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**What makes carbon removal methods fit for purpose?**

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Working paper 004

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What makes carbon removal methods fit for purpose?

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**Abstract:**

Carbon dioxide removal is necessary to mitigate climate change, but not all methods will be fit-for-purpose. Some can be unethical, unsafe, counterproductive, and ecologically damaging. But, because fitness is a value judgment, it is critical to have a clear definition of its meaning. We propose to define fit-for-purpose as an attribute of a carbon removal method that indicates that its detrimental side effects are sufficiently small to be acceptable. A method is not fit for purpose if it risks unsustainable environmental or societal damages. We then identify six criteria that can be used to judge a method's fitness-for-purpose based on those chosen by other organizations, including carbon negativity, measurability, additionality, safety, and low environmental risks. We compare our perspectives on these criteria to those presented by six entities including Microsoft, Carbon Direct, Frontier, California's Air Resources Board, the United Nations Development Program, and the Accountability Framework. This work reflects our thinking in 2023 with some updates in 2024 and intends to be a starting point for a more thorough development process that ought to be adopted by the international carbon removal community in an inclusive process.

## 1 Introduction

Nations agreed to limit global warming to 2 °C and pursue mitigation strategies to limit it further to 1.5 °C (United Nations, 2015). Each passing year of delayed climate action has increased the need for Carbon Dioxide Removal (CDR), methods that capture CO<sub>2</sub> from the atmosphere and store it durably in oceanic, biotic, and geological reservoirs and products (IPCC, 2021). With today's slow pace of action, the 1.5 °C limit will be impossible without CDR (Morton et al., 2021), and soon the same will be said for the 2 °C limit. Thus, meeting the Paris Agreement commitments has imposed a significant responsibility on CDR. These responsibilities are expanded by the idea that CDR can also return the atmospheric CO<sub>2</sub> concentrations to lower, safer levels (Hansen et al., 2017; Lackner et al., 2012). These are lofty and consequential expectations for CDR. It is in the interest of the public and industry that we ensure these are met. As interest in this nascent industry grows, ensuring expectations starts with defining what makes a proposed CDR method fit-for-purpose.

### The need for fit-for-purpose CDR methods

CDR methods have received increased funding from the public and private sectors. As an industry scales, standards must be set to not only ensure performance but also limit negative impacts (Jackson et al., 2017). This is true for CDR methods that will need to be scaled globally to capture and sequester multiple gigatonnes of CO<sub>2</sub> per year (Minx et al., 2018; Smith et al., 2022). To meet climate goals, the industry will need to become as large as the fossil fuel industry and likely bigger (SwissRe, 2021). An example of negative scaling impacts includes the engineering of rivers which in their totality has altered the supply of sediments to delta ecosystems and coastal environments (Syvitski and Kettner, 2011). Without safeguards in place, even small negative impacts from one

technology or pathway can compound to cause significant severe consequences if scaled on a multi-gigaton level.

Not having clearly defined fit-for-purpose criteria can lead to highly experimental, unethical, or even counterproductive CDR methods receiving funding and scaling opportunities. Aside from the obvious issue of exacerbating climate change or ecological damage, there is the risk of taking funding away from other technologies that might make better use of it (Sekera et al., 2023). Additionally, without strong definitions of what is fit-for-purpose, there is the possibility to design standards that legitimize counterproductive methods. This then allows for suboptimal outcomes that will hurt the fight against climate change because there will be an impression that more progress is being made than in reality. An example of that can be seen from the state of conventional carbon offsets, which often appear to amount to greenwashing (West et al., 2020). Unfit technologies have the potential to create a sense of mistrust and cynicism within the climate movement, leading to the public questioning the credibility and usefulness of carbon removal, and techno-centric climate change mitigation efforts in general. Similar arguments have been made regarding the high stakes from misguided public engagement (Nawaz et al., 2024).

The goal of robust assessment criteria is not to slow down the general scaling of CDR methods but rather to efficiently meet climate goals by only scaling the ones that work. This will allow for the efficient use of limited time and resources and establish credibility within the climate movement. As an example, Chopin et al. (2024) argued deep-ocean seaweed dumping is risky and not the best use of valuable biomass. Deep ocean dumping enthusiasts might feel otherwise. CDR needs to become a key part of the climate change mitigation effort, but it must be clear what makes a CDR method fit-for-

purpose, and the answers must be evidence-based. Obtaining funding, planning decarbonization strategies with CDR, or scaling specific methods without establishing a basis for what makes a CDR method fit-for-purpose is irresponsible and potentially harmful to both the field of CDR and the climate change movement.

### **Academic assessments**

CDR technologies have been assessed in the academic space in a myriad of ways for over a decade. Studies have assessed their potential capacity, cost, environmental impacts, social benefits, durability, technological and measurement readiness levels, and resource use (Fuss et al., 2018; McLaren, 2012; Mercer and Burke, 2023; National Academies of Sciences, Engineering, and Medicine, 2022; National Academies of Sciences Engineering and Medicine, 2019; Smith et al., 2016; Strefler et al., 2021). For example, the Royal Society (2009) put forth eight criteria for assessing carbon removal technologies including legality, effectiveness, timeliness, environmental, social, and economic impacts, costs, funding mechanisms, public acceptability, and reversibility. McLaren (2012) included relative readiness, global capacity, costs, and side-effects. Fuss et al. (2018) looked at costs, potentials, and side effects. Sovacool (2021) selected technical, financial, socio-environmental, political risks and benefits. Honegger et al. (2021) looked at the potential implications to the Sustainable Development Goals. A wide range of normative criteria have been identified to assess CDR technologies.

While academic assessments are necessary, they may not reflect what goes on in implementation. Implementation in the space of CDR is determined by the rules encoded in legislation, policies, and standards of governments, agencies, institutions, non-governmental organizations, companies, and buyers. In the landscape of CDR markets, these

documents play significant roles in the definition of fitness for purpose.

### **Definition and process**

In science and technology, the English word “standard” is used with two different meanings: as a normative document and as a measurement standard (ISO, 2004). The carbon removal industry should be concerned with both. The latter is the province of the international vocabulary of basic and general terms in metrology (VIM) and the agencies and organizations that develop the measurement protocols based on the VIM. Although measurement standards are considered in our assessment, we are interested in the former meaning.

In a normative sense, standards are defined by the International Organization for Standardization (ISO) as documented agreements containing technical specifications or other precise criteria to be used consistently as rules, guidelines, or definitions (ISO, 2004). For carbon removal, at least thirty organizations around the world have developed such documented agreements (Arcusa and Sprenkle-Hyppolite, 2022; Mercer and Burke, 2023). Organizations may be international like the United Nations Clean Development Mechanism, national like the Australian Emission Reduction Fund, regional like the Regional Greenhouse Gas Initiative in the United States or led by private not-for-profit and for-profit enterprises like Verra, Gold Standard, Nori, and Puro.Earth. Many more organizations are likely to evolve, as the carbon removal industry scales.

One key element embedded in the standards is the assurance that the materials, products, processes, and services are fit for their purpose. According to the ISO, fit-for-purpose is “the ability of a product, process, or service to serve a defined purpose under specific conditions” (ISO, 2004). The definition of fit-for-

purpose emerges from various sources, including academia and the community of practice. What emerges from academia may serve a bigger goal, e.g., mitigating climate change, but often requires translation into the implementation space. What emerges from the community of practice, which represents the entities who supply, sell, purchase, or otherwise have an interest in, may oftentimes not be driven by the same bigger goal but may often be more practical.

Industry has encoded fit-for-purpose criteria in their documented agreements using various terminology including “do no harm” principles, pre-requisites, considerations, or criteria for high-quality or selection, to guide their decision-making process. What becomes embedded in the standards is the representation of the majority interest of those present during the development. This may vary from maximizing profits, minimizing costs, protecting people and nature, satisfying investors, absolving corporations from liability, and attempting to protect from greenwashing. Well-designed standards would balance interests while not losing sight of the technology’s intended goal.

As there is no global carbon regulator, the plethora of standards for carbon removal have evolved without an obvious guiding framework (Arcusa and Sprenkle-Hyppolite, 2022). This has resulted in differences in methodologies and outcomes (Bey et al., 2021; McDonald et al., 2021), despite operating in a market that intends to deliver a commodity. Carbon removal is currently a differentiated

product which has led to calls to develop industry oversight and harmonization (Arcusa and Sprenkle-Hyppolite, 2022; Mercer and Burke, 2023; and this industry call<sup>1</sup>). Responses in the regulatory and non-regulatory carbon markets space are visible (e.g., the European Union’s Certification of carbon removals initiative<sup>2</sup>, the Integrity Council for the Voluntary Carbon Market Core Carbon Principles and the Program Level Assessment Framework<sup>3</sup>, and the Center for Negative Carbon Emissions’ Conceptual Framework for the Certification of Carbon Sequestration<sup>4</sup>). These initiatives are currently competing to define certification, including what makes carbon removal fit-for-purpose.

In this paper we aim to affirm the importance of fit-for-purpose criteria for carbon removal methods to assist the community with the development of responsible CDR. To that end, we follow the ISO’s definition requiring both a purpose and conditions. First, we describe the purpose of carbon removal in the context of climate mitigation drawing from academic literature. This defines the problem carbon removal aims to solve, the goal it seeks to achieve, and the context in which it is applied. From this, we propose a method-agnostic definition of fit-for-purpose in the context of carbon removal. We then identify the conditions - the fit-for-purpose criteria - and provide the rationale for their selection, drawing from documents prepared by entities involved in the space of carbon removal, environmental protection, and social safeguards. Each criterion is described in detail. We then compare our list to those from a variety of different organizations

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<sup>1</sup> <https://carbonplan.org/blog/cdr-standards-call>

<sup>2</sup> [https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13172-Certification-of-carbon-removals-EU-rules\\_en](https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13172-Certification-of-carbon-removals-EU-rules_en)

<sup>3</sup> <https://icvcm.org/the-core-carbon-principles/>

<sup>4</sup> <https://keep.lib.asu.edu/items/172390>

focused on implementation, including investment companies, government agencies, and non-profit organizations. This work intends to be a starting point for a more thorough development process that ought to be adopted by the international carbon removal community in an inclusive process. We do not concern ourselves in this article with *how* to implement the criteria. That is the subject of other work.

## 2 The purpose of carbon removal

Taking the ISO definition of fit-for-purpose, we can determine the fit for purpose criteria of carbon removal by first asking the question: What is the purpose of carbon removal?

