Social Considerations and Best Practices to Apply to Engaging Publics on Ocean Alkalinity Enhancement

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Abstract

Ocean alkalinity enhancement (OAE) seeks to add alkaline material to the ocean's surface or to remove acidity from the ocean using electrochemical processes. In the wake of numerous propositions to trial, test or up-scale OAE for carbon dioxide removal (CDR), multiple social considerations have begun to be identified. To ensure that OAE research is responsible (is attentive to societal priorities) and successful (does not prematurely engender widespread social rejection), it will be critical to understand how OAE might be perceived as risky or controversial, and under what conditions it might be regarded by relevant social groups as most worthy of exploration. To facilitate the answering of these questions, this chapter: (1) characterizes what is known to date about public perceptions of OAE; (2) provides methodological suggestions on how to conduct social science research and public engagement to accompany OAE field research, and; (3) addresses how knowledge gained from social research and public engagement on OAE can be integrated into ongoing scientific, siting, and communications work.

1.0 Introduction

In the wake of numerous propositions to trial, test or operationalize ocean alkalinity enhancement (OAE) for carbon dioxide removal (CDR), multiple social considerations have also begun to be identified, if not yet examined more fully (Oschlies et al. 2023) . A long history of studying the social uptake of new technologies reveals that many never surpass the threshold of social acceptance, including technologies that members of the scientific community had regarded as safe and wise. Some also introduce concrete consequences for communities that are unanticipated or egregious and/or that deepen social inequities. The stigmatization of whole classes of technology can result from early failures with specific approaches, as has been the case for nuclear power. While initially regarded by physical and material scientists as 'too cheap an energy source to meter', first generation reactors were perceived by public groups as born of war, too difficult to manage, and likely to lead to catastrophic harm (Ramana 2011). Clean energy advocates have remained trepidatious in their support of second-generation reactors, given the near complete shutdown of this technology across four decades. This rejection has also occurred with genetically modified foods, which a vast majority of scientists believe safe for human consumption and soil health (Directorate-General for Research and Innovation (European Commission) 2010). New technologies perceived by public groups to be highly risky—even those with potentially significant benefits—may never achieve widespread use, as policy pressure to limit their dissemination are many and democracies, if imperfect, are designed to respect public will.

This chapter aims to set out key research priorities and accompanying methodological approaches to further public engagement and social science research as field-level investigations of OAE proceed. Much of what we cover might also apply to ocean-based CDR more broadly. We recognize that natural science and engineering research on OAE is in its early stages, and so accept that a large suite of social considerations in need of investigation are not yet apparent or will only become so as initial field trial results emerge. We thus mean to equip OAE researchers, developers, policy makers and funders with suggestions as to how to conduct accompanying social science research and engagement needed for robust and responsible OAE trial and deployment.

Developing approaches to OAE that are socially supported will be critical to the success of this and other mCDR options in the coming decade(s). Many tend to assume that social concerns can be addressed by providing accurate knowledge and improving literacy on the technology in question. However, accurate knowledge by itself is insufficient (although public knowledge and literacy on OAE will likely improve over time). Only in rare cases does such provision of information vanquish any social concerns. At present, some evidence suggests that OAE is perceived negatively or is less acceptable than other mCDR options (Nawaz et al 2023) While it is tempting to assume that all that is needed is to 'get the numbers right, communicate these, treat people well, and show them that it's a good deal for them and is just like comparable risks' (Fischhoff 1995)—such an approach will very likely back-fire in the case of OAE (see also Kahan et al. 2015; Pidgeon and Fischhoff 2013).

Social research and engagement on OAE needs to provide unbiased information, but is about far more than that. Instead, what is needed are open conversations where not only the 'facts' are relevant, but so too are the social logics, values, and governing conditions relevant to OAE. Importantly, such conversations with publics on OAE need to involve an "opening up" (Stirling 2008) of research to the many possible formulations that this class of technologies might take, so that social priorities can be embedded in the formulations of OAE that follow. This opening up principle is intrinsic to "responsible research and innovation", or RRI, which emphasizes the incorporation of societal values, needs, and expectations in research on emerging technologies like OAE (Burget, Bardone, and Pedaste 2017). Scholars have highlighted several dimensions to guide RRI approaches including 'anticipation', 'inclusivity', 'reflexivity' and 'responsiveness' (Owen et al. 2013). By this, we mean research on OAE must *anticipate* the potential, unforeseen consequences of OAE; it must be *inclusive* in how it assesses potential risks, benefits, and potential alternatives; it must be *reflexively* aware of the limits of understanding and that certain framings of research are not universally held; and it must be *responsive* to the views of social groups and the concerns that they raise, as well as to changing circumstances. In summary, to ensure that OAE research is ethical (is attentive to societal priorities) and successful (does not prematurely engender widespread social rejection), it will be critical to understand in what ways and how OAE might be perceived as risky or controversial, and under what conditions it might be regarded by relevant social groups as most worthy of exploration.

Three primary goals toward these ends follow:

1. We briefly characterize [section 2] what is known to date about public perceptions of OAE, and what is also known or tends to be true about perceptions of new technologies in general. This is meant as both a starting framework for future research on OAE and as a summation useful to scientists and engineers so that *a priori* assumptions about how people *should think about OAE* are grounded in this body of research. This existing knowledge will also help scientists understand their social audience and engage with publics when projects are in their early stages. The focus in this section, in particular, aims to spell out those factors known to influence public perception – knowledge key to communication and to social research that need follow.

2. Our next goal [section 3] aims to spell out the primary research methods that might be employed when conducting public engagement research linked to OAE projects at different stages and scales (e.g., early stage and highly local versus a regional or national mandate to expand OAE as a primary carbon dioxide removing technology). This includes specific approaches most widely used in the social assessment of new technologies, and it includes key principles for conducting ongoing and iterative community engagement, guidance on mapping and working with representative communities, developing baseline understandings of potentially affected communities, and ultimately, involving these groups in decision-making on OAE.

3. Our third and final goal is to address how knowledge gained from social research on OAE might be integrated into scientific, siting, and communications work on OAE – including steps that might ensure continued and quality public engagement.

Our audience across these goals are social scientists and those with whom they work who might use these approaches when conducting engagement research on OAE. By 'those with whom they work', we mean those working on or funding OAE science and engineering research. Ultimately one goal is to build literacy about social science approaches to enhance communication across interdisciplinary research teams. This will help ensure that social considerations are robustly considered in projects from the outset and that knowledge of social considerations (e.g., perceptions, impacts) is developed as part of broader OAE research.

What this guide is *not:* This is not a communication guide for promoting OAE. Social acceptance of OAE will take on a life of its own across different times and places and will be understood and received in ways that cannot be controlled. Rather it is our hope that a solid foundation in the social implications of this new class of technology will better inform its development. For this reason, there is an urgent need to incorporate a wide and diverse body of social research and social groups into the evaluation of OAE, so that its potential is explored with all of those it might affect.

A point of clarification: by engagement we mean any social science approach that explores public thinking, responses to, support or rejection of, and/or expectations as to what OAE is, what impacts it might have (positive or negative), or how OAE might better reflect or respond to social concerns. We also take the position that community engagement should be a part of all OAE and all ocean CDR projects (Nawaz et al. 2023). In this sense, social research and engagement are synonymous terms. By methods for social research, we mean specific approaches to the collection of 'data', its analysis, or its interpretation wherein the goal is to understand and address how people think about OAE.

2. Tracking what might influence public perception of OAE

Here we present several factors that already appear or will likely become relevant to public perception of OAE and mCDR based on the limited literature on the topic. We also draw upon insights from broader literature on perceptions of novel technologies and climate mitigation approaches, proximate studies of marine-relevant approaches, and we assume that terrestrial CDR is also instructive to the extent that it shares some features (e.g., crushed mineral material). Thus, specific OAE approaches are ideal, but as these are limited, we also address proximate work on public thinking about any materials added to terrestrial or ocean systems. For example, be that fertilization approaches (adding material to encourage phytoplankton growth so that such growth might capture atmospheric carbon) or enhanced rock weathering (adding crushed silicates to agricultural lands to capture carbon).

Early work on OAE and related technologies draws eight initial propositions regarding perceptions of field-level trials:

(1) Overall, OAE and its nearest equivalents are seen as relatively less acceptable, more likely to invoke affectively negative feelings or to be viewed as relatively more or most risky when compared to other carbon removal strategies (Cox, Spence, and Pidgeon 2020; Jobin and Siegrist 2020; Bertram and Merk 2020; Shrum et al. 2020; Spence, Cox, and Pidgeon 2021).

(2) Concerns about environmental impacts and perceptions of the vulnerability of ocean and marine systems may be determinative of rejection of OAE and its equivalents (Cox, Spence, and Pidgeon 2020; Nawaz, Peterson St-Laurent, and Satterfield 2023).

