on health leaned toward positive expectations, in contrast to work from Europe which often highlights the public's concerns about CCU and related technologies harming human health (Arning et al., 2020; Batres et al., 2021). That U.S. respondents perceive positive economic benefits suggests that CCU might earn support even among segments of the U.S. public who are skeptical about climate change and efforts to mitigate it. This mirrors work suggesting that support for CCU may outperform support for CCS in part because climate skeptics can get excited about the co-benefits of CCU even if they don't see any value in reducing greenhouse gas emissions (Whitmarsh et al., 2019). This finding also aligns with previous work suggesting that focusing on co-benefits/risks of climate change initiatives that are not directly related to addressing climate change may be particularly effective among certain segments of the population (Hart and Feldman, 2021, 2018).

5.2. Need to consider impact of gender and race/ethnicity on CCU perceptions

Beyond describing how the American public as a whole might view CCU, the current research delved into how these perceptions differ across key demographic categories (gender and race/ethnicity). This approach is unique in CCU perception research thus far. While some studies have tested gender effects in CCU support (Arning et al., 2019; Whitmarsh et al., 2019), none have examined how these demographic differences interact with other factors, nor how race influences public perceptions. It is important for future research to examine these demographic influences in part to better understand the influence they may have in different cultural contexts. For example, while race plays a large role in U.S. identities and public perceptions of a range of social issues including climate change (Pearson et al., 2018), it may not be as predictive in the European context where most previous CCU research has been conducted.

Unlike previous work (Arning et al., 2019), we found a consistent effect of gender on CCU perceptions (RQ1a). We found that men supported CCU more than women and saw more benefits (vs. risks) across all dimensions of CCU, particularly when considering local CCU facilities (RQ2a). We also found that men were more optimistic than women about the specific benefits of CCU on the economy and health outcomes (RQ3a).

The effects of race and ethnicity were more complicated. Race/ethnicity did not have main effects on CCU support (RQ1a). However, race effects emerged when considering the risks of CCU, in that White respondents anticipated less risk than Black or Hispanic (but not Asian) respondents. White and Black respondents had slightly different assessments of the comparative risk of the various aspects of CCU (RQ2a): Black participants rated local CCU facilities as riskier than CCU in general or CCU products whereas White participants rated local facilities as similar in their risk profile to CCU in general (but both riskier than products). Additionally, White participants thought that health benefits of CCU would be more pronounced than climate benefits, whereas Black participants expected the opposite (RQ3a). These findings fall in line with environmental justice research that suggests that racial minorities are more attuned to local environmental risks than White Americans due to their outsized exposures to those risks (Mohai, 2003; Whittaker et al., 2005).

5.3. The effects of environmentalist identity on CCU perceptions depend on race and ethnicity

The role of race and ethnicity became even more pronounced when considering the interplay of race and environmentalist identity on CCU perceptions. As anticipated and across all outcome measures, the higher participants were in environmentalist identity and the more comfortable they were tampering with nature, the more positive their views were about CCU. Our exploratory analyses found that these psychological traits mostly seem to affect CCU perceptions independently, with strong main effects rather than interactions between environmentalist identity and aversion to tampering with nature for most outcomes.

Aversion to tampering with nature was a strong and consistent predictor of opposition to CCU and perceptions of its risks, mirroring the relationship between this aversion and other climate and environment-related technologies such as CDR, genetically modified organisms,

pesticides, and sustainable meat (Gonzalez Coffin et al., 2024; Raimi et al., 2020b; Wolske et al., 2019). This similarity provides more evidence that researchers can draw on longstanding literatures on public perceptions of other climate-related technologies to inform and predict the public's emerging reactions to CCU. Our finding that aversion to tampering with nature did not interact with demographic categories suggests that this particular psychological trait seems to operate independently of social identity, at least in a U.S. context.

While aversion to tampering with nature mostly had main effects on outcomes, environmentalist identity interacted with race and ethnicity. Our exploratory results found a smattering of effects of race and ethnicity, most of which were only significant for one outcome. Yet a strong and consistent pattern emerged: whereas White participants (and the sample as a whole) rated CCU more positively for all outcomes as their environmentalist identity increased, perceptions of CCU among Hispanic respondents remained more neutral across the spectrum of environmentalist identity. A similar pattern emerged between Black (vs. White respondents) at different levels of environmentalist identity, although these interactions only reached significance for some outcomes.