In the context of meeting international climate goals, the purpose of carbon removal is twofold. First, like point source capture and storage, carbon removal limits the impact of unabated anthropogenic emissions on atmospheric concentrations (Lackner et al., 2016, 2012). For example, carbon removal can neutralize the emissions of hard-to-abate industries, like heavy-metal processing and long-distance travel (Davies et al., 2018), as well as unabated dispersed point sources like transport and agriculture (Lackner, 2010). Secondly, once humanity has reached net-zero emissions, carbon removal can reduce the CO<sub>2</sub> concentrations in the atmosphere back down to “safer” levels, that some argue could be around 350 ppm (Hansen et al., 2008). Carbon removal removes historical and concurrent emissions (National Research Council, 2015).

We note that activities that reduce or avoid emissions may store carbon as part of their activity but do not produce negative emissions (Schenuit et al., 2023). Examples include point source capture and storage (CCS), improved forest management, or ecosystem conservation. Although critical to stopping climate change, they cannot be considered carbon removal and should not be treated as equivalent (Nordahl et

al., 2024). However, there is nuance in this statement as they can be certified as carbon sequestration whether they prevent new or remove existing emissions.

## 3 A definition of fit-for-purpose CDR

Many diverse types of CDR will be necessary to meet the climate challenge (Minx et al., 2018). Ad-hoc decisions about what is an acceptable method may be more flexible and faster than following a standard, but they are also more easily susceptible to special interests and are lacking consistency. We therefore argue that in a democracy, a universal, documented, transparent, inclusive, and standardized process is necessary to reach decisions on what are acceptable CDR methods. In consequence, a method-agnostic definition of what is a fit-for-purpose CDR method is necessary. We propose as a starting point to define fit-for-purpose as an attribute of a carbon removal method where its detrimental side effects are sufficiently small to be acceptable. A method is not fit for purpose if it risks unsustainable environmental or societal damages. With this definition comes the next step of identifying the criterion by which to assess a CDR method as fit or unfit.

## 4 Criterion identification and rationale

Now that we made clear the purpose of carbon removal, what criteria should standard design include to define fit-for-purpose? In the following, we identify criteria and describe the rationale for their selection (**Fig. 1**). The next sections explain what those criteria should mean.

Given the purpose of carbon removal of neutralizing any excess carbon emission, a carbon removal technology should ultimately remove more carbon from the environment than it adds to it (Tanzer and Ramírez, 2019). In other words, it ought to **be carbon negative**. Otherwise, the technology is counterproductive, and it would be better to not utilize the process.

Along the same lines, it is unproductive if a carbon removal method is carbon negative but is not sequestering more carbon than natural processes are already sequestering without human intervention. At a minimum, a carbon removal method must enhance an existing process. The degree of enhancement may be a challenge to agree upon. In all cases, a carbon removal method must add to any carbon that is already present or would naturally be present in a reservoir. A carbon removal method should therefore **be additional**.

The IPCC defines CDR as removal of CO<sub>2</sub> from the atmosphere. This narrowly focuses on CDR methods that only capture the CO<sub>2</sub> as a gas. The atmosphere is tightly connected to the upper surface ocean and short-term biosphere together forming the mobile carbon pool. Certain CDR methods propose to remove CO<sub>2</sub> from other parts of the mobile carbon pool, with the input taking the form of carbon, for example Biomass Carbon Removal and Storage (BiCRS). This should be acceptable because of the tight coupling; removing carbon from one or the other has essentially the same impact (Lackner, 2010). What should be unacceptable is to remove carbon using methods that disturb stationary carbon pools, including the geosphere, long-lived biomass, or deep ocean. These reservoirs contain long-lived carbon, and removing carbon from these pools is akin to fossil fuel extraction. Therefore, CDR ought to be methods that **remove carbon or CO<sub>2</sub> from the mobile carbon pool**, including the atmosphere, surface ocean, and short-lived biomass **and move it to the stable carbon pool**, including the geosphere, long-lived biomass, and the deep ocean.

Once in a reservoir, carbon must remain there for a meaningful amount of time to be accepted as emission neutralization. A meaningful duration is one that is climate relevant. Because CO<sub>2</sub> causes damages from temperature over thousands of years (Archer

and Brovkin, 2008) and from ocean acidification over tens to hundreds of thousands of years (Archer et al., 1998), the timescale of sequestration ought to match the timescale of damages (Arcusa and Lackner, 2022). However, it ought not matter whether the reservoir holds onto the carbon for a meaningful duration from the onset or the carbon is repeatedly re-added; however, the latter will significantly impact the cost of the method (Prado and Mac Dowell, 2023). As a result, a carbon removal method ought to **store carbon on a climate-relevant timescale**.

In most proposed methods, an odorless, colorless gas is moved into a reservoir. Evidence of this movement is critical to foster trust and establish reality. The ultimate evidence is the deli of defensible data that shows the presence of more carbon in a reservoir. Conversely, the deli of defensible data that shows the presence of less carbon in a reservoir than expected, is evidence of carbon being lost from the reservoir. This positive accounting approach (Lackner and Brennan, 2009) is empirical, objective, and defensible. It requires carbon removal to **be measurable**.

The entire purpose of carbon removal is to control the CO<sub>2</sub> concentration in the atmosphere to limit the progression of climate change and allow for all life on Earth to continue evolving. If a carbon removal method satisfies all other criteria, but degrades the environment, then it is still working against the intended goal. Therefore, carbon removal methods must not degrade the environment. Using the same logic, if people must be put in harm's way for a carbon removal method to function, then it is working against its original purpose. Therefore, carbon removal must also **not endanger the environment and the safety of any individuals, communities, or cultures beyond what could be deemed acceptable**.

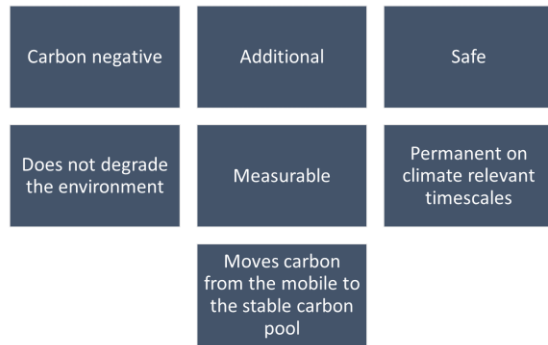


Figure 1. Summary of the proposed fit-for-purpose criteria for carbon removal methods that store carbon dioxide in various reservoirs like oceans, soils, biomass, and rocks.

The rationale behind many of these criteria can be visualized. The bathtub analogy is often used to explain carbon removal and has been argued to be a more accessible way to envision climate mitigation<sup>5</sup>. The tub represents the atmosphere, the tap represents carbon emissions, and the drain represents carbon removal. This analogy represents the basic purpose of carbon removal and its necessity. If water does not drain as fast as the water flowing from the tap, the water level rises and will eventually overflow. Here we extend this analogy to incorporate more of the nuances and visualize the fit-for-purpose rationale.

In our more advanced analogy, instead of having just one bathtub representing the atmosphere, we use four different “tanks,” with each tank representing a different carbon reservoir on Earth (Fig. 2a). The biosphere, hydrosphere and atmosphere make up the mobile carbon pool. The fourth tank represents the geosphere which is the stable carbon pool (Fig 2b). Each of the three tanks in the mobile carbon pool are connected via tubes and have a drain that leads to the geosphere tank. This

setup shows that the carbon added to one of the reservoirs in the mobile carbon pool will quickly balance out with that of the other mobile carbon reservoirs. It also shows that the carbon stored in the geosphere can only be displaced by humans. The blue lines represent natural movements of CO<sub>2</sub>. The thicker orange line represents anthropogenic CO<sub>2</sub> emissions. In the context of this analogy, it represents the water being manually taken out of the geosphere and poured into the atmosphere tank which is different from a natural process represented by a drain. Using this setup, we aim to explain a few of the intricacies of certification.

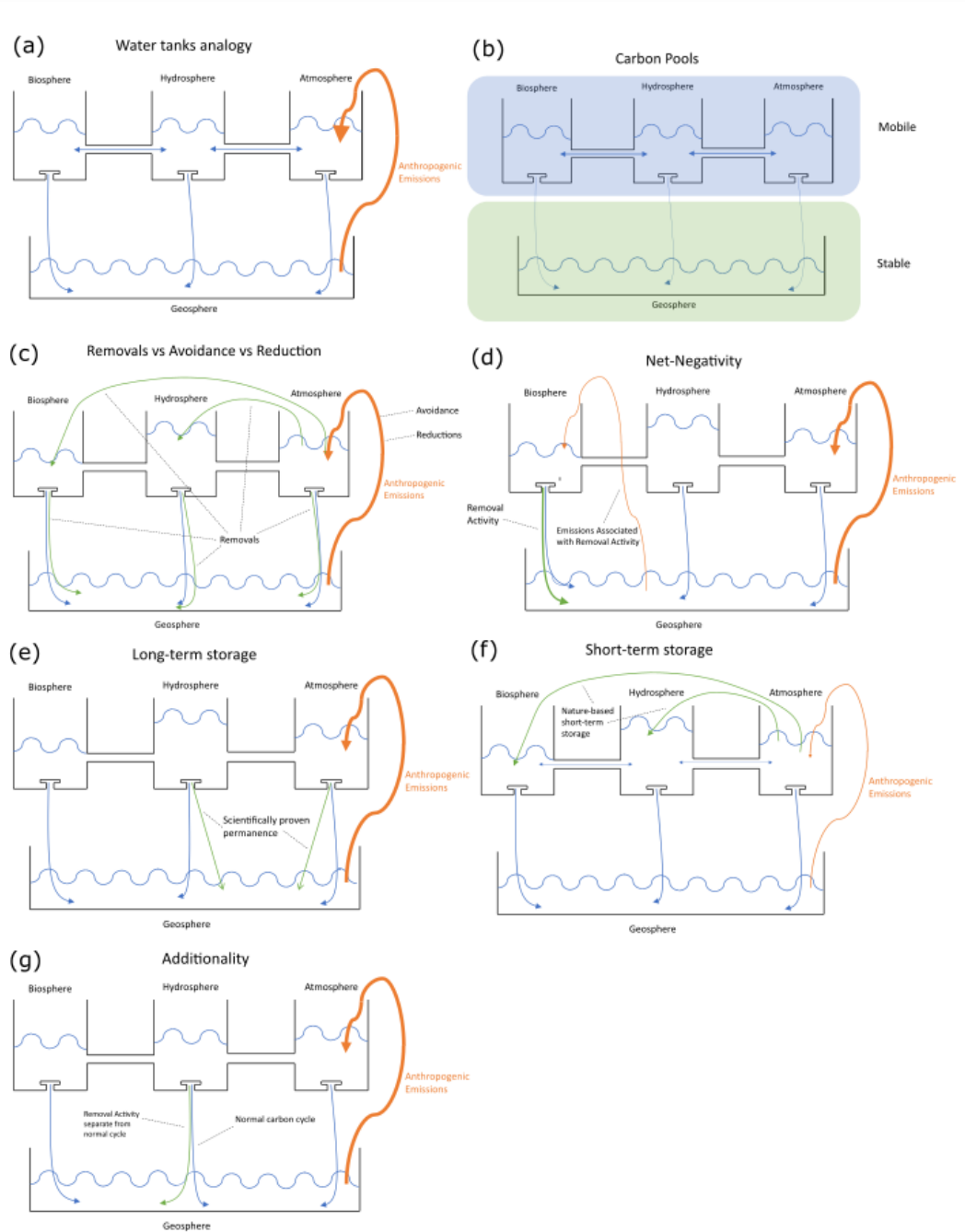
Figure 2c demonstrates the differences between emissions reductions, emissions avoidance, and carbon removal. Emissions reductions and avoidance change the anthropogenic CO<sub>2</sub> emissions, the orange line. In contrast, carbon removals transfer carbon from the atmosphere to the other mobile carbon reservoirs, or from the mobile carbon pool to the stable pool, represented by the green lines.