(3) Interventions perceived as involving dispersal of materials are less desirable than those involving controlled storage (e.g., burial on land or beneath the seabed) (Cooley et al. 2023).

(4) Source materials involving heavy reliance on mining are less likely to be supported (Moosdorf, Renforth, and Hartmann 2014; Spence, Cox, and Pidgeon 2021).

(5) Associations of OAE with analogies of waste dispersal or the ocean as 'landfill' will likely be aligned with rejection or deep discomfort (Cox, Spence, and Pidgeon 2020; Veland and Merk 2021).

(6) The energy burden of technologies and the status of energy transition activities will likely affect acceptability (Andersen et al. 2022).

(7) The justness of the conditions of research and practice will be key and involve at the very least concerns about monitoring (e.g., is there good citizen oversight?) and responsibility of innovators and investors (e.g., is transparency of storage duration clear? Is there a polluter pay model in place (Ingelson, Kleffner, and Nielson 2010).

(8) The political and value considerations held by the publics involved will also likely matter (Satterfield, Nawaz, and St-Laurent 2023; Shrum et al. 2020).

Below, we discuss these propositions in reference to the three ways in which people's thinking about new technologies tends to unfold. First, judgements about new technologies tend to be linked to or sensitive to the attributes of the technology itself (the features it has and the affective signals associated with those features). Second, judgments tend also to be a function of the attributes of those perceiving the technology (their values, social position or ethical evaluations). Third, views about how the technology is or might be managed or governed are also determinative of judgements (e.g., what policies exist, the quality of research and monitoring, the existence of community involvement and oversight, etc.). As we review these in further detail, we discuss how each has or might be used to research OAE's perceived acceptability, riskiness, or social viability.

2.1 Attributes of the technology as predictive of rejection/acceptance

Ultimately, most people evaluate risks as a function of many things, including the attributes or intuitive qualities they assign to or perceive to be characteristic of the technology itself. This is as against or a counter-intuitive claim for many natural and physical scientists or formal risk assessors, who might instead define risk as severity [times] magnitude or mortality and morbidity (Siegrist and Árvai 2020) Factors that drive perception have been long identified across a diverse range of technologies, including feelings of dread that people may feel about a technology or exposure to it; the degree of control people feel they have over the risk it might pose; the extent to which their exposure is voluntary or not; the perceived severity of its consequences; and one's familiarity with the technology itself (Fischhoff et al. 1978; The Perception of Risk 2000; Cox et al. 2021a). Many such factors have been tested and isolated in prior studies, but perceptions of control will likely be key. This is due to the possibility that people may view the introduction of materials to the ocean as something that cannot be controlled once released, or because enhancement might be deemed an irreversible act. Interventions perceived as involving broadcast dispersal of materials are less desirable than those involving controlled storage (e.g., burial on land or beneath the seabed)(Cooley et al. 2023). In the case of fracking, by way of example, perceived benefits of shale gas extraction were offset by the perception that irreversible risks to water systems accompanied this practice and amplified perceived risks overall (Thomas et al. 2017). Genetic engineering has been rejected widely for similar reasons due to the belief that the risks to human or agricultural systems are both catastrophic and irreversible (Sunstein 2005).

Perceptions that scientists might be unable to contain or control many ocean-based interventions tends to accompany the belief that the consequences of interventions will be negative for marine ecosystems and livelihoods, and may also indicate that such approaches will be perceived as highly risky or highly unacceptable. One early UK study found, for example, that support for ocean liming and ocean iron fertilization was lower than support for solar radiation management or solar geoengineering as it has come to be known, because of concerns about the unpredictability and uncontrollability of the ocean environment (Cox et al. 2021a). Previous work also suggests that outdoor experimentation carried out at a small-scale and under well-controlled conditions is likely to be generally acceptable to affected publics (Cummings, Lin, and Trump 2017). However, publics may also be skeptical of scientists' abilities to carry out controlled and accurate research in atmospheric contexts (e.g., Merk et al. 2015) or in the marine environment, given that it is such an open, interconnected system (Pidgeon et al. 2013; Bertram and Merk 2020).

Public perceptions are commonly assumed to be shaped as well by the extent to which OAE approaches are viewed as 'natural' or not (Bertram and Merk 2020). Those interventions perceived as "tampering with nature" (Corner et al. 2013; Wolske et al. 2019) or characterized as (un)natural are more likely to be rejected. However, the emerging habit of labelling interventions as 'natural' is now so pervasive to have led to an over-use of claims of 'nature-based' solutions, which may introduce a backlash effect longer term (Seddon et al. 2020;

Bellamy 2022). Specifically, people may consider promises of OAE as mimicking natural geochemical weathering reactions to be equivalent to a falsehood deserving of distrust. Distrust of natural claims may also occur when the scale of, for example, macro-algae CDR aims to remove a megaton of carbon dioxide rendering the use of infrastructure, ships and storage highly industrialized and so suspect (Osaka, Bellamy, and Castree 2021).

The ’signals’ that are perceptually linked to particular aspects of OAE will also be a function of the analogies people draw upon as they make sense of these. That is, people make sense of new and novel technologies by drawing upon old ones (Pidgeon et al. 2012; Visschers et al. 2007). For example, amongst groups in the UK, carbon removal has been found to invoke associations with fracking and shale gas (Cox et al. 2021b). It is likely that OAE will invoke its own set of accompanying associations, but one possibility is that materials discharged into the ocean will be perceived as waste products or waste disposal. As Merk et al (2022) found, in the context of CCS, CO2 is often perceived as waste even though it is not toxic, radioactive, or explosive.

Lastly, the source of materials used for alkalinity enhancement, rock weathering, or other material-intensive processes may also become a key attribute in the evaluation of this and related CDR technologies. For example, the mining needed to procure materials and the energy costs involved with their sourcing, grinding and distribution may reduce potential support for this form of CO2 removal, all the more so if their environmental or social consequences are deemed high (Moosdorf, Renforth, and Hartmann 2014).

Key message: The technology’s specific attributes will have a powerful influence on the acceptability of OAE overall and under no circumstances should any approach be considered ‘neutral’ at the outset. Rather, publics will engage in proposed OAE trials and operation in reference to (a) signals they will *read into* the technology, with (b) some attributes of the technology likely to be perceived as relatively more worrisome including non-site attributes such as the source of materials used in operation, and the perceived ‘broadcast’ or ‘waste-like’ assumptions about material distribution in marine systems.

2.2 Attributes of the perceiver -- beliefs about ocean systems, values and worldviews

2.2.1 Beliefs about oceans and marine environment

In need of continued evaluation are also the ethical and value positions that people hold regarding OAE. These include worldviews about what kind of system the ocean is or what kind of political orientations people carry as both are likely influential regarding how OAE will be received or supported. For example, previous research has found that the ocean is often perceived as fragile and pristine (Hawkins et al. 2016; Cox et al. 2021b), and finds that interfering with the ocean might be seen as ‘hubristically’ transgressing the human ability to understand and control complex ecosystems (Macnaghten, Davies, and Kearnes 2019; Wibeck et al. 2017; Gannon and Hulme 2018). Research in Scotland and Norway has previously shown that publics believe even changes in the open ocean or the deep sea would affect them and that they were not confident in the abilities of experts to protect the marine environment (Ankamah-Yeboah et al. 2020). The concern people express about the ocean is commonly linked to a positive emotional connection with it (McMahan and Estes 2015). Importantly, previous public perception research on a wider range of marine and terrestrial CDR approaches suggests that emotional connection to the ocean manifests similarly in coastal and inland populations (Cox, Spence, and Pidgeon 2020; Cox et al. 2021b). Coastal First Nation populations in British Columbia have also protested strongly against fertilization experiments, which were viewed as insufficiently supported by science and dismissive of legal agreements (Tollefson 2012; Buck 2018).

Such views will likely vary with context of a particular OAE project or be borne of contextually-specific local meanings (Mabon and Shackley 2015; Gannon and Hulme 2018), and cultural connections to the marine environment – for example, the extent to which the ocean is perceived as an important food or resource provider (Potts et al. 2016). Perceptions may also differ between Global North and South and Indigenous and non-Indigenous groups (Pidgeon et al. 2013; Carr and Yung 2018; Whyte 2018) – there has so far been very little research on the perceptions of publics outside North America and Europe including Indigenous communities within these nations and across the global south. Views about ocean systems will also articulate with the specific sites of dispersal selected, be that near adjacent coastal populations or in the distant ocean; be viewed as despoiling of natural beauty or using a site of a previous industrial activity. Ultimately, views of marine environments are unique and varied and that variation might include those who view ocean systems as adaptable. Such views tend to be associated with the judgement that alkalinity enhancement and ocean fertilization are comfortable or viable options. Whereas notions of the marine system as fragile correspond to discomfort with both these CDR approaches (Nawaz, Peterson St-Laurent, and Satterfield 2023).