This may be because Hispanic and Black participants at all levels of environmentalist identity saw more risks of CCU than White participants did. Thus, the enthusiasm that environmentalist Hispanic and Black participants might have otherwise felt about the environmental benefits of CCU might have been dampened by their heightened concerns about its risks in a way that White environmentalists were not attuned to. These results echo work showing that racial minorities in the U.S. have a broader conception of what counts as an environmental issue than their White counterparts (Song et al., 2020), thus suggesting that heightened environmental identity among these groups could result differential weighting of the various consequences of climate actions. While this finding is exploratory, it points to the need to look at the interplay of race and ethnicity and pro-environmental beliefs in climate-related outcomes. It is not just that groups may differ in the *degree* to which they are concerned about climate change or support various outcomes to address it, but that their attention to different tradeoffs in any climate response may lead them to support or fear different *qualities* of the solutions.

The nature of that quality does not seem to be driven by differences in fears about tampering with the natural world. Unlike environmentalist identity, aversion to tampering with did not vary in its effect on CCU perceptions across demographic categories. Future research might explore what else may be playing a role, such as differences in which aspects of environmentalist identity are most salient to different racial and ethnic groups or the types of environmental groups they may be inclined to join.

5.4. Limitations and future directions

This survey tested the American public's initial reactions to CCU, reactions that are not yet well developed given the low level of public awareness of these technologies. As this technology expands, it is likely that these initial impressions will be overridden by practical concerns such as the costs of CCU products or job opportunities in local communities. In the future, factors like education or income level may become more important predictors of CCU support, as people consider the option of the CCU industry as a career. Indeed, evidence from other new technologies (i.e., fracking) suggests that abstract attitudes like political ideology are less predictive of support or opposition in local communities due to increased focus on economic factors (Raimi et al., 2020a). The current low level of public awareness also means that how the technologies were described here (or in any test of CCU perceptions) are likely to affect beliefs about them, as people do not have existing mental models about these technologies or attitudes about them (de Best-Waldhober et al., 2009; Jones et al., 2015). Research on related technologies such as carbon removal suggests that minute changes in how these novel technologies are framed can affect public perceptions given that these are often the first time participants are reading about them (Hart et al., 2022).

6. Conclusion

As the merits of CCU in mitigating climate change continue to be debated by scientific experts, the current research demonstrates that public acceptance or rejection of this technology may add an additional layer of complication to CCU's development and deployment. The present study suggests that as discussions of CCU expand beyond elite circles to involve the general public, reactions to CCU will not be uniform. While we find that the American public feels somewhat positively about CCU, they are less enthusiastic about CCU facilities in their local community than they are about CCU as a general concept or about CCU-derived products. Lack of support for CCU facilities could translate to local resistance that limits the scalability – and thus climate mitigation potential – of different CCU pathways. We also found differences across people, with men showing more optimism about CCU than women, and more complicated differences along racial lines. The aspects of CCU that some subgroups find most promising may be less appealing to others, just as the salience of various risks may differ. While CCU may be more palatable than CCS, this research suggests that (at least in the U.S.), CCU developers may find less support for CCU when trying to build local facilities than when talking about it in the abstract or when promoting CCU-derived products. Our work also suggests that the U.S. public—or at least segments of that public including racial and ethnic minorities—may perceive environmental tradeoffs in which CCU's climate benefits may come at the costs of other environmental outcomes such as land use changes for CCU infrastructure or local air pollution caused by leaked CO_2. It is therefore crucial to include diverse stakeholder communities in any decision-making about CCU, whether about siting new industrial facilities or offering new CCU products in the market. We note that perceptions about CCU are likely to change as this technology becomes more familiar to the American (and global) public, and future research should explore how these emerging public perceptions evolve with experience and with various framings of the discussions around CCU.

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CRediT authorship contribution statement

Kaitlin T. Raimi: Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Kimberly S. Wolske:** Writing – review & editing, Writing – original draft, Methodology, Funding acquisition. **P. Sol Hart:** Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Conceptualization. **Soobin Choi:** Writing – review & editing, Writing – original draft, Visualization, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary information

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