Fig. 2d demonstrates the meaning of carbon negativity. The thickness of the lines demonstrates the volume of the transfer. The green line which transfers carbon from the biosphere to the geosphere must be thicker than the emissions that are removed from the geosphere due to the same activity, shown in orange. Figure 2e demonstrates long-term storage which involves removing carbon from the mobile carbon pool and transferring it strictly to the geosphere for permanent storage. Conversely, figure 2f demonstrates short-term storage which involves transferring carbon from the atmosphere to one of the other mobile carbon reservoirs (hydrosphere or biosphere). Lastly, figure 2g, demonstrates the concept of

<sup>5</sup> Chami, R., Nieburg, D., Fullenkamp, C., Hilmi, N., Bramley, B. (2024). The tap & the tub: A better way to envision climate change mitigation. Illuminem, Aug 11, 2024. Available at:

<https://illuminem.com/illuminemvoices/the-tap-and-the-tub-a-better-way-to-envision-climate-change-mitigation>

additionality. The green line representing removals must be bigger than the blue line which is already draining into the geosphere. Therefore, it must be “additional.”



## 5 Criterion descriptions

We argue the fit-for-purpose criteria should evaluate proposed CDR methods for their performance, durability, environmental integrity, and safety. We discuss each of these requirements in depth.

### Assumptions

In the design of the fit-for-purpose criteria, we follow the architecture of carbon management proposed by Arcusa et. (2022) and Zakkour et al. (2024). This structure envisions that storage operators (i.e., reservoir managers) are responsible for the stored carbon. Other configurations are possible (e.g., capture company, government, project developer) but for the purpose of this study, the storage operator is the one we choose because of the decision asymmetry. The operator chose to store carbon. In addition to storing carbon, this responsibility also involves measuring and monitoring the reservoir through time. If the monitoring finds a decrease in the reported reservoir content, the operator is responsible to remediate the loss through re-sequestration. This is because carbon lost from storage is treated like any other fossil fuel emission (Lackner et al., 2000). Re-sequestration may be done through the operator's own method, or through the purchase of carbon removal from a market.

### Carbon negative

The overarching purpose of CDR is to be an essential tool in the fight against climate change. Therefore, CDR methods must remove more carbon than they produce, a concept known as carbon negativity. Methods must demonstrate they are carbon negative or have a path towards it. Current practices ask for a demonstration of net-negativity which implies tracking carbon along the entire supply chain of the CDR method to subtract those emissions from the removal (Tanzer and Ramírez, 2019). In a net-zero world,

where one tonne of carbon extracted from the stationary carbon pool must be matched by the purchase of a tonne of carbon removal and this matching occurs upstream (Allen et al., 2009; Jenkins et al., 2021; Lackner et al., 2000), the CDR method would be economically unviable if it is not carbon negative (Lackner et al., 2023). A method that requires two certificates of sequestration upstream to produce only one cannot function economically. It would therefore be enough to determine the economic viability of the method rather than its net emission impact. For good measure, under a net-zero regime, counterproductive technologies could be discouraged through additional policies and the CDR operators could be required to disclose their fossil fuel use, including in the wastes they use in their process.

### Measureable

CDR methods must meet four basic requirements to be accountable (Arcusa et al., 2022), following the basis of "positive carbon accounting" (Lackner and Brennan, 2009). First, they must have an identifiable reservoir boundary. Identifying the bounds of the reservoir allows for the clear accounting of how much carbon is added or released from a reservoir or how the reservoir content has changed. Without this clear delineation carbon accounting would not be possible because one could argue away responsibility. This step will be easier for some reservoirs than others.

Second, the removed carbon must be quantifiable through measurement. The measurement sampling design must be adequate to be representative and repeatable. The equipment must be appropriate for the task and calibrated according to equipment standards. Direct measurements are preferable. Measurements may also include remote sensing with ground truthing, or modeling with ground truthing, if these approaches reduce

measurement uncertainty. This step will also be easier for some reservoirs than others.

Third, in most instances the change in reservoir content must also be quantifiable through measurement (Lackner and Brennan, 2009). If content cannot be measured, it can be acceptable to demonstrate through the scientific process that physical leakage can be measured instead (e.g., Hovorka, 2017), or that removed carbon has no physical means to be released over timescales of 10,000 years (Arcusa et al., 2022). These measurements are necessary for monitoring, remediation, and verification. Operators will need to monitor their reservoir through time to determine that carbon remains sequestered. Monitoring will need to be able to detect a release from the reservoir, whether that be measuring leaks or measuring the carbon content, preferably. Operators will also be reporting their stored carbon amounts to receive certification. Auditors will want to check the reported carbon matches the stored carbon. Certain reservoirs will have natural fluctuations in their content. To counter this, a reasonable margin for error can be established or the average of measurements made over a predetermined period can be made.

Finally, all measurements need not be instantaneous, but they must be made on demand with an acceptable error margin that is consistent across reservoirs. If measurement uncertainty is larger than the estimation of removed carbon then the CDR approach will not be considered fit-for-purpose, and the measurement method will have to be improved to result in a smaller uncertainty. Certification will only apply to the quantity of removed carbon for which there is reasonable certainty. This is to protect the operator who will be responsible for discrepancies.

#### **Additional**

The current standard practice for demonstrating additionality requires the use of a counterfactual, a model of what has not happened or is not the case (Raymond, 2010). This model is used to show what would have happened in terms of removals if the proposed CDR method had not been implemented. When it comes to geologic sequestration this issue of additionality is simple because there is not a lot of change in the contents of the natural reservoir due to natural processes, so any increase in carbon content in the reservoir is going to be due to the CDR technology. However, with other CDR pathways like reforestation or ocean iron fertilization, additionality can become quite complex since carbon content of the reservoir can increase or decrease due to natural processes, and this is where the idea of the dynamic baseline comes in. As time goes on, the counterfactual can be continuously updated, providing a dynamic baseline from which to subtract the total carbon in the reservoir (Novick et al., 2022). The difference determines the total additional carbon removed solely by the CDR method.

Echoing previous work on the matter (Bento et al., 2016; Fischer, 2005; Liu and Cui, 2017; Millard-Ball, 2013; Raymond, 2010), we argue that the use of a counterfactual to prove additionality is a harmful practice for several reasons. Firstly, counterfactuals can be manipulated to benefit a specific party (Liu and Cui, 2017). For example, since counterfactuals are hypothetical, there is a range of possibilities, and it can be manipulated to appear as if the reservoir would have captured less carbon through natural processes than it would have in order to benefit the organization storing carbon by giving them an increased number of carbon credits. Evidence of such manipulation is evident in latest news (Elgin, 2020; Lakhani, 2023). Secondly, since the counterfactual is a hypothetical situation modeling what would have happened in an alternate reality, the more

time that passes, the more inaccurate it will become. This is different from a projection because a projection predicts the future in the same reality, so as time passes a projection can be calibrated and become more accurate. A dynamic counterfactual as proposed by Novick et al. (2022) is an improvement, however, it still cannot be verified.

Instead, Arcusa et al. (2022) proposed that storage operators take responsibility for all the carbon in the reservoir, including natural uptake. Upon the loss of any carbon from the reservoir, the operators would be liable for remediation. In this alternative approach, the need to demonstrate additionality is no longer necessary. Thus, the definition of CDR from the IPCC can be implemented without recourse for counterfactual baselines. The implications of such a proposed practice need to be explored. For example, it assumes that people would not take such a risk if the likelihood of requiring remediation is high. This assumption may not hold, particularly if other disincentives are not in place.

### **Does not degrade the environment**

The overarching purpose of CDR is to be an essential tool in the fight against climate change. Therefore, it would be counterproductive if a CDR approach benefited the environment by removing carbon from the atmosphere while simultaneously degrading it in a separate way. Because of this the CDR industry does need to be held to a high standard in terms of environmental safety and protection.

We make the distinction between CDR pathways and specific projects. Here we look at the environmental fit-for-purpose of the CDR pathway rather than a specific project's location or supply chain. That is because certain CDR pathways may never become or may not be ready to be fit for purpose. Whereas any fit for purpose CDR pathway could be detrimentally

located or have detrimental supply chains. Therefore, any CDR project must be developed following local and national environmental protection laws, demonstrate ethical business practice, and have public approval during their development and certification (discussed later). Absent a local or national process to determine the environmental impact of a project, a comprehensive environmental impact analysis (EIA) should be developed and demonstrated to be considered for certification.

For a CDR pathway to be fit for purpose, it must have limited impact on the environment. We define the environment here broadly, including the atmosphere, hydrosphere, biodiversity, and soil health. Atmospheric impacts include the possibility of the CDR pathway emitting non-CO<sub>2</sub> greenhouse gases such as methane or nitrous oxides and the possibility of producing particulate air pollution beyond socially acceptable limits. Pathways that will significantly disturb other existing carbon reservoirs can be equally unfit if it is a result of the CDR pathway rather than a question of location, supply chain, or personnel. Impacts on the hydrosphere include significant water diversion and pollution of groundwater and waterways beyond socially acceptable limits. Impacts on biodiversity may include destruction of habitats and interference with endangered species. Impacts on soil health include contamination, and loss of nutrients and topsoil.