2.2.2 Beliefs about the problem of climate change:

Public perceptions of CDR research have tended to assume that climate beliefs can shed light on views about and/or the acceptability of OAE and other CDR. But new research suggests that views on climate urgency might be as or more predictive(Cox, Spence, and Pidgeon 2020; Nawaz, Peterson St-Laurent, and Satterfield 2023). It is possible that people who find climate change an urgent problem are more inclined to be interested in novel and potentially controversial options in general, or because they have lost hope as to energy transitions or in other approaches to capture and store CO2. It's also possible, however, that people who find climate change to be urgent find new CDR methods to be insufficient, slow, or failing to address structural or root causes of climate change itself (Lamb et al. 2020). Similarly, claims of urgency can be perceived as suspicious justification for poor public consultation or scientific practice.

2.2.3 Ethical positions

Ethically central across several studies is the problem of moral hazard. This refers to people who perceive CDR including OAE to exacerbate ongoing emissions. The logic is that the ongoing failure to decarbonize energy and food systems will only continue if methods to remove greenhouse gases are introduced, that is, CDR is seen as deterring mitigation in the first place

(Cox et al. 2018; Markusson, McLaren, and Tyfield 2018; Carton et al. 2023). At the centre of this debate are those who regard net-zero as a temporary phase on the path away from fossil fuels, versus those who view net-zero as a means to ongoing fossil fuel extraction (Buck 2020). This tension is likely key to public groups' views on any OAE research and deployment, with those who see OAE as enabling continued emissions as most likely to reject its research and development. Also important here is what sorts of emissions are perceived as being 'allowed' to be 'counterbalanced' through CDR (Lund et al. 2023; Buck et al. 2023). What emissions are seen as 'legitimately' hard-to-abate/residual? How are public(s) involved in defining this? Ethical concern for and obligation toward future generations is another morally charged position aligned with discussions of CDR options and with the growth of anti-fossil fuel norms more broadly (Green 2018). As with moral hazard concerns, two social trajectories are possible: an unwarranted reliance on CDR in the absence of significant emissions reduction thereby placing future generations in peril (Dooley et al. 2021). Or, the assumption that rapid decarbonizing will occur putting generations at risk should modelled projections fail to anticipate that future accurately (Morrow et al. 2020).

2.2.4 Political worldviews

Views on the 'truth' of climate change itself, and the policies adopted to address it, have long been politically polarized (Strefler et al. 2018; Campbell and Kay 2014), and public acceptability of climate policy has been shown to be linked to broader political alliances and cleavages. It is thus reasonable to assume that aspects of this polarization will migrate to carbon dioxide removal. Thus far, it appears that political positions (e.g., those representing left-to-right or egalitarian to hierarchical political world views) are influential but not absolute. For example, following tutorials on CDR options, some then regarded the threat of climate change as less severe, which also reduced perceived need of mitigation policies. The effect was relatively more pronounced among political conservatives (Campbell-Arvai et al. 2017). Ultimately, conversations across publics need remain open and heterogenous, not polarized, to enable consideration of options. As well, those who do attend to and/or recognize a broad set of perceived benefits for some ocean CDR options appear to hold that position and remain more steadfast as concerns acceptability in general and [largely] independent of political position (Satterfield, Nawaz, and St-Laurent 2023).

Key message – If people view marine systems as fragile, regard mitigating actions as morally compromising to GHG emissions and energy transitions, or adhere to politically polarized positions, they may be less likely to find OAE acceptable. Viewing climate change as an urgent problem could have mixed influences, leading to impatience or suspicion about technologies in early development phases.

2.3 Attributes of risk management and governance

Key to all efforts to address the social viability of OAE, indeed all CDR, is how that technology is or will be managed and the quality of consultative public engagement. This includes attention to environmental justice and the quality of public trust in those managing the technology -- its risks and benefits across all phases, and locations of the work. Trust itself is sensitive and easy to destroy by early missteps. Similarly, distributional justice will be of primary concern for most people and so clear articulation of the choice of sites for trial and consultation in advance is of primary concern (McCauley et al. 2019).

2.3.1 Governance

Governance is an all-encompassing term, but across contexts such as this, citizens are most likely concerned with the following operating principles, many of which are out of purview for scientists and engineers and so preparation in advance of any form of public engagement is advised. Governance questions most likely to be central involve (a) how the project will be studied and monitored such as: Are local actors/citizens involved in monitoring and oversight (e.g., citizen science approaches) and (b) how will their concerns be addressed by the policy and scientific community? What are the conditions under which operation or trial might cease and who controls that decision? What is the distribution of risks and benefits overall and in reference to specific impacted or vulnerable communities? How eventual projects will be financed is also out of purview for most OAE scientists and engineers, however it is wise to anticipate the following questions: What are the likely mechanisms for financing OAE, be that a carbon pricing or similar market mechanism, green bonds and/or impact investing, or 'polluter pay' models? (Rickels et al. 2021; Bellamy et al. 2021). More broadly, it is common to be asked how global responsibility will be addressed (Mohan et al. 2021; Bellamy et al. 2021; Morrow et al. 2020). For example, will responsibility for using such technologies be a function of carbon footprints per capita, in reference to lesser histories of emissions or developing country needs, or will cost recovery primarily involve financial incentives for original polluters? Will a public agency or utility operator oversee operations or a trusted but independent entity? Lastly, should an OAE project fail or move into closure, is a social assurance or bond for clean up or removal of the facility itself in place?

2.3.2 *Environmental Justice*

Environmental justice is itself key to governance, including distributive justice (who suffers the impacts of development versus any gains), procedural justice (how decisions are made and whether they receive robust consideration of those most impacted) as well as recognition and reparative justice (recognizing and addressing past harms rather than assuming a neutral or benign present) (Batchelor n.d.; Whyte 2011). In sum, focused consideration must be given to communities, especially vulnerable ones in the global north and south) that might be relatively more affected by OAE trial and operation, including specific delineation of impacts to human health, livelihoods, local biodiversity, and other potential effects. This is often addressed in reference, equally, to potential co-benefits of OAE including whether these differ across contexts or communities. To understand how OAE will impact people, it will be essential to consider specific configurations of projects and specific research or deployment contexts. As such, a more fulsome understanding of the potential consequences (both positive and negative) of OAE will only be understood by engaging with local communities alongside any experimental research on or deployment of OAE. Any possibility that OAE might also produce new inequities should be considered. Central to these questions are First Nation and Tribal communities across settler nations, and Inuit and Sami communities in the circumpolar north.

In both cases, energy development has already dramatically affected many communities in general and in such a way as to transgress rights and jurisdictional authority. The idea that such technologies can be 'sold' as green development has largely resulted in significant loss of trust (Mohan et al. 2021) and has neglected the extent to which communities have a long history of living with the effects of engineered nature (Whyte 2018). Nesting any CDR option in reference to a community's larger goals is also key – be those economic development, educational opportunities for youth, or pursuit of land claims with nation states. See Salomon et al. (2023), for example, for wider governing principles with regard to Indigenous communities and emerging science.

2.3.3 Trust

Ultimately all research concerning the influence of trust indicates that governance efforts should aim to maintain and enhance civic trust, and recognize – equally – that trust is extremely easy to lose across early mis-steps, and very difficult to [re-] gain. This is known as the trust asymmetry principle across the risk and behavioural sciences literature (Slovic 1993; Poortinga and Pidgeon 2004) and is perhaps the most studied concept when seeking to understand public rejection or acceptance of new technologies (Cummings, Lin, and Trump 2017; Siegrist 2021) including those aimed at climate mitigation (Boyd, Hmielowski, and David 2017). When risk management is badly handled (e.g., unfounded claims of no risk followed by a hazardous event) or responsibility for a failure is side-stepped by public agencies and industry, such actions tend to be received by citizens as a failure of transparency that is difficult to repair and an indicator of future behaviour.

Key message – how OAE or any carbon removal system is governed should be of primary concern. This should address the justness of risks and benefits, particularly when vulnerable communities are involved. Failure to gain or maintain public trust will be central, as is transparency about how the system will be managed and financed, and how impacts are reported and addressed.

3.0 Beyond known factors: Methods moving forward

Having established a minimum set of factors likely embedded in public thinking about the risks or acceptability of OAE, our next goal is to suggest methods for engaging affected and interested groups in OAE. We strongly recommend that a consultation and engagement plan be developed at the outset of any research effort on OAE (whether place-based or not) and throughout its different stages of development. The methods that follow are thus aimed at identifying social concerns or conditions for acceptance across different phases of OAE research and development, and across different geographical scales as the scope and range of social constituents for ocean CDR vary. As with the above set of factors [section 2], the methods covered are not exhaustive, but they are those most commonly employed. For clarification we use the language of understanding public views, which is our umbrella term for both (a) the reasons that OAE may be deemed acceptable or not, and (b) the impacts that social and/or expert groups co-identify as driving their support or rejection, or necessitating attention or additional research. As well, all methods should involve: extensive preparatory work which we briefly characterize below, and a clear plan on how this research might be iteratively used to inform, modify, or articulate science and engineering practices.

3.1 Doing your homework before sited-based engagement activities or selecting pilot sites

Before any research activities, it is important to establish a baseline understanding of who the potentially affected community might be. This theoretically should begin with first mapping the areas that the project affects—critically, this must go beyond just the physical footprint of the project, to also include all the additional land, inputs, and infrastructure that the project uses. In the context of OAE, this affected area is not straightforward as injections of alkalinity into marine spaces travel in fugitive ways, likely proving difficult to 'map' or monitor. At the very least, a cursory evaluation of this history of and social considerations in place before committing significant resources to a trial is wise. Because of this ambiguity, it is ideal of course to anticipate the full scope of activities in an area, including future activities and/or sites.

Social characterization analysis of this kind facilitates an understanding of how local political processes and dynamics work, in addition to broader contextual factors. Relevant factors include the following considerations in particular: **Social:** What are the demographics in the area, what kind of history exists between community developers and regulators, what is current status of education, health and living standards? Are there particular historic factors of note? (NETL 2017, WRI 2010). Key questions are: what vulnerable groups are in the area (e.g., who might be affected by an installation but outside decision authority)? Are areas heavily industrialized and so the burden of development projects is already high? Who is most likely to experience significant impacts associated with otherwise quite small changes? **Political:** what kind of local political situation is present, what kind of local and international lobbying/advocacy groups exist? **Economic:** what are major employment sectors, what are economic trends in the region regarding job growth, unemployment, cost of inputs, etc.? **Environmental:** what kind of legacy of environmental damage or intervention exists?

Other factors will also be not only relevant but also helpful in selecting pilot sites. It can be assumed that scientists and engineers will have reasons for designating some sites for mesocosm and field trials as 'ideal'. These might include seeking coastal areas with shallow seabed or turbulent waters to ensure admixture of materials and their locations in the water column are optimal. The same is true when considering the social viability of sites for OAE research and deployment. Ideal sites might include those where: **jurisdiction, decision-making authority, and regulatory context is clear.** These include sites where who has jurisdiction as to coastal and ocean space is clear and legal approval to operate has been sought or granted. Sites are less optimal when there is overlapping or competing jurisdiction or if jurisdictional authority is vague, or where regulatory/legal context is unclear (e.g., poor designation of activities allowed, of permitting needed) (Webb, Silverman-Roati, and Gerrard 2021; Hoberg 2013). Similarly, sites where: **trust in local governance and climate action is comparatively sound are optimal (**see 2.33 above**)**. By this we mean sites where the governing body's record to date on energy transitions, civic engagement or meeting climate targets is clear and supported; where clear rules are in place for suspending trial and operation are agreed upon; and where operators will abide by normal regulatory practices and are not exempt from these when scaling up operations.

3.2 **Methodological preparation for all forms of engagement**

All methods for engagement require development in reference to information that might be necessary or useful and the tailoring of research to upstream (early-stage development) contexts. For example, as part of specific designs, mini tutorials might be employed or even staged in additive steps but the explanations are comparatively minimal and definitional (see section 3.2.5). Conversely, the deliberative and small group work described below might include extensive advance research on how to provide informational material, when and in what form. Lastly, decision-centric designs that seek to integrate public and expert knowledge might require developing knowledge once known social, environmental or other impact can be classified or measured. At minimum, all engagement designs will benefit from the following key considerations.

Tailor methods to the early-stage nature of research on this topic. Given the aforementioned upstream context of research, accept that public concerns and thinking are less formed. This means both (1) ensuring adequate time for participants to learn about OAE within engagement activities, and (2) following Stirling (2008) ensuring that engagement efforts remain open-ended regarding the full possible suite of technological configurations and approaches that could arise. This might involve clarifying different possibilities regarding what an ‘end-stage’ technology might look like and how it might vary from original proof of concept.

Outline potential impacts and uncertainties. Any engagement activity with local groups will inevitably generate many questions around the likely environmental and socio-economic impacts (both positive and negative) of the activities proposed. These impacts should be raised pro-actively and areas of uncertainty should be acknowledged. For OAE, these might include, for example, biodiversity-related, fisheries-related, human health-related, visual/aesthetic, marine traffic or navigational effects, among other impacts.

Be transparent about the full potential scale of OAE deployment. Ideally, engagement activities should provide participants with what OAE might look like at scale–not just with regard to an individual project’s small field trial. While it may be tempting to only engage people on their views regarding very small-scale activities, it will be critical—for both ethical and pragmatic reasons—to explore views on larger scale implementations. It is well known that understanding large scale events such as humanitarian disasters is difficult if not beyond comprehension (Slovic 2007). But this does not preclude the potential usefulness of comparing OAE at the 2 MT scale as compared to the production and storage (sinking) of macroalgae or the use of offshore direct air capture and storage at similar scales. This would likely throw both social preferences and likely tradeoffs into relief by introducing considerations such as shipping (to gather, bundle and sink macro algae), or drilling (to store CO2 in offshore basalts).

Characterize the full supply chain of OAE activities. Similarly, while it might appear at first glance that engagement only need explore views on direct interventions to marine biogeochemistry, OAE will involve a range of other activities that need to be brought into engagement efforts. This would include both the sourcing and processing of material inputs (e.g., mining of materials), as well as the management and end-use of waste outputs.

Recognize and address the challenge of tutorials and communication more broadly. Communication around novel technologies and their potential risks and benefits is likely not an intuitive process for many non-social scientists (and indeed many social scientists). Developing and pre-testing materials—whether tutorials or preparations for Q&As, or other—needs to consider risk communication research (Balog-Way et al. 2020). For example, numbers need to be provided in context so that people can understand them by way of equivalents, such as carbon dioxide removal anchored to the number of cars removed from the roadway. Similarly, different frames can be used to present a topic, and care is needed to avoid frames that might have undue influence on views (e.g., using naturalistic framings as referenced above). Communications need to be pre-tested to ensure that complex concepts involved in OAE are made accessible to a broad base of groups with variable levels of education and existing understanding. Visual aids, relatable analogies, graphic representations, and other approaches will be of use. Where possible, introduction of OAE could include lab visits, site visits, tours (WRI 2010) or other mechanisms to help people understand the kinds of activities that might be involved. Two-way communication is foundationally important (Abelson et al. 2003; see also Puustinen, Raisio, and Valtonen 2020).

Make sure your narratives of purpose and outcome are clear. Is it clear that the research goal is one of trial only, and/or are operational goals also clear and transparent? It is useful to provide information of proposed research in advance. And, we find, claims of hyper-urgency or naturalness can be read as excuses to avoid regulation or downplay ecosystem or social risks (Osaka, Bellamy, and Castree 2021). Oppositional actors should be identified and approached so as to research and include their concerns – they will not be speaking for themselves alone (Low, Baum, and Sovacool 2022).

Clarify the relationship of OAE removals to emissions. With estimates of the potential scale of necessary carbon removal differing widely across approaches, it remains important to clarify and develop greater transparency around what kind of emissions OAE exists to remove and at what scale (e.g., Gt, Mt, etc.). Emphasizing the connection to hard-to-abate emissions—rather than the enabling of business-as-usual for fossil extraction—must be clear. Ideally, the temporal horizon for OAE will also be known by those proposing research as compared to other CDR options.

Plan to discuss failure, success, and next steps. Engagement should plan to discuss how the researchers will deem a trial sufficient to proceed to next steps—and under what circumstances it would be deemed not fit for next stages of research.

3.3 Five Engagement Methods in Brief

Accepting that preparatory work noted above is complete, many engagement methods become possible. Below we address six methods commonly used where each is meant to be illustrative only and each is somewhat aligned to the stage and purpose of OAE scientific work. These are listed below and then elaborated more fully in the sections that follow. Table 1, below, also locates all methods in reference to their stage of application and purpose.

Early stage (alongside mesocosm experiments or early field trials):

1. **World café deliberative approaches**: Particularly useful for providing initial insight, scoping of questions people have, fit with local priorities, discourses used by different engaged groups.
2. **Participatory foresight:** Particularly useful for understanding current and envisaged governance landscapes, including who is speaking for which communities and what their primary priorities and positions are.
3. **Indigenous methods and protocols:** Essential to understanding the research process itself as requiring recognition of histories, engagement protocols, and situating all work in reference to community priorities, knowledge protocols and relations.