To be considered fit-for-purpose, the CDR pathways will have to minimize its negative environmental impact to within socially acceptable limits and be held accountable for any negative impacts that it does end up having through penalties. What is socially acceptable may vary spatially and temporally and will need to be periodically revisited. How society decides to impose penalties will also vary geographically and temporally.

### **Permanent on climate-relevant timescales**

Different carbon reservoirs have different expected storage durations because of their physical characteristics. Some reservoirs inherently keep carbon stored for longer periods than others. For example, a building material made of wood may contain carbon for the lifespan of the building or 50-300 years (Mequignon et al., 2013) whereas an old growth forest could remain for millennia (Wirth et al., 2009) and mineralized carbonates for hundreds of thousands of years (Lackner et al., 1995).

This difference in expected storage duration matters because once in the atmosphere, CO<sub>2</sub> will continue to impact temperature and ocean acidification for tens to hundreds of thousands of years (Archer et al., 2009). Some have argued that short term storage does have a benefit. It avoids economic distortions (Fearnside, 2002) and it delays and reduces peak warming (Dornburg and Marland, 2008; Girardin et al., 2021), if implemented in complement to emission reduction (Matthews et al., 2022). Others have argued that storage shorter than the millennial timescale is inefficient and poses an intergenerational problem (Kirschbaum, 2006; Scott et al. 2015), the idea that current generations should preserve the environment for the benefit of future ones (Venn, 2018). In addition to intergenerational equity, the failure of storage to be permanent also presents a particular problem for the polluter pays principle (Arcusa and Lackner, 2022), and for risk exposure. The polluter pays principle is also known as the producer's responsibility (Jenkins et al., 2022) and is a globally accepted principle. As Arcusa and Lackner (2022) explain, in a world where gigatons of carbon are stored for only one hundred years, future generations could find themselves with increasing concentrations of CO<sub>2</sub> once again. They then would need to

manage the situation through more CDR or adapt to rising temperatures. There is no guarantee that future generations will have access to our knowledge nor to the same level of technology. The future has no advocate.

Many proposed CDR activities have short, expected storage durations, does that make them unfit? The answer might be no, if conditions are met to abate the concern of violating both principles of intergenerational equity and the polluter pays. What these conditions are might be up for debate. Some have argued that the temporary benefit can be calculated (Parisa et al., 2022), but others have pointed out that temporary benefits only have a lasting impact if the benefits accumulate (Matthews et al., 2023). Others have demonstrated that the upfront payment for repeating the same storage every five decades is less than 10% of the storage cost (Arcusa and Lackner, 2022). This would lend itself to the idea of blended tonnes, also called horizontal stacking, the idea that multiple storage could be purchased one after the other with upfront payment<sup>6</sup>.

A method that is fit-for-purpose would therefore seem to either require permanence on climate-relevant timescales due to the inherent characteristics of the reservoir or lend itself to some form of contractual management.

### Safe

The last requirement that we will consider is individual and community safety. In this case, by safety we mean avoiding or getting rid of hazards that society is not willing to tolerate, or minimizing the ones that they are, through engineering and project alterations and redesign. This criterion is much dependent on the societal context in which the CDR pathway is

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<sup>6</sup> Nori (2023). Whitepaper - Blended Tonne. Available at: [https://github.com/nori-dot-eco/carbon-](https://github.com/nori-dot-eco/carbon-removal-whitepapers/blob/main/cdr-blended-tonne.md)

[removal-whitepapers/blob/main/cdr-blended-tonne.md](https://github.com/nori-dot-eco/carbon-removal-whitepapers/blob/main/cdr-blended-tonne.md)

being judged. For example, today, coal power plants kill more people per year than nuclear power plants because many coal miners get sick from working in the mines (Ritchie, 2020). However, nuclear power plants are regarded as more dangerous (Hacquin et al., 2022), and therefore require much higher security and safety regulations. A similar case can be made for car crashes versus plane accidents. Car crashes are much more common, and yet there are many more security measures taken before boarding a plane than getting into a car (Sivak et al., 1991). Safety is partially scientific, but also involves public perception. Therefore, while we will have to have safety and societal safeguards in place for the fit-for-purpose criteria, these requirements are likely to change along with the public perception of CDR over time. Like how the regulations for pipelines and cars change due to new data and new perceptions, so too will the requirements for the safety of CDR pathways.

## 6 Criteria Established by Other Organizations

In the previous section we explored what the criteria mean for our purposes. We now turn to the observation that the criteria we have selected are also criteria used by existing standards but with different meanings. This is a common issue in normative processes. The same criteria are interpreted in diverse ways and here we describe a few of these interpretations across a range of organizations: three corporations, one government, an international agency, and two non-profits. We rely on publicly available information for this assessment.

### Microsoft

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<sup>7</sup> Microsoft (2022). Carbon dioxide removal program. Available at : <https://www.microsoft.com/en-us/corporate-responsibility/sustainability/carbon-removal-program>

<sup>8</sup> Microsoft (2024). Criteria for high-quality carbon dioxide removal. Available at:

Microsoft is a technology corporation with a stated goal to be carbon negative by 2030 and achieve carbon-neutrality (including historical emissions) by 2050<sup>7</sup>. They plan to do this by reducing their Scope 1 and Scope 2 emissions to near zero, significantly reducing their Scope 3 emissions, and then utilizing CDR methods to offset the rest. Microsoft separates their fit-for-purpose criteria for CDR into two groups: prerequisites, and considerations. They define prerequisites as requirements that must be met, and considerations as preferences used to distinguish between methods that have passed the prerequisites. The source of the following information can be found on their website<sup>8</sup>.

#### Prerequisites:

*Net Negativity:* Microsoft defines net negativity as removing “net atmospheric carbon dioxide on a life-cycle basis.” This means that they are only counting the atmosphere as the carbon source and require a life cycle analysis of each process to determine whether the process removed more carbon dioxide from the atmosphere than it emitted. They also mention additionality, durability, avoidance of leakage, and clear removal attributes as key prerequisites within the net negativity requirement. They do not define these terms any further.

*Scientific Verification:* Microsoft requires that all projects, regardless of approval from the International Carbon Reduction and Offset Alliance (ICROA)<sup>9</sup> will be required to pass an independent review to make sure that they meet all the net negativity criteria.

*Avoidance of Harm:* Microsoft wants their projects to avoid or minimize the

<https://query.prod.cms.rt.microsoft.com/cms/api/am/binary/RW1mYgP>

<sup>9</sup> The International Carbon Reduction and Offset Alliance. Available at: <https://icroa.org/>

environmental and social harm that could be caused. No further criteria are provided on what standard these harms should be minimized to.

Considerations:

*Global Carbon Removal Potential:* Microsoft wants projects to have a large potential to scale and “contribute meaningfully” to the carbon removal effort eventually.

*Affordability:* Microsoft wants their projects to have a long-term target price of \$15/tCO<sub>2</sub>, with \$100/tCO<sub>2</sub> being achievable in 5-10 years.

*Climate Equity:* Microsoft wants to support projects which support those communities which are disproportionately affected by climate change.

*Technology Innovation:* Microsoft wants to support projects which have unique technologies that can reduce certification costs, be decentralized, or scale in unique ways.

Microsoft’s prerequisite category is straightforward. They will only fund technologies scientifically demonstrated to be net negative, and do not cause social or environmental harm. Although they do not expand on any of the key terms (additionality, durability, etc..) it is important to note that they are aware of the importance of these concepts. However, they also do not expand the definition of social or environmental harm, making it challenging to assess their definition of “harm.” The considerations included show that Microsoft’s goal is to primarily fund technologies which they see as having a large-scale global impact while also becoming affordable in the short term. These preferences could limit Microsoft’s ability to reach and influence companies which are

unsure about their technology’s scalability, or unsure about their ability to reduce the price of their technology below the desired threshold. Conversely, it also shows that Microsoft is only going to be funding what they determine to be serious technologies, instead of distributing funds to smaller startups who are still in the early design stages.

**Carbon Direct**

Carbon Direct is an organization which invests capital in carbon removal companies and assists corporations in creating a path to carbon neutrality. For their investments they use a list of criteria to determine whether CDR approaches meet their standards. They initially start by separating their criteria into two categories: “must have” and “should have.” “Must have” criteria are mandatory and non-negotiable, whereas “should have” criteria are ideals rather than requirements. The broad considerations that Carbon Direct have for choosing their projects include additionality; precise accounting using LCAs; social, environmental, and economic safeguards; durability; environmental justice concerns; leakage; monitoring, reporting, and verification; and a few others depending on the specifics of the method. The source of the following information can be found on their website<sup>10</sup>.

*Additionality:* Carbon Direct requires that their projects prove that they capture additional carbon by using a robust counterfactual to establish a dynamic baseline measurement.

*Precise Accounting using LCAs:* Carbon Direct requires that their projects specify the types of carbon accounting methods used and clearly separate and report the emissions

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<sup>10</sup> Carbon Direct (2022). Carbon removal vetted for integrity and quality. Available at: <https://www.carbon-direct.com/solutions/remove>

reductions and avoidance away from the carbon removals. They also require proof that removals have only been counted once, and not used by different entities. They would recommend that their projects use a comprehensive LCA and/or regional-based sampling methods to quantify emissions and removals.

*Social, Environmental, and Economic Safeguards:* Carbon Direct requires that their projects demonstrate that they have negligible risk of negatively impacting the surrounding ecosystem or local communities through criteria such as soil health, biodiversity, water, and air pollution. Additionally, projects must be transparent about any potential harm they might cause and show that they are taking steps to mitigate those harms as much as possible. They would also prefer their projects to actively pursue co-benefits to the surrounding environment and communities such as advancing sustainable livelihoods, building climate resilience, increasing water conservation, and other activities.

*Durability:* Carbon Direct requires that their projects provide a projected duration for which the captured carbon will be stored and provide an estimate for the risk of reversal. Additionally, the project must specify who is liable for the carbon once it has been stored. They would prefer if their projects had a negligible risk of reversal and have some insurance for carbon removal that has been reversed by using buffer pools or other similar techniques.

*Environmental Justice:* This criterion has many of the same considerations as the Safeguards, but it emphasizes the principle that one should be “equitably protected” from the impacts of climate change. It also specifically recognizes that oftentimes the communities which contributed least to causing climate change are being affected the most. Carbon Direct requires their projects to consistently

engage with the communities in which they are located, provide equitable living wages, be conscious of cultural or religious land, and minimize negative impacts on local community health among other considerations. They also reiterate that they prefer projects which actively pursue co-benefits which promote sustainable livelihoods and economic opportunities for local community members.