Mid-Stage (Scaling up to fuller pilot studies, site selection criteria or choices across options):

4. **Survey research:** Appropriate to broad scale consideration of prevailing positions and the factors that explain these across larger areas or populations and/or in reference to magnitude of specific pro or con positions.
5. **Decision-specific public engagement**: Particularly useful for integrating measures that reflect value concerns held by publics or impacts designated by experts. These can then be tracked as 'performance measures' that inform tradeoffs or become the basis for: developing alternatives to a proposed approach; or designing monitoring conditions for a trial.

Late-stage (seeking large population public views regarding involvement of OAE or similar as a significant part of national policies to meet climate goals):

6. **Deliberative polling** – seeks to gauge support reflecting regional and population calibrated positions: pro or con. This also includes civic engagement of concerns and consideration in between polls to reflect conversations active in media, popular blogging or similar civic contexts.

3.4 The Deliberative Turn: In recent years, social science scholarship on public thinking about new technologies has undergone what is referred to as the 'deliberative' turn, which emphasizes the need for social research into public thinking throughout the period of a technology's development. Deliberative work can be most useful in the early-to-mid stages of development. Typically, small group designs involve 10-15 carefully selected participants to reflect as fully as possible the full diversity of a region (e.g., from urban to rural or to specifically address Indigenous or resource-dependent communities). Each workshop generally lasts a minimum of one day but often runs over 2 or 3 days or more where needed.

Deliberative methods emphasize communicative competence, mutual and high-quality conversation, and respect for difference across interpretive communities (Parkins and Mitchell 2005). Motivated by political science theories of deliberative democracy – and greater public participation in policy decision making (Dryzek 2002; Fishkin 1991) – newer research is expressly focused on 'upstream' contexts. By this we mean participatory and anticipatory (i.e., early) public engagement where policy development recognizes that scientific knowledge is but one of several ways through which people engage with their environments, in this case ocean-based contexts. Such methods accept that public thinking is value-based, and that environments are understood through interpretive logics that are also perceptual, cultural, ethical, and relational (Eden 1996; Borth and Nicholson 2021).

When technologies are new and novel, as is the case for all forms of CDR, designs that 'open up' conversation are a priority (Stirling 2008), where such opening refers to research practices that expand the diversity of perspectives included and the creativity and ingenuity by which bidirectional exchange and learning occurs. Quality of research is regarded as 'high' when diversity of stakeholders is evident (especially locally interested parties, and under-served or vulnerable communities, but not developers per se), many media are used for articulating ideas (e.g., written, verbal, visual), and when accessibility and non-coercive qualities in informational materials is ensured. Sessions are typically recorded for use in thematic data analysis once workshops are complete. Results might include summative pro or con positions on a new technology, but more typically they involve a characterization of: the research questions or addressing of unknowns that people most seek; the conditions under which proceeding might be deemed most viable (e.g., use of citizen oversight, or concurrent gains across renewable deployment); and elaborated details as to the social logics used to comprehend OAE research (as necessary, urgent, unwise, etc.). The spectrum of methods is itself spread across a continuum of those more highly analytic and decision centric through to those more deliberative, though attention to both is crucial (Renn 1999; Renn 2004; Renn 2015).

Inclusive participant sampling considerations are key to the success of all deliberative methods. Key selection criteria are diversity in terms of age, gender, ethnicity and race, educational and occupational background, as well as in terms of stance on OAE research (pro, con, ambivalent). The inclusion of dissenting or opposing voices is expressly necessary to enable inclusive deliberative engagement. It is also necessary to make engagement events and processes accessible to groups that otherwise might be excluded. Some ways of doing this include; selecting venues that are easily accessed by public transport; publicizing planned activities in advance and across multiple outlets; offering engagement events at multiple, asynchronous, convenient times; and offering events in languages other than the lingua franca, where relevant; offering to provide free childcare for event participants; considering compensating participants for their time; and including virtual engagement options (NREL 2022, NTEL 2017).

3.5.1 Engagement Approach 1: World Café and Mini-Public Approaches (early stage and possibly throughout):

The World Café method is a participatory process that aims to facilitate meaningful and inclusive discussions among large groups of people (Brown 2010; Pidgeon et al. 2009; see Pidgeon 2021 for a CDR example). It is commonly used to explore complex issues, generate new ideas and foster collective wisdom. The purposes of a World Café are to promote collaborative dialogue, tap into collective intelligence, foster innovation and creativity, and encourage action planning (Löhr, Weinhardt, and Sieber 2020). More generally, the method provides a platform for open and inclusive conversations where diverse perspectives on an issue can be shared and explored. The key strengths of the World Café are its inclusivity, creativity, scalability, and flexibility. It is designed to include diverse perspectives, leading to a sense of issue ownership from participants, and provides interactive space for scoping a broad range of perspectives about an issue. It's success also lies in its usefulness across academic and practitioner need for rapid but also systematic insight (Schiele et al. 2022)

The structure of a World Café typically involves participants being seated at small tables with designated hosts to facilitate the conversation. The process begins with a brief introduction and a "big" question or theme, which attendees are asked to discuss. Each table can focus on a specific sub-question or topic related to the theme. Participants engage in several rounds of conversation, with each round lasting 20-30 minutes, while hosts stay at their tables to ensure continuity. Materials such as paper tablecloths, large poster templates, sticky notes and markers are provided to help the participants at each table creatively document conversations. After each round, participants move to different tables, cross-pollinating ideas and building on previous discussions, with key insights and ideas captured and documented. The conversation is often followed by a plenary session where participants collectively reflect on patterns, themes, and insights that emerged, and identify potential actions and strategies based on the collective wisdom generated during the conversation. Brief surveys assessing views of one or more technologies can be included when multiple cafes (and mini-publics) across a region are expected.
Sampling considerations in all designs emphasize diversity of participants. In early stages breadth of participants is key, in later-stage research the focus is likely locally-affected communities and so more localized representation. It is assumed that different knowledge systems and reasonings will be in place and that the boundaries between these can be difficult to overcome, however collaborative.

3.5.2 Engagement Approach 2: Participatory foresight workshops (early stage):

Participatory foresight workshops (with stakeholders from industry, civil society, local communities, local and regional administration etc.) can be used to scope a wide range of plausible future threats and opportunities which could be presented by OAE in a given settings (Elsawah et al. 2020). They can also be used identify governance frameworks/instruments that would be robust across plausible OAE futures (e.g., they have been used to explore the potentials of global SRM governance and mCDR policy frameworks).

The structure of a participatory foresight workshop generally involves; **(1)** scanning, in which participants are asked to identify a broad range of political, economic, social, technological, environmental, and other factors that could shape OAE development within a given setting and a given timeframe; **(2)** a deliberate group process to reduce this collection of factors down to several that the group considers key to the future of OAE; **(3)** joint imagining of different ways these factors may develop in the future; **(4)** a deliberative process to map how these factors may interact in the future; **(5)** the creation of narrative descriptions (in the form of short texts) by smaller groups of participants which detail their joint vision of a specific future, and which include several of the factor projections from the list previously developed; **(6)** a group back-casting exercise to create a timeline of the key technological, economic, political and social changes that would have to happen between today and each imagined future.

Participatory foresight processes are designed to draw upon the various knowledge types, perspectives, assumptions, expectations, and worldviews of those involved (Pereira et al. 2023; Rutting et al. 2023). The outputs can thus only be as diverse as the range of voices in the room. Having a well-considered participant selection strategy is key. Including the widest possible range of affected stakeholder voices will result in more inclusive future thinking and learning. When a broad range of voices are included, the foresight method is effective for facilitating trans- and interdisciplinary communication and learning about future (OAE) challenges and solutions. It can be useful as an early stage ‘anticipatory assessment’ tool for **scoping the societal and political feasibility and desirability** of OAE in a given context, with a specific set of stakeholders. It can help to widen **understanding of feasible and desirable OAE developments** based on the interactions between a broad range of political, economic, technological, and social risks and benefits. Such participatory foresight approaches can also be used to identify ways that OAE (and other CDR approaches) may be **integrated into existing governance landscapes**. These insights will always be context dependent, but generalizable lessons may be learned from drawing on comparative case studies.

As public license is ultimately key to the development of OAE, using designs of this kind can help develop OAE specific policies and build trust across differing publics. In such cases, the goal is to co-produce, quite literally collectively draft, regulatory frameworks involving publics and administrative representatives. Success has been mostly widely demonstrated in urban design or the creation of ‘smart cities’ (Marsal-Llacuna and Segal 2017), as well as contexts such as wind farm operation and siting. Both qualitative and quantitative methods are used to evaluate and refine decision making, policies, and regulatory commitments (Simao, Densham, and Haklay 2009; Jami and Walsh 2017).

3.5.3 Engagement Approach 3: Indigenous Methods and Protocols (early stage and throughout):

Over the last decade, the emergence of Indigenous scholarship and fundamental methodological insights have transformed the practices of social scientists, inspiring critiques of the research enterprise as colonial and extractive. The former refers to the many ways that knowledge derived from "Western" canons has developed to justify dispossession of lands (Dell and Olken 2020), assert claims of racial and social inferiority, and maintain apartheid-equivalent governing practices (Wolfe 2006). The latter refers to research deemed as solely benefiting the researcher in reference to both the knowledge acquired, the benefits that follow (to the researcher and not the community) and the purpose to which it is used. Decolonizing these practices includes all methods to a large extent, but is particularly crucial to approaches involving Indigenous community engagement. Indeed, all engagements with Indigenous groups that consider siting projects on or near their territorial lands and water require methodological reflection. There is a diversity of capacity and political positions within and across all communities, but three priorities for research design are fundamental:

Firstly, recognition that the history of colonization is de facto, a history of profound re-engineering of Indigenous territories through mineral, oil and gas extraction, large scale logging operations, agricultural transformations and over-fishing. More often than not these activities have been justified by states as necessary for *progress* or as solutions for environmental, economic and social prosperity (Whyte 2018). The misrecognition of this history is, for example, central to a failed ocean fertilization trial, ethically (and problematically) justified as beneficial to phytoplankton growth and so to migrating salmon in waters offshore where the experiment took place (Buck 2018; Buck 2019). Justifications of pejorative, anthropogenic change also fall short in Indigenous contexts where there exists a long history of positive shaping of ecosystems, terrestrial and estuarine foods, fire regimes, etc. (Whyte 2018; Buck 2015).

A second priority is to design research in a fundamentally collaborative manner by which we mean: (a) develop research questions such that they are co-created, offering robust inclusion of community priorities, starting with *their* definitions of the impacts that matter, and *their* framing of research such that it meets existing priorities (be they rents for use of territorial space, implications for resources and local economies, or recognition and governance of all operations) (UNDRIP 2008). And, (b) meaningfully involve Indigenous partners in analysis, interpretation and communication of results. Key here too, is recognizing Indigenous people as rights holders not stakeholders, including the right to free prior and informed consent, and the right to sue should operators not abide by law and policy. Lastly, (c) many communities have their own protocols and established research agreements, which spell out all conditions of work and expectations for accountability. These often also define ethical and intellectual property expectations, compensation for time, and require negotiation and agreement (e.g., Sealaska

2004). In addition, communities may identify places and topics around which they refuse to engage (Simpson 2007; Simpson 2014). Such protocols, including those seeking to address reparations for past harms, are or can be legally binding, and seek to re-establish First Nation or Tribal community rights to jurisdictional authority and decision making (e.g., MOU ‘Namgis and Crown).

A third priority is to design research practices and categories such that they reflect and honor ontologies and epistemologies of Indigenous knowledge systems (e.g., Swinomish Health Indicators). This includes land-based, relational histories with non-human relatives; particular worldviews evident in their languages; and, responsibilities to territory (Marsden 2002). Also central are storied or narrative forms of interpretation and evidence; knowledge encoded in placenames and oral histories (Marsden 2002); and, knowledge about the particular colonial histories that have also disrupted these. Positioning the voices of community members as knowledge-holding experts, and recognizing their cultural authority is foundational as compared to the sole authorial voice of the OAE researcher.

Comprehensive direction and reflection on these approaches can be found in the work of Linda Tuhiwai-Smith (2019), Margaret Kovach (2021), and Shawn Wilson (Wilson 2020), Tuck and Yang (2019) among others.

3.5.4 Engagement Approach 4: Structured decision-making: Integrating public and expert insights (mid-stages)

Designs more analytically focused seek all of the above but employ greater structuring of engagement methods to ensure the conversation is descriptive (e.g., as to what research or information matters to the decision) and evaluative (e.g., which OAE designs across alternatives are most desired, safe and why), and what modifications or alternatives are key. These methods provide a central opportunity of integrating public and expert knowledge in the evaluation of its feasibility, as well as environmental and social impacts of OAE.

All such methods are both knowledge- and value-centric and aim to convert values or social priorities to performance measures that can be used to evaluate policies, actions or specific decisions (Renn 1999; Estévez et al. 2015; Mahmoudi et al. 2013; Burgman et al. 2023). For example, if the case were deciding upon different locations for a pilot installation of an OAE facility, high public support might be a function of designs that: prioritize social benefits (e.g., which can include expert knowledge on tax revenues, or social priorities for learning or employment opportunities), require relatively less energy (e.g., again, based on expert assessment), work with locally trusted institutions and actors (who might define ethical parameters and assign consent), and offer outcomes or conditions co-designed (e.g., such as ensuring that work will cease should problematic impacts follow).

An illustrative approach covered here known as *structured decision making* (Gregory et al. 2012) is motivated by theory derived from the decision sciences and is part of a larger set of *prescriptive* methods derived from multi-attribute decision making (Keeney 1996; Renn 1999). These aim to respect and address routine and often semi-conscious habits that are pervasive across judgements about new technologies such as those *described* in section 2 above. Thinking or information processing of this kind is often referred to as rapid, fast or 'system one' thinking as it engages affective cognition or processing (Kahneman 2011). Prescriptive theory instead accepts these behavioural phenomena as a given and thus deploys a series of steps that 'slow down' thinking and articulate decisions in reference to 'structured steps' to activate deliberative or 'system two' thinking.

Three key strengths of structured decision making are that it: (a) uses small-group collaborative design to develop the criteria and indicators or 'metrics' that will be used to evaluate an OAE project, for example; (b) combines both local concerns and knowledge with expert and/or scientific information where available; and [c] integrates factual and value-based information into the analytic portions of the work.

Detailed methods advice is available (e.g., Gregory et al. 2012)with many cases drawn from resource management, but the central steps are as follows with iteration across these assumed: (1) Establish the **decision context** for the workshop including the timing, purpose and bounds of the work, including how the insights gained will be used. For example, this method might be used to compare the viability or different sites for OAE trials or it might involve the conditions under which trials can or cannot proceed. (2) **Develop objectives** for the project and the different metrics by which these might be evaluated. Here it is critical to involve and respect all forms of knowledge (expert, local and Indigenous where applicable) and to include as wide as necessary a set of objectives. For instance, one of many objectives might include 'maintaining high water quality', which might itself include several sub-objectives including water safety (perhaps measured as possible contaminant levels for humans, fish or marine mammals); water aesthetics (measured by local people in reference to colour, smell, pattern or turbidity), and flow (do materials stagnate or move and disperse). A full set of objectives might include groups such as environmental impacts (of which water is one and species of concern might be another), social consequences, governance considerations, and financial considerations. As above, each matter to the decision underway and each may include several sub-objectives and their measures. Measures can be qualitative or quantitative. (3) **Develop alternatives:** Consider the different alternatives by evaluating each across the above objectives, accepting that some objectives might be deemed relatively more consequential or important than others. Discard options that are poor across objectives and modify plans such that better alternatives and their conditions might be developed. (4) **Consider consequences:** Once a smaller set of alternatives have been isolated, discuss these in reference to the possible consequences of each, accepting that some alternatives may be eliminated due to the possibility of significant harms. (5) **Evaluate tradeoffs:** If and when proceeding with a plan or technological application remains the goal, it is usually the case that no one option is perfect and that tradeoffs are instead involved. Deliberate which tradeoffs are acceptable or relatively more desirable, and which are not. (6) **Implement and Monitor:** Should a project go ahead, develop a plan to follow its operation and monitor its progress.

3.5.5 Engagement Approach 5: Survey design (early and especially mid stages)

Historically, studies of the perceived impacts, risks, and acceptability of new technologies have relied heavily on survey questionnaires, and this remains the case. More recently, mixed method designs, using a blend of survey and deliberative workshops, have been prioritized (Cox, Spence, and Pidgeon 2020). These approaches address some of the limitations of surveys, by providing participants with more opportunity for learning and deliberation, and by allowing for a deeper exploration of these reflections. Such insights can be used to better interpret and illuminate positions found in large, representative surveys. The goal of survey research is not to obtain consent or to treat results as a poll, but rather to illuminate the factors that may help explain judgments as they exist and change (Fowler Jr 2013; Gray and Guppy 1999).