*Leakage:* Carbon Direct requires that their projects demonstrate a negligible risk of leakage from the sequestration reservoir and prefer if their projects continue working to lower that risk throughout the course of the project.

*Monitoring, Reporting, and Verification:* Carbon Direct does not claim to have any specific requirements when it comes to MRV, however they prefer if their projects obtain third-party verification of their approach and accounting. Additionally, they would like to see their projects use ground truthing as opposed to relying on modeling.

Carbon Direct asks for specific requirements for each category for each major CDR pathway. Even with the considerable specificity that Carbon Direct provides, they remain vague about what durability means and how much they value it. They claim that the higher the durability the better, but there is no clarity on how much they value 10,000-year geologic sequestration versus 100-year biomass sequestration. There are other benefits and drawbacks to each of these sequestration techniques, but Carbon Direct is vague about how much durability plays a role in their decision making. Similarly, MRV is an important part of carbon accounting which they claim is a priority in their considerations. However, Carbon Direct does not set any requirements for the MRV techniques that must be used, instead they prefer that their projects use best practices. Lastly, Carbon Direct requires the use of counterfactuals to prove additionality without mention of the downsides of this

technique. As mentioned before, the use of counterfactuals can lead to manipulation and poor accounting. Despite these criticisms, Carbon Direct has thought thoroughly about their criteria and have established a robust and transparent method by which they evaluate CDR projects, and therefore, any project that is funded by Carbon Direct comes with a level of credibility.

### **Frontier**

Frontier is an organization which was created by Stripe, Alphabet, Shopify, Meta, and McKinsey Sustainability to provide funding to scale CDR technologies. Frontier provides their criteria in short form on their website where it is easy to find and understand.<sup>11</sup> Their criteria are durability, physical footprint, cost, capacity, net negativity, additionality, verifiability, and safety and legality.

*Durability:* Frontier wants to focus on CDR approaches which store carbon permanently, which they define as greater than one thousand years.

*Physical Footprint:* Frontier wants to use carbon sources and sinks that do not occupy substantial amounts of land.

*Cost:* Frontier requires their projects to have a path to being affordable at a large scale, which they define to be less than \$100 per ton of captured carbon. The key phrase here is “a path to being” which allows them to fund engineered pathways which are currently too expensive to be feasible on their own.

*Capacity:* Frontier requires their projects to have a path to scale to a significant size, which

they define as being able to capture and store greater than 0.5 gigatons per year.

*Net Negativity:* Frontier requires their projects to sequester more emissions than they produce.

*Additionality:* Frontier requires their projects to demonstrate that they are storing carbon additional to what would have already been stored if the project has not taken place. They, however, do not specify how exactly they would like to see this proof.

*Verifiability:* Frontier requires that their projects use “rigorous and transparent methods” for the monitoring, reporting, and verification of their carbon removals and leaks.

*Safety & Legality:* Frontier requires their projects to work towards having “the highest standards of safety, compliance and local environmental outcomes.”

The standards that Frontier uses are in line with both Carbon Direct and Microsoft. Frontier, unlike the other two companies, has clearly stated a minimum-year limit on their permanence consideration. However, to be climate-relevant, their minimum of 1,000 years needs to be increased by at least an order of magnitude. Additionally, Frontier does not mention a difference between scientific permanence and contractual permanence so this limit will not allow for any biomass-based carbon removal methods to be included. On the additionality aspect, Frontier does not exclusively state the necessity of a counterfactual like Carbon Direct, but they do not state that they will not accept it either. And lastly, like Microsoft and Carbon Direct, in their criteria Frontier does state the requirement of

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<sup>11</sup> Frontier Climate (2022). An advance market commitment to accelerate carbon removal. Available at: <https://frontierclimate.com/>

MRV, but they do not go into detail about any specific MRV tools or methods that will be required. However, Frontier has also published their updated Q&A for guidelines for CDR Measurement and Verification in May of 2023.<sup>12</sup>

### **California Air Resources Board**

The Low Carbon Fuel Standard (LCFS) is a standard in the state of California, which, among other uses, rewards organizations that store carbon dioxide through geologic sequestration<sup>13</sup>. Unlike the criteria laid out by organizations which are planning on investing in carbon removal technologies, the LCFS is a government program, and therefore they are required to be more transparent about their selection criteria. The LCFS provides a detailed standard for what the state of California deems as certifiable geologic sequestration. Many of these criteria do not overlap with our fit-for-purpose criteria, but the most relevant are reviewed. The full list of criteria can be found on their website and in appendix A.

#### Well Construction and Operating Requirements:

*Well Construction:* For geologic sequestration, the LCFS states that the well must be constructed to prevent fluids from moving to unauthorized areas, allow the use of testing and monitoring devices, and permit the “continuous monitoring of pressure in the annulus space between the injection tubing and the long string casing.” Additionally, the well construction has many guidelines to do with the materials, manufacturing techniques, size, and configuration of the well.

#### Injection Monitoring Requirements:

*Testing and Monitoring:* The LCFS sets out a detailed testing and monitoring procedure for the injection process. This is necessary for geologic storage because it is important to know as soon as possible if there is something wrong with the injection process. If something goes wrong during the injection process and it is not caught, then this could be a highly costly mistake because the assumed CO<sub>2</sub> sequestered, and actual CO<sub>2</sub> sequestered could be vastly different. Therefore, it is important that the testing and monitoring process be detailed and thorough.

#### Financial Responsibility:

The project operator must show and maintain monetary responsibility of the resources required for the project. The LCFS goes into detail describing the various financial tools and responsibilities that the project operator has and can use.

#### Modification or Revocation and Reissuance of Permanence Certification:

*Termination of Permanence Certifications:* The LCFS states that the Executive Office can terminate a Permanent Certification if the projector operator does not comply with one permanence criteria, failed to disclose all the facts prior to the issuance of the permanence certification, or is conducting an activity that endangers public or environmental health.

The detail with which the LCFS criteria are written provides a template for the thoroughness that should be required when determining standards for individual methodologies. However, to analyze their fit-for-purpose criteria, we need to look at high level

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<sup>12</sup> Frontier Climate (2023). CDR Measurement & Verification Q&A. Available at: [https://raw.githubusercontent.com/frontierclimate/carbon-removal-source-materials/main/TEMPLATE%20Project%20Application/2022\\_08%20\(fall\)/Guide%20-](https://raw.githubusercontent.com/frontierclimate/carbon-removal-source-materials/main/TEMPLATE%20Project%20Application/2022_08%20(fall)/Guide%20-%20CDR%20Measurement%20%26%20Verification%20Q%26A.pdf)

[https://raw.githubusercontent.com/frontierclimate/carbon-removal-source-materials/main/TEMPLATE%20Project%20Application/2022\\_08%20\(fall\)/Guide%20-%20CDR%20Measurement%20%26%20Verification%20Q%26A.pdf](https://raw.githubusercontent.com/frontierclimate/carbon-removal-source-materials/main/TEMPLATE%20Project%20Application/2022_08%20(fall)/Guide%20-%20CDR%20Measurement%20%26%20Verification%20Q%26A.pdf)

<sup>13</sup> California Air Resources Board. Low Carbon Fuel Standard. Available at: <https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard>

ideas. Additionally, since this standard is specifically designed for geologic sequestration, it will not have the same themes as the criteria used by the investment organizations. Two ideas, the minimum site selection criteria and the storage complex delineation, are relevant for our purposes.

Through the fit-for-purpose criteria it will be important to establish what the minimum criteria should be to select a sequestration site. This criterion will not be the same as the one detailed in the LCFS because the LCFS only works with geologic storage and our criteria is meant to be applicable across all carbon removal pathways. Secondly, storage complex delineation will be an extremely important concept moving forward, not just in terms of security (vs. leakage) but also in terms of to delineate where one reservoir begins and another ends as it pertains to biomass or ocean reservoirs. The fit-for-purpose criteria will need to explain processes and provide options for how operators can delineate their reservoirs for accounting as well as security.

The other more specific criteria described by the LCFS such as Well Construction or Post-Injection Site Care do not lend themselves to be as useful for the purpose of our criteria list, but clearly will be important reference points when standards for various removal and storage pathways need to be written.

### **United Nations Development Programme**

The United Nations Development Programme (UNDP) created eight Social and Environmental Standards for their projects to follow, available on their website<sup>14</sup>. These eight standards detail how each project should be evaluated, and what it should and should not include. We have

provided a summary of each standard below. More detailed information can be found in Appendix B.

#### Climate Change and Disaster Risks:

*Climate change and disaster risk analysis, planning and implementation:* UNDP requires that all projects be evaluated for their potential to be impacted by climate change and disaster, as well as their potential to increase an area's potential to be impacted by climate change and disasters. If significant potential is identified, then UNDP takes further steps to identify and mitigate these risks.

*Greenhouse gases:* UNDP attempts to reduce and where possible avoid the increase of greenhouse gas emissions through their projects. If a project does require a significant increase in greenhouse emissions, then the project is required to document the source of these emissions and take steps to mitigate and reduce those emissions where possible.

#### Community Health, Safety and Security:

*Community health and safety:* UNDP requires their projects to protect local communities from the potential negative impacts caused or produced by the project. Both direct and indirect impacts of the project on the community are included by the UNDP in this characterization.

*Assessments and management plans:* The UNDP requires that their projects assess the potential risks and safety hazards that they might cause to the community around them during all stages of the project. They must then try to avoid or reduce as many of these negative impacts as possible. After all avoidance and/or reduction measures are taken, the project will be

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<sup>14</sup> UNDP (2021). UNDP Social and Environmental Standards. Available at:

<https://www.undp.org/publications/undp-social-and-environmental-standards>

evaluated. All projects must also take appropriate health and safety measures.

*Community exposure to health issues:* UNDP requires that their projects avoid or minimize the health risks that the project could expose the community to.

*Infrastructure design and safety:* The UNDP requires that any construction or operation in a project be in line with the national and international requirements, as well as any industry standards set by professionals. The construction and operation of any technology or structure should not pose any significant risk of health issues to the community or workers.

*Universal Access:* The UNDP requires that the design and construction of facilities be accessible equally to all the public when possible.

*Hazardous materials management and safety:* The UNDP requires that the project avoid or reduce as much as possible the community's exposure to toxic or hazardous materials.

*Emergency preparedness:* The UNDP requires that their projects be prepared and have procedures to address emergencies (both anticipated and unanticipated). These plans should be periodically reviewed and revised if necessary.

*Risks associated with influx of project workers:* The UNDP requires that projects anticipate and address the issues associated with increasing the number of project-workers. This risk can span from the spread of diseases to threats of sexual violence, to training capacity.

*Impacts on ecosystem services:* The UNDP requires that projects understand and mitigate the impacts that they could have on ecosystem services that serve nearby communities. Projects must take measures to

address the indirect negative impacts that they can have on the community.

*Security-related issues:* The UNDP requires that projects take security measures to protect sensitive or dangerous property or information from the public. Projects must mitigate the risks that can be created by sensitive information or property landing in the wrong individual's hands.

Culture Heritage:

*Avoidance, assessment, and mitigation of adverse impacts:* The UNDP requires relevant projects to provide an assessment of the impact they will have on the cultural heritage of a community. Then, the project must work to avoid having any impact on their cultural heritage if possible and reduce their impact to the minimum if not.

*Chance find procedures:* The UNDP requires their projects to include "chance find procedures." These procedures will determine how chance finds of cultural heritage will be addressed and managed prior to the chance find itself.

*Community participation, stakeholder consultations and use of experts:* The UNDP requires that all projects with potential for impacting a community's cultural heritage must use Cultural Heritage experts and relevant stakeholders to assist in the identification, handling, and documentation of affected cultural heritage.

*Continued access:* UNDP requires that projects do not restrict access to Cultural Heritage if possible. If it is not feasible then the Cultural Heritage will be accessible through stakeholder consultations and other alternative methods.

*Confidentiality and restricted access by communities:* With the relevant stakeholders

and experts, UNDP projects should determine whether information regarding Cultural Heritage would be considered sensitive information, and if it should or should not be disclosed to the public. If it is determined that the information should not be disclosed, then the project should respect and maintain the practice of the relevant communities as it relates to the Cultural Heritage in secret.

*Integration and use of Cultural Heritage:*

The UNDP requires projects that wish to integrate and/or use Cultural Heritage as a part of their project to meaningfully engage with the relevant communities and inform the affected communities of their rights, the scope of the project, how their participating will impact the project, and the potential consequences for them. The project should respect the community's culture, and work to make sure that the meaning of the cultural Heritage is not impacted or distorted.

Displacement and Resettlement:

*Prohibit forced evictions, allowing evictions in exceptional circumstances only:* UNDP projects should not force individuals or families to move out of their home or land. Evictions in general (not forced) should only be allowed in rare circumstances where the eviction meets specific criteria.

*Avoid, minimize, and mitigate physical and economic displacement:* UNDP projects should work to avoid physical and economic displacement by considering all other feasible options. When displacement cannot be avoided, the project should work to minimize the impacts of displacement on the displaced people and provide them with timely access to effective remedies.

Indigenous Peoples:

*Respect for domestic and international law:* The UNDP requires that their projects do

not violate the human rights of Indigenous peoples under international law.

*Identification of Indigenous peoples:*

UNDP projects must acknowledge that "Indigenous peoples" does not refer to one group of people, but rather diverse groups of people who have diverse cultures, values, and identities. UNDP projects will treat diverse groups of Indigenous peoples differently and equally while respecting their cultures.

*Land, territories and resources:*

UNDP projects should acknowledge that Indigenous peoples have the right, as a group, to use their lands (which they have traditionally owned) as they see fit. UNDP projects will not conduct activities that undermine Indigenous peoples' right to their land. They will be consulted and take part in the decision-making process for any processes that happen on their land.

*Full, effective, and meaningful participation and FPIC:*

UNDP projects should engage relevant Indigenous communities early and continuously throughout the design, construction, and implementation of the project. This engagement should be meaningful and effective, and the information gained from the engagement should be used throughout the decision-making process.

Labor and Working Conditions:

*Forced Labor:* UNDP Projects will not use, or knowingly support the use of forced labor. If the project determines that forced labor is being used to support their work, then they will immediately take steps to fix the situation.

*Child Labor:* UNDP Projects will not use or knowingly support the use of child labor, defined as the labor of people under the age of eighteen. If it is determined that child labor is or could be being used, the project will take immediate steps to fix the situation.

*Occupational Health and Safety:* UNDP Projects will take steps to protect workers' health and safety through the design and implementation of the project. The project will work to fix and address any reported situations where the workers' health and safety is not being prioritized, or if there is a potentially dangerous situation.

Pollution Prevention and Resource Efficiency:

*Pollution Prevention:* UNDP Projects should avoid releasing pollutants as much as possible. If avoidance is not possible, then they should work to reduce the release of pollutants to the minimum.

The UNDP Social and Environmental Standards are unique and not related to carbon removal. They could be used in the context of the impacts that carbon removal could have on the surrounding environment. The purpose of fit-for-purpose criteria is to create a suitable standard for carbon removal to meet climate goals. This purpose lends itself easily to technical and environmental criteria. The technical criteria are important because the technical standard needs to be high for sequestration to be accountable. The environmental criteria are in line with our purpose because we cannot certify projects that contribute to the degradation of the environment while trying to mitigate climate change. While the social criteria are important, it is not something that we believe should be governed by a framework that assesses the fitness of a method. Therefore, we can take several points of influence from the first, second, and eighth standards, however we will not be heavily influenced by standards 3-6 (aside from the industry standards and international and national laws).

**Accountability Framework**

The Accountability Framework (AF) is the result of several notable global organizations, such as the World Resources Institute, the World Wildlife Fund, and the Nature Conservancy among tens of others, working together to create a "comprehensive and consensus-based framework to guide goal setting, implementation, and monitoring for ethical supply chains", according to their website<sup>15</sup>. It references human rights, human health, as well as other important topics in addition to climate change. The criteria provided by the accountability framework included monitoring and verification, but it did not go into detail about *how* they would want systems monitored and processes verified. This is due to the framework being aimed at providing overarching big-picture guidelines instead of detailed criteria for distinct processes. We will provide brief summaries for each of the criteria provided by the AF. The source of the following information can be found on their website<sup>15</sup>.

Guidelines for Effective Monitoring Systems:

*Baseline and follow-up monitoring:* AF states that baseline data is collected the first time that a supplier is monitored. It should "characterize current conditions" for the entire area that is supposed to be monitored in the future. This baseline data is what future measurement data will be compared against. The AF states that the baseline data should also conduct a historical analysis to determine any potential impacts that prior activities could have on future activities conducted on the same area. Follow-up monitoring should take place during regular appropriate intervals to collect data and compare it to the baseline. Follow-up monitoring can help determine issues with the process, as well as track the progress of a project over time, depending on the types of data collected.

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<sup>15</sup> Accountability Framework Initiative. Available at: <https://accountability-framework.org/>

Follow-up monitoring can be designed to assess cumulative impacts of the project, which might not be detectable otherwise.

*Characteristics of effective monitoring systems:* The AF states that to be effective, monitoring must have a few essential criteria. Firstly, monitoring must be frequent and thorough to detect meaningful change. The frequency and thoroughness of the monitoring depends on the environmental variables and project considerations. Secondly, the monitoring must be tailored to the “commodity, geography, production context, and nature of the issues being assessed.” This means that there is no standard monitoring methodology because it is dependent on many independent variables. Thirdly, the monitoring procedure should lend itself to data analysis and comparison to determine the necessary changes or constants. Lastly, the monitoring data should be used to inform decision-making, and in turn changes in the system should change the monitored variables when appropriate.

*Metrics for assessing compliance and progress with commitments:* The AF lists a few important characteristics that monitoring metrics should have. They should be clearly defined to understand what is being monitored and why it is important. They should be “standardized and repeatable” to have ease of comparability with the baseline data over time. They should be sensitive enough to detect meaningful changes, but not so sensitive that they pick up a lot of noise. Lastly, they should be supplemented by qualitative information from key stakeholders and experts to give the quantitative data context.

Guidelines for credible verification:

Verification is important because it “serves to assess and validate the findings of monitoring processes” and if employed properly, can serve as a reliable tool in the decision-making process.

*Characteristics of a credible verification process:* The AF outlines several key qualities that are important to have a credible verification process. Firstly, the verification process must be consistent and rigorous. That is, it must be easily repeatable and thorough so that it is a detailed process which can be performed regularly. Secondly, verification must be conducted with qualified, impartial, and independent auditors so that it is done well and has credibility from the outside. Like the previous point, the verification process must be transparent so that it can maintain its credibility. Lastly, the verification process must be well-documented so that the information is available in case it needs to be reviewed in the future.

*Third-party verification:* The AF mentions third-party verification multiple times in previous sections and then goes into more detail by giving this concept its own section. This goes to emphasize the importance that the AF gives the perception of credibility in the verification process. A large part of the purpose of verification is to show others that a particular method or practice is credible and reliable. Receiving third-party verification significantly increases the credibility of a particular process. If the third-party has government oversight, has no conflicts of interest, and is a legal entity then the process will get even more credibility.

Unlike some of the standards reviewed above which have been niche, the criteria provided by the AF are general and applicable to a broad range of activities beyond supply chains, including carbon sequestration. The AF makes two arguments relevant to CDR. First, it demonstrates that a higher-level approach to creating a “comprehensive and consensus-based” framework is effective in creating understandable and applicable criteria regarding baseline setting and monitoring. These requirements would be applicable to all types of reservoirs and relevant to most CDR

methodologies. Second, the AF makes the case that an impartial, independent, transparent, third-party verification is necessary. The suggested metrics for assessing compliance and progress could also work for CDR. However, the generality of the AF has limits. The guidelines for baseline setting and monitoring are not entirely transferable to CDR. For example, each reservoir is unique and will need specific protocols. Nevertheless, important lessons can be learned from the AF's guidelines for effective monitoring and credible verification.

## **7 Comparisons**

### **Durability and permanence**

Through the reviewed literature we have seen that durability (i.e., permanence) is a common theme. Most organizations reviewed cite that the CO<sub>2</sub> that is sequestered must be durable. Durability in this situation means that once the carbon is stored, it has an extremely low chance of escaping. Some criteria cite one hundred years of storage as durable, while others cite 1,000 years. Some criteria even distinguish between high-durability storage (geologic) and low-durability storage (biomass reservoirs). There is a distinction to be made between durability and permanent storage based on normative values. Durability may be related to a reservoir's unique characteristics whereas permanence is the answer to "how long is long enough." In our fit-for-purpose criteria we therefore must take a stance.