Whether combined with smaller group work or not, survey research benefits from several key design principles. The first is that designs are well hypothesized, which means isolating a 'dependent' or outcome variable of interest (e.g., acceptability or perceived risk), alongside a larger set of demographic, knowledge, and value-based variables (e.g., regarding participants' perceptions regarding nature, politics, vulnerability, ocean systems, etc.), often known as explanatory variables, which might predict that dependent variable. Many such factors are covered in Section 2 above. Common dependent variables of focus include acceptability/support, both risk *versus* benefit and risk *and* benefit measures, negative versus positive feelings toward a technology, reported support for enabling policies, or willingness-to-pay to offset GHG emissions. Survey approaches should also specify whether the goal is to elicit initial heuristic responses, or more reasoned views (described above as 'system one' vs. 'system two' thinking). Approaches that elicit system one thinking tend to be more useful in early-stage research, where judgments might be more fully impressionistic, rapid or intuitive; the second option might better serve surveys employed once a technology is better known and views on it have become relatively stable.

A second principle is ensuring robust tutorials for novel concepts and technologies. A challenging question is how to present OAE in a survey when the very idea of it is so new. A well-established approach is to provide information via a short, pithy paragraph at the beginning of the survey—this text should provide key information in as neutral a format as possible. When a topic is new, such as OAE or mCDR, assumptions that information to be provided can truly be 'neutral' should, however, be treated with skepticism. All descriptions frame responses, intentionally and not, thus it is better to be explicit about the design logic of any tutorial – for example, being inclusive of risk *and* benefit language. Where approaching 'neutrality' in a tutorial is particularly difficult, split samples and multiple tutorials may prove useful to investigating the effect of different framings.

Proper sequencing of a survey questionnaire is another important principle. Best practices involve beginning with dependent variables before moving to explanatory variables, to avoid any order effects (Greenberg and Weiner 2014). Because, again, this topic is so new, another strategy is to provide information in stages, which changes the structure of the survey itself. Sequential designs necessitate more cumulative or pathway structures, which intentionally route participants through a series of questions that build a portrait of thinking as it emerges.

The assumption here is that new topics are complicated and thus it is cognitively easier for people to have questions decomposed into steps that help clarify thinking (Gregory, Satterfield, and Hasell 2016). Typically, these begin with a global 'first question' that looks at a discrete value position and then seeks to unpack that, given additional questions or considerations. An alternative approach is to begin with a tradeoff between two positions (e.g., positive or negative toward an action, policy or technology) and then seek to delve into the value, factual or policy basis for that position (Hagerman et al. 2021). Such designs can also reveal whether positions are relatively fixed or open to consideration of information or alternatives as provided.

Any survey's sampling strategy is key to the representativeness of results, their quality, and their reliability and validity given the survey's goals. Sampling can range from convenience approaches to careful representative sampling, which is closely and systematically reflective of the total population frame designated (e.g., all people in a country or region), including target sampling (e.g., climate activists). Sampling errors are common and the considerations are many but good reviews of survey design principles and sampling problems are widely available (e.g., Stantcheva 2022).

3.5.6 Engagement Approach 6: Deliberative Polling (later stages)

Deliberative polling is a method that bridges deliberation with conventional polling via random sampling, and offers a few advantages as an engagement method for OAE research. Adding 'deliberation' to polling offers participants the opportunity to reflect and consider options, rather than just offer 'top of head' opinions (Fishkin & Luskin, 2005). As it is extended (multi-day) in nature, this method also offers more opportunity for participants to process new information, as compared with other options like interviews or surveys (Fishkin et al., 2000). These opportunities for discussion, reflection and clarification are likely critical in the context of a complex technology and context, such as with OAE. Adding random sampling to deliberation ensures representativeness of participation, a feature that distinguishes this from other deliberative approaches like focus groups or citizen juries, which cannot necessarily offer insight into views amongst a wider population. Deliberative polling thus can produce a useful understanding of what a larger public might think on OAE—if they were to be given the opportunity to take the time to consider, reflect and discuss the full suite of relevant perspectives and options (Mansbridge 2010).

Deliberative polling follows this structure: participants are provided with balanced briefing materials that offer a launchpad for broader discussion. These materials lay out different arguments and provide rigorous, factual, impartial (as much as possible) information relevant to a policy proposal. These materials are vetted in advance by an advisory board, for balance and accuracy. Participants gather for deliberations, either in-person on-online through a platform, usually for multiple days (e.g., a weekend) (Fishkin and Luskin 2005). Participants spend the weekend in small-group discussions led by moderators, and in sessions where they can ask questions of policy experts. Participants are asked to talk, listen, comprehensively consider different views, and weigh different arguments. At the beginning and end of the deliberations, participants are asked to answer a questionnaire about their views.

The outcome of deliberative polling activities might be a deeper understanding of how a representative sample in a given area views a potential deployment of OAE. Importantly, what deliberative polling does *not* offer is production of a consensus (Fishkin, Luskin, and Jowell 2000). Instead, the emphasis is on understanding overall views and the aspects of such a deployment that might produce greater or lesser confidence, or support.

3.6 A note on 'consent'

What consent to an activity like OAE might mean is complex and not easily resolved, in part because of different understandings of consent (Wong 2016). Regardless, in the context of infrastructure development projects, climate mitigation activities and international law, it is considered best practice to obtain the free, prior, and informed consent of affected communities (Rayner et al. 2013; Sohn 2007). Consent may appear most critical at the time when implementation of a large-scale activity is being considered (e.g., building a plant), but it may also be key to early research stages. Processes of participation and consent-seeking should be ongoing from early stages throughout later stages of research and deployment, and should be iterative as activities, proposals, and plans evolve. While this chapter focuses primarily on early-stage research, consent will likely be an issue that increases in importance as later stages of research and operation unfold, as the magnitude of activities, and affected groups, continues to grow. Ultimately, if a group rejects a proposal or even conversation, following best practices means that that 'no' must be respected.

4. Post-engagement activities: Making engagement transparent, accountable, and responsive

The gold standard for societal engagement is to ensure that communication and learning is bi-directional and responsive, and includes mutual learning across scientists and stakeholders. OAE projects will benefit from remaining open to change in research practice as a function of public engagement—indeed, researchers should ultimately be prepared to cease operations or move elsewhere if it becomes evident that the proposed project is not societally feasible in a given context. It will be essential to understand the many perceptual, value and governance drivers of views that people hold, publics and experts alike, as these continue to prevail in thinking across many new technologies. A few principles to ensure that engagement is of highly quality and **responsive** are outlined below.

Make engagement two-way: For public engagement to be meaningful, it has to be incorporated back into the project to inform and shape the project moving forward. Achieving this will likely depend on the specifics (e.g., team size) of individual projects. A few things will be helpful in ensuring that this occurs: **(1)** regular collaboration and dialogue across social science and/or engagement teams with the broader team, such as regular feedback sessions and check-ins following the initial engagement activities, **(2)** involvement of social scientists or engagement specialists in decision-making processes to ensure that community views and priorities are meaningfully addressed, and **(3)** incorporation of specific community collaborators into closer relationship with the research team (e.g., Indigenous leaders in local area) (for motivating engagement, see Rotman et al. 2012) . Projects may want to co-draft an explicit 'two-way engagement statement' to encourage and improve transparency around commitments and plans (see Department of Energy 2022). One fundamental element of such two-way engagement is making data openly available and involving local communities in monitoring efforts. Researchers and funders should therefore explore opportunities for supporting platforms for community members to follow monitoring and maintain access to monitoring data (Department of Energy 2022). Engagements that emphasize responsive, two-way engagements with local stakeholders have been shown to result in sustained mutual learning between experts and citizens, and to improve community ownership and overall project outcomes (NREL 2022).

Begin conversations about community benefit agreements (CBA) early: CBAs are contracts between project developers and communities that provide support for a project conditional on the developer providing a set of socio-economic benefits (Department of Energy 2017). At an early stage of small-scale field trials, it may seem premature to begin a conversation on how benefits of an OAE project might be distributed if deployed at scale. However, such arrangements can be a point of discussion in the early stage, and may prove critical to more lasting views on a potential project.