First, we decided that to be considered permanently stored, a storage methodology must demonstrate an extremely low probability of release on 10,000 years timescales. While this might seem like an unnecessarily long time, this number is important. Due to the exceedingly long residence time of carbon dioxide in the atmosphere and the oceans, 100 or 1,000 years of storage is not long enough. CO<sub>2</sub> released after 100 or 1,000 years will resume climate impacts

on future generations that are living at that time. Letting them deal with a problem that they did not cause, and may not be able to address, is intergenerational inequity. Furthermore, a definition of 1,000 years does not address the problem of ocean acidification, which is the other consequence of releasing carbon dioxide into the environment. Only sequestration over multiple millennia would do so.

Second, carbon removal certification programs should not distinguish between the reservoirs that the carbon is stored in in terms of outcome. A certificate ought to have the same meaning whether produced from a geologic formation or an oceanic reservoir. That is, a certificate guarantees proven, safe, and permanent sequestration regardless of which reservoir carbon was originally stored in. The buyer of the certificate need not have to check on the permanence of the certificate. As shown by the differences in the geologic sequestration standards (LCFS) and the forest reservoir sequestration standards (CAR), these two methods of sequestration have vastly different protocols and methodologies, resulting in different meanings of their certified product. The consequence of this variance is evident in the current markets (Arcusa and Sprenkle-Hyppolite, 2022), where credit prices can range from a few to thousands of dollars (Joppa et al., 2021). Instead, the "high durability" storage should be classified as permanent based on the scientific proof. The "low durability" storage should be classified as permanent based on some form of contractual chain of custody. That is, through monitoring and verification, we should be able to periodically verify that the carbon dioxide is still sequestered. If the CO<sub>2</sub> escapes, then it is the responsibility of the storage operator to re-sequester that escaped CO<sub>2</sub>. Through this contractual responsibility, the "low durability" storage should also have the same value as the geologic storage because it

internalizes its potential for not being permanent.

Although these positions are quite different from what has been previously used by industry and standard setting organizations, they are important for the long-term climate mitigation plan.

### **Additionality**

Through the literature review section additionality has been a common theme. This criterion is important and sensible to have because companies and consumers will want to know that the sequestered carbon that they are paying for is making a difference in the fight against climate change. If the carbon would have already been sequestered, regardless of their payment, then they would not be getting any value of their money. Therefore, it is important that any carbon removal and sequestration process be removing and storing carbon additional to what would have already been stored via natural processes.

However, all the criteria that were reviewed in the literature review section were either requiring or recommending the use of a counterfactual to prove additionality. In this situation, a counterfactual would be a model, simulating a world where a carbon removal method – that was being employed in the real world – was not being used. Therefore, by comparing the actual amount of carbon sequestered, to the simulated amount of carbon sequestered, the amount of additional carbon sequestered by the CDR method can be determined. While this makes sense in theory, it runs into several issues when put into practice.

Firstly, a model that splits the timeline can simulate a greater or lesser amount of CO<sub>2</sub> sequestered, just by changing the values of a set of variable. This leaves the model open to manipulation. Secondly, unlike a projection, which projects the future in the same timeline,

and therefore can become more accurate as time passes through the addition of new data, an alternate reality simulation gets less accurate. Since reality never catches up with the model, the longer the counterfactual is used, the less accurate it becomes.

In our proposed fit-for-purpose criteria we acknowledge the need for additionality in carbon removal and certification, but we propose a simpler solution. The most straightforward solution we propose is to conduct a baseline test for the reservoir to determine its original carbon content. We then use this baseline as a static baseline (as opposed to the dynamic baseline provided by the counterfactual) from which to judge additionality. Although for some natural reservoirs like forests, the storage operator might be able to “take credit” for nature’s work, we also propose that they take the liability for that stored CO<sub>2</sub>. If that carbon reservoir leaks some carbon, they will be responsible for re-sequestering all of it, based on the static baseline.

This approach to additionality does require some compromise, but we believe that it is simpler, and therefore more suited to function overall.

### **Social and environmental standards**

In addition to the technological criteria for CDR pathways, we argue some basic environmental and social safeguards are necessary in the fit-for-purpose criteria to protect ecosystems and communities around the technology. As shown in the literature review section, these will typically be safeguards that are common in other industries to make sure that activities do not violate human rights or severely harm surrounding ecosystems. We draw attention to two distinctions.

First, since we believe that CDR aims to improve the environment, we argue it must

accordingly be held to higher-than-normal environmental standards in the fit-for-purpose criteria. It would be unproductive if a CDR pathway sequestered carbon while causing other environmental harm, especially if this pathway is to be scaled to large scales. Furthermore, it would be equally counterproductive if a CDR pathway sequestered carbon while harming people. Accordingly, CDR pathways must be made safe. However, safety is a representation of its society. What is considered safe in the United States may not be acceptable in European countries. Therefore, while safety can be a fit-for-purpose criteria, it must be defined.

Secondly, the goal of the fit-for-purpose criteria is to determine whether a technology accomplishes the minimum requirements to be labeled as a fit-for-purpose “CDR pathway.” This entails the many requirements that are listed above. However, we do not believe solving societal ills is the aim of the CDR industry. Therefore, we argue the industry should not be held to a higher social standard (social acceptance, high minimum wages, pay equity, etc.) than any other industry. All industries should be held accountable, not just the CDR industry. Therefore, it is not justifiable to include higher social standards in the fit-for-purpose criteria.

What is necessary however, is for the CDR industry to take a stance against violations of human rights and the suppression of worker rights within its ranks, for governments to enforce and tighten its existing laws protecting workers, and for people to support unionization to protect workers rights. It is unacceptable for any industry to violate human or workers’ rights. Therefore, while the CDR industry should strive to uphold strong environmental and social standards and values, the certification of carbon storage should not be used as a catch-all for systemic societal issues.

### **Carbon negativity**

When addressing the key components of carbon credits, all the relevant reviewed literature mentions carbon negativity as a key aspect. In some sense, carbon negativity is the most fundamental aspect required to create a carbon credit because it is the criteria that requires proof that more carbon is being sequestered than emitted. However, while there is wide agreement that there needs to be proof of carbon negativity to receive certification of carbon credits, there are differing views on what this proof should be.

The criteria for Frontier simply state that projects must sequester more carbon than they emit without providing any further guidance. Microsoft and Carbon Direct both require a life cycle analysis to show that more carbon is being stored than emitted throughout the life cycle of the carbon removal and storage process. While LCAs seem like an appropriate tool to evaluate emissions versus storage of carbon, it has been argued that this method of proof is flawed (Lackner et al., 2023). LCAs are adept at quantitatively evaluating environmental footprints, but they are not the correct tool for precise quantitative accounting. The results of an LCA depend heavily on the system boundaries that are drawn, and the amount and quality of data that is available along the entire supply chain. Both of these characteristics make LCA easily manipulable and extremely complicated to do accurately at the level of precision that is required (Lackner et al., 2023).

For this reason, we support here the proposal by Lackner et al. (2023) to follow a method of proof which requires the accounting of emissions to be done as far upstream as possible – the point of fossil fuel extraction. This limits the need to collect high-quality data throughout the supply chain and increases the accuracy of the accounting overall. Additionally, this method is not reliant on the subjective

boundaries that need to be drawn for LCAs. While we do acknowledge that the proposal of upstream accounting will require larger changes in the bureaucratic accounting process compared to the LCA method, we argue that it will help us achieve our climate goals more reliably by being a more accurate system of accounting.

### **Measurability**

Unlike the other four criteria in this discussion section, measurability is not a criterion that is outlined clearly in the literature that was reviewed. Microsoft mentions it tangentially when using “avoidance of leakage” as a criterion but does not specifically discuss measuring the carbon entering or residing in the reservoir as a criterion. Carbon Direct mentions both “low risk of leakage” and “monitoring, reporting and verification” (MRV) as criteria. However, Carbon Direct also specifically states that they do not require any specific requirements for MRV and prefer their project partners to go through third-party verification. Frontier requires “rigorous and transparent methods” for MRV but does not specify further. These three organizations represent the buyers and investors in the literature that we reviewed and none of them have provided detailed requirements for the measurability of the carbon that is stored.

The Low Carbon Fuel Standard, which is a standard specifically for geologic storage, provided a more detailed set of requirements for the well construction, testing and monitoring, and well termination. While informative, these standards cannot be applied to most other forms of carbon storage (such as storage in biomass, oceans, or above-ground geologic formations).

The Accountability Framework provides guidance for effective monitoring and credible verification systems. The framework requests projects to establish a baseline status after which frequent, context dependent monitoring occurs

that informs the decision-making process. Subsequently, the framework requests a well-documented, consistent, rigorous verification process to be conducted by credible and impartial auditors. This framework provides guidance, which is applicable to all kinds of certification projects, including non-carbon storage projects, but is not specific enough for the certification of carbon sequestration.

The criteria that we provide for measurability clearly states, for all types of carbon storage, that the reservoir needs to be clearly delineated, and that changes in the content that enter or leave the reservoir must be measurable. While the kinds of delineation and the methods for monitoring the change in content will be different for each type of reservoir, these requirements are necessary to know precisely, within an acceptable margin for error, how much carbon is being stored and certified. This approach outlines the kind of rigor required from project developers and verifiers to make a carbon credit that is credible.

## **8 Concluding discussion**

This study aimed to affirm the importance of assessing the fitness-for-purpose of carbon removal methods as a step towards responsible CDR technology development. A definition for the term fit-for-purpose in the context of carbon removal was proposed, specifically the attribute of a CDR method where its detrimental side effects are sufficiently small to be acceptable. In line with the ISO’s definition of fit-for-purpose, the ability of a product, process, or service to serve a defined purpose under specific conditions, we sought to define the purpose of carbon removal and its specific conditions by asking two questions: what is the purpose of carbon removal? What criterion can be used to assess the fitness of carbon removal methods? Through the exploration of these two questions, we delved into six fit-for-purpose criteria used by many organizations, namely carbon negativity,

measurability, additionality, sustainability, permanence, and safety.

Because some aspects of fitness-for-purpose are value-driven by nature, the meaning of these criteria can differ between organizations. In our assessment, this was the case. More alignment could be found for safety and environmental safeguards, but not for additionality, permanence, measurability, and carbon negativity. This might be surprising, but it speaks to the business interests of the latter. A climate counterproductive method (i.e., those that fail at additionality, permanence, measurability, and carbon negativity) can meet environment and social safety, but will undoubtedly fail at these performance-based criteria. Existing misalignment highlights the need for a process to shape the meaning of all fit-for-purpose criteria.