Inform modeling efforts: Modeling is one area of potential importance in terms of incorporating engagement findings. Models, especially integrated assessment models, are designed to seek techno-economically optimized outcomes: modifying models to solve for diverse 'societally desirable/acceptable' outcomes (i.e., taking distributive justice into account, relative distribution of costs and benefits etc.) may help provide answers to the questions affected publics are most interested in. Bringing modellers, social scientists, and stakeholders into conversation early and often to engage them in reflexive or situated modelling practices may be one way to do this (Schulte et al. 2022; Low and Schäfer 2020; O'Neill et al. 2020; Salter, Robinson, and Wiek 2010). This should be done at all stages of the modelling process: Upstream input might involve using public engagement outcomes to inform future modelling efforts, for example by identifying societally relevant questions about OAE that might be modelled in the future. Downstream input might involve bringing stakeholders and modellers together to discuss whether the model outputs have answered societally and scientifically relevant questions (i.e., to aid decision-making on OAE), or whether modification of the technology itself improves social outcomes. For example, upstream, modellers might ensure inclusion of environmental impacts precisely because they could produce social consequences. Concentrated but highly localized additions of alkalinity might be omitted as inconsequential from an overall biophysical point of view. Yet, inclusion in modelling might be warranted because such additions could result in localized reductions of dissolved CO_2, negatively affecting phytoplankton and thus fisheries. Downstream, unanticipated negative findings linked to trace materials might be further modelled for their capacity to introduce health effects or to stigmatize waters important to a coastal community's tourism (Nawaz et al. 2023). More broadly, all modelling could potentially benefit from citizen science engagement. A recent study aimed at methods to track marine plastics, for example, used data collection of this kind via easily useable sensors to enhance the accuracy of modeling the volume and point source of plastic waste and debris (Merlino et al. 2023).

Research outcomes should be available and accessible. Beyond informing publics about the project itself, research outcomes should be shared widely and well beyond the immediate project context. This might mean, for instance, not just publishing in an academic outlet, but also producing materials, such as fact sheets and community briefing summaries, that can be understood by local groups in both immediate and other areas, and sharing these via different venues (i.e., at local meetings, online, in schools and libraries).

5. Summary of Recommendations

No chapter of this kind can address all potential factors and linked methods, let alone the detail that makes each tractable. However, what does matter for each audience is largely discrete and so we summarize this chapter by designating how it might serve (a) social science public engagement leads working on OAE projects; (b) natural science/engineering leads on OAE research; and (c) funders looking to support OAE research.

Social science leads can use this guide to reference some of the factors that have explained why people support or reject some new technologies in reference to both features of the technology itself, the values of those evaluating the technology and its context, and the features of OAE's management and governance. We have also provided recommendations as to why historical context matters and how that might affect perceptions, or influences the articulation of future threats and opportunities. We have offered tailored suggestions as to which methods might align with different research and development stages for OAE, with references to fuller guidelines herein. And we have provided recommendations on what it means to conduct work that is inclusive, reflects Indigenous knowledge, protocols, and designs; and opens up deliberative and civic conversations whereby the knowledges and values people have can be used in meaningful and concrete ways across decision-centric methods. This can include decisions that are well structured and deliberated and that combine public and expert knowledge. How all research might then be incorporated back into science and engineering research design and so inform the research moving forward is also of potential use to social scientists in this field.

Natural science and engineering leads

We understand that the work described in this chapter is not work that most natural and engineering scientists will do, but they can use this to help curate their direction to social science researchers who might do that work or to understand methods in reference to their context or stage of work, particularly early stages. Most importantly, it will help them understand when and where problems of public perception are not simply due to a lack of knowledge, and to instead seek engagement practices where knowledge is co-produced and where deep understanding and integration of public concerns into their own methods (e.g., modelling) and design (e.g., materials used or siting chosen) is a priority. Several suggestions are also offered as to how to expand their own thinking and communication beyond details of the technology itself, and instead how OAE might articulate with how people think about risk, how the full lifecycle and governance of an OAE system might influence views, and how the power of conversational approaches (such as World Café designs) can enhance trust and openness as technologies evolve. Brief guidance on how a plausible futures' threats and opportunities approach can be scoped with stakeholders is provided, as are decision centric methods. The latter are optimal for stages where key operational features (siting, materials, monitoring) and environmental or social conditions might be modified to address public concerns. This chapter might also be useful for understanding that all research is context dependent and sensitive and that communities with histories of colonialism and marginalization might not view options to 'engage' as desirable, might not share the classifications of nature that scientists can assume, but may be more open to conversation and collaboration when using Indigenous methods referenced here. More broadly, this chapter emphasises that all those involved in OAE research projects should actively and transparently reflect on the knowledges, assumptions and values driving their work.

Funders and proponents of OAE

Much of what we have already referenced above applies to this group as well. But, in particular, using deliberative and decision centric designs to hold conversations about community benefit agreements might be key, with the assumption that work on such agreements should begin early, recognize jurisdictional authority, and accept that some contexts will simply not be viable sites for OAE projects. Budget calculations for project work will become easier via review of this chapter so that engagement efforts are understood and properly funded. Similarly, the goal of engagement will be clearer and so too how to best produce high-quality knowledge of what is viable socially, and why.

Key Recommendations:

1. Views of OAE across different public groups will reflect how people read the signals implied by any new technology with perceived ‘broadcast’ or ‘waste-like’ assumptions about material distribution in marine systems a likely key concern. [section 2.1]

2. If people view marine systems as fragile, regard mitigating actions as morally compromising to GHG emissions and energy transitions, they may be less likely to find OAE acceptable. Viewing climate change as an urgent problem could have mixed influences, leading to both solid support or suspicion about technologies in early development phases. [section 2.2]

3. Governance of OAE (how the system will be managed, financed, monitored) and representation of those with jurisdictional authority, including Indigenous groups, will be key. Failure to maintain public trust is central, as is early discussion of operation at scale during engagements. [sections 2.3-4; 3.2; and 3.5.3]

4. Integration of social science work should begin at the earliest stages and include natural and engineering investigations that reflect key public concerns; involve collaboration across research teams, and a specified plan for feedback and modification of research as new questions and insights arise. [Section 4]

5. Six engagement approaches are provided, each tailored to research that is early stage (mesocosm experiments or early field trials); mid-stage (scaling up to fuller pilot studies, site selection criteria or determining choices across options); and late stage (seeking large population public views regarding involvement of OAE as a significant part of national policies to meet climate goals). [Section 3.3-3.5]

6. Principles of responsible research and innovation should guide engagement, particularly: *anticipating* as best as possible unforeseen consequences of OAE; *including* social concerns in risk evaluation criteria; being *responsive to* new knowledge as it emerges; and *communicating* reflections on the limits of understanding as it unfolds.

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Table 1: Engagement methods/approaches suited for different scale project-level engagement research on OAE

Engagement methods/ approaches	Stage of application	Requirements	Purpose	Questions the method can begin answering	RRI principle(s) addressed by the method
(1) World Cafe[1]	Early-stage	Background regarding local context (governance, political, cultural, demographic, etc.)	Initial insight, scoping of people's questions and concerns, fit with local priorities, discourses in play, understanding governance and operating conditions	What are primary concerns and ethical considerations? How does OAE align or not with local priorities? "No-go" zones—what actions and/or locations are off the table? What questions should researchers be asking in further iterations? How does the project need to change or alter project design?	Inclusivity & reflexivity
(2) Participatory Foresight	Early-stage	Background regarding local (governance) context	Scoping plausible future (perceived) threats and opportunities which could be presented by OAE in a given setting, identifying governance instruments that may be robust across plausible OAE futures	What are local stakeholders' understandings of feasible and desirable OAE developments? How can different types of knowledge (i.e. academic, practitioner, local and indigenous) be integrated into OAE project planning and governance processes?	Anticipation & inclusivity
(3) Indigenous Methods	Early-stage	Deep reflection on colonial research practices and their reshaping through Indigenous methods	Co-construction of research priorities, how the marine system involved is classified and what it is constituted	What impacts are deemed most important, which species or sites are most culturally important? What histories of place define the marine-scape? Whether or not OAE articulates with Indigenous priorities and future development?	Inclusivity & reflexivity
(4) Decision Making Designs	Mid- and late-stage	Clear 'decision context' is known, i.e., what are different potential options on the table for consideration	Inform specific decisions; highlight trade-offs; consider and/or develop alternative solutions; integrate knowledge and values of experts and publics	How do different groups weigh trade-offs involved with different OAE options? What specific features of options (ecological impacts, ownership questions, funding, etc) are particularly important to informing views?	Inclusivity & reflexivity
(5) Surveys	Early- and late-stage (early: for understanding broad, coarse-scale understanding of views and factors that drive them, later stage specifics on large-scale field trials	Clear 'sample frame', or understanding of who should be delineated as relevant groups for weighing in on an OAE project	Broad scale consideration of prevailing positions across large areas or populations and/or verification of positions in general versus those proposed by specific vocal groups	Suited to questions of distribution of acceptability or rejection of different CDR options or specific. Widely used for revealing latent variables that influence acceptability, broadly stated	Inclusivity
(6) Deliberative Polling	Late-Stage: In association with large-scale field trials	Clear policy question to ask participants, e.g., "should we implement XYZ project"; clear sample frame, or understanding of who should be delineated as a relevant group.	Understand approval or disapproval from statistically representative sample; understand logics and thinking behind these approval/disapproval findings	Would participants approve of a specific version of OAE?	Inclusivity

[1] Similar methods include deliberative mapping, citizen panels, mini public

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