What should this process look like? This work highlights the need to engage a broad set of voices, as is called for by procedural justice (Nawaz et al., 2024). As happens to jobs and pollution (Emilcar, 2014; Li and Zhou, 2017), this work also highlights the need for international agreements to prevent offshoring to countries that would allow unfit methods. The misalignment found in this work also speaks to the need of standardization and consensus building to minimize the potential for special interests. Together, this would suggest the need for a transparent, multi-stakeholder, consensus-based, international convening process. Or “no innovation without representation” (Guston, 2023). Such a process could be started locally by national standard agencies (e.g., NIST in the United States) and multi-stakeholder led independent governance body (e.g., the Integrity Council for the Voluntary Carbon Market) and passed on to the international stage by intergovernmental organizations (e.g., ISO and the IPCC).

How could the results of this process be translated into practice? Sekera et al. (2023) put forth a biophysical inputs-outcomes metric to analyze CDR methods. However, this approach does not delve into risks of the included methods in a meaningful manner, basing its assessment instead on their sequestration capability and resource requirements. An additional tool might be imagined to be used before such an assessment. This new tool could be method-agnostic and embed the fit-for-purpose criteria developed by the process in a series of questions probing the proposed method. One consideration might be the need for flexibility in the face of uncertainty. For example, there may be a period at a method’s early stage where its fitness may not be fully known. The process to determine the fitness of a CDR method must therefore also allow for scientific progress. A gated approach where a CDR method can be reviewed with revisions multiple times would provide that flexible yet precautionary decision-making.

In such a process and with such a tool, not all CDR methods proposed currently will be deemed fit-for-purpose and this will make special interests upset. However, the potential that humanity fails to manage one of the greatest crises it has ever faced is too consequential. Just like special interests need to be kept separate from discussions of addressing climate change (Lackner and Wilson, 2008), special interests must be kept out of legitimate selection of fit CDR methods. CDR deployment must not be delayed and simultaneously, only CDR which is fit-for-purpose must be deployed.

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## **10 Appendix A: detailed summary of LCFS criteria**

### **Site Characterization:**

*Minimum Site Selection Criteria:* The minimum criteria for site selection are defined using volume, porosity, permeability, injectivity, and a minimum injection depth. Additionally, systems to confine the reservoir need to be created and/or identified and tested.

*Risk Assessment:* A risk assessment for the selected site must be completed to quantify the risk of CO<sub>2</sub> leakage over a 100-year period post-injection. This risk assessment will be used to plan future steps for testing and monitoring of the site. The Project operator must submit a Risk Management Plan which summarizes the activities evaluated for risk, what risk they cause, the magnitude of each risk, and how the operator plans to monitor and minimize those risks. To receive a "Permanence Certification" by the LCFS standards, the site must have a 90% chance of retaining 99% of CO<sub>2</sub> after one hundred years post-injection.

*Geologic and Hydrologic Evaluation Requirements:* The LCFS standards require that project operators submit an evaluation of the geological and hydrological characteristics of the sequestration area. This evaluation is provided by using a variety of data, tests, and calculations.

*Storage Complex Delineation and Corrective Action:* The storage complex needs to be clearly delineated using computational modeling in order to determine the reservoir boundaries. Wells that need corrective action need to be identified and receive the required action to plug potential leakages.

*Baseline Testing and Monitoring:* LCFS requires that project operators must monitor the surface, sub-surface, and deep subsurface for CO<sub>2</sub> leaks. The baseline test is the first test performed which will establish the standard to which all future measurements will be compared. This baseline test must be planned and executed to "detect, validate, and quantify potential CO<sub>2</sub> leakage." After the baseline test, regular monitoring must occur to detect any meaningful changes in the reservoir and any additional CO<sub>2</sub> leaks.

### **Well Construction and Operating Requirements:**

*Well Construction:* For geologic sequestration, the LCFS states that the well has to be constructed to prevent fluids from moving to unauthorized areas, allow the use of testing and monitoring devices, and permit the "continuous monitoring of pressure in the annulus space between the injection tubing and the long string casing." Additionally, the well construction has many guidelines to do with the materials, manufacturing techniques, size, and configuration of the well.

*Pre-Injection Testing:* Prior to injecting CO<sub>2</sub> into the well, it must be thoroughly tested and documented in order to establish pre-injection baseline information. These tests include recording information such as the depth, thickness, porosity, and permeability of the sequestration zone, as well as making sure that the well is in line with the well construction requirements. The project operator must submit a Pre-Injection Testing Plan detailing how all of this will happen. Additionally, after testing the information and data should be available to be reviewed.

*Injection Well Operating Requirements:* Like the requirements for Well Construction, the LCFS has a lengthy list of requirements for Injection Well Operations. These requirements include a map diagramming the injection facilities, a maximum theoretical surface injection pressure, appropriate

monitoring schedule and documentation system, and the proper treatment of water that is injected for processes involving EOR. There are several other requirements listed which are particular to well operation for geologic sequestration which are not relevant for the scope of this paper.

*Operating Restrictions and Incident Response:* The LCFS has constraints to ensure that all the CO<sub>2</sub> being injected into the well can be certified. If there is an issue with the well integrity, then injection must cease because any CO<sub>2</sub> injected into the well after its integrity has been compromised cannot be certified. Additionally, the LCFS also describes the protocol for the project operator when there is an incident during the injection process.

### **Injection Monitoring Requirements:**

*Testing and Monitoring:* The LCFS sets out a detailed testing and monitoring procedure for the injection process. This is necessary for geologic storage because it is important to know as soon as possible if there is something wrong with the injection process. If something goes wrong during the injection process and it is not caught, then this could be a highly costly mistake because the assumed CO<sub>2</sub> sequestered, and actual CO<sub>2</sub> sequestered could be different. Therefore, it is important that the testing and monitoring process be detailed and thorough.

*Mechanical Integrity Testing:* The mechanical integrity test in the LCFS is there to make sure that the well maintains its structural integrity throughout the injection process. If the well's structural integrity weakens or fails, then there is elevated risk that CO<sub>2</sub> could leak at a higher-than-expected rate. This testing process will ensure that if the well integrity is compromised, the project operator will know about it soon.

### **Well Plugging and Abandonment and Post-Injection Site Care and Site Closure:**

*Well Plugging and Abandonment:* After a well is no longer needed for use, it must be plugged and closed properly. Appropriate tests and protocols need to be followed for plugging a well to ensure that CO<sub>2</sub> does not leak at a higher rate than expected. The LCFS outlines detailed standards for how to plug and abandon a well. This procedure involves checking the mechanical integrity of the well, and flushing the well with a buffer fluid among several other steps.

*Post-Injection Site Care and Site Closure:* If all the wells at an injection site are plugged, then the Injection site could be closed. There are several checks and protocols that need to be followed to safely close an injection site. After closing, the injection site still needs to be monitored for leaks for a period. Additionally, for 24 months after the injection site closure, the site must go into a post-injection site care protocol. 15 years after the site closure the project operator is eligible to submit evidence that plume stabilization has occurred. After plume stabilization has occurred, the operator can be certain that no CO<sub>2</sub> will leak naturally from the injection site and the site can be abandoned.

**Emergency and Remedial Response:** To have the Sequestration Site certified, the LCFS states that the project operator must provide the Executive Officer with an "Emergency and Remedial Response Plan." This plan details the procedure on the site if an emergency that has the potential to endanger public health occurs.

*Emergency and Remedial Response Requirements:* The emergency must first be classified as a major, serious, or minor emergency. Then, accordingly, the Emergency and Remedial Response Plan must

include a list of potential scenarios which could cause an emergency, the potential consequences for each scenario, potential local infrastructure that could be affected by each scenario, and then an action plan to respond to each scenario.

**Financial Responsibility:** The project operator must show and maintain monetary responsibility of the resources required for the project. The LCFS goes into detail describing the various financial tools and responsibilities that the project operator has and can use.

**Modification or Revocation and Reissuance of Permanence Certification:**

*Termination of Permanence Certifications:* The LCFS states that the Executive Office has the ability to terminate a Permanent Certification if the project operator does not comply with one permanence criteria, failed to disclose all of the facts prior to the issuance of the permanence certification, or is conducting an activity that endangers public or environmental health.

*Minor Modification of Permanence Certifications:* The LCFS states that Permanence Certifications can have minor modification made by the Executive Office to correct typographical errors, require more frequent monitoring, allow for a change in ownership, or other minor change which do not affect the permanence of the sequestered carbon dioxide itself.

## **11 Appendix B: detailed summary of UNDP criteria**

### **Biodiversity Conservation and Sustainable Natural Resource Management:**

*Precautionary Approach:* The UNDP requires that the precautionary approach be applied to any significant interaction with natural habitats or ecosystems. This means that any potential harm or risk that can be caused to these environments should be proactively mitigated.

*Risk Identification and Assessment:* The UNDP requires that a detailed risk assessment of the direct and indirect impacts that the activity has on the “natural resources, biodiversity, ecosystems and ecosystem services” is completed and provided. Additionally, potential cumulative impacts across land and time will be evaluated and addressed.

*Use of Experts:* UNDP requires that qualified experts be used to evaluate and approve projects.

*Siting preference:* UNDP projects should be sited in areas that have minimal impact on biodiversity and ecosystem services. Additionally, where possible, lands that have already been impacted or converted for land use should be reused.

*Modified Habitats:* UNDP requires that their projects minimize any additional unnecessary conversion or degradation of the natural environment. Additionally, where possible, the project should enhance the natural environment.

*Natural Habitats:* UNDP only allows their projects to negatively impact the natural habitat when all other possibilities have been considered and decided as not viable. Additionally, appropriate conservation and mitigation plans must be put in place and observed to minimize the negative impact to the natural habitat.

*Mitigation Hierarchy:* UNDP prioritizes avoidance of negative impacts over reduction of negative impacts. When avoidance is not a viable option, mitigation strategies are designed to result in no net loss of biodiversity, and ideally a net gain in biodiversity. If reduction of negative impacts is also not a viable option, then UNDP will consider offset/ compensation options.

*Use of biodiversity offsets:* The UNDP will only approve the use of biodiversity offsets after viable avoidance and reduction measures have been implemented. If biodiversity offsets are used, then they should result in no net biodiversity loss at minimum.

*Critical Habitats:* The UNDP requires that projects have no negative impacts on critical habitats. Exceptions are made only under specific circumstances.

*Illegal Trade:* UNDP projects should not support activities that “increase the risk of illegal trade in protected areas.”

*Protected Areas:* UNDP projects that are legally located on protected areas will be monitored and required to follow any protected area management plans, engage with stakeholders in the area, and enhance the environment where possible.

*Management of ecosystem services:* UNDP requires that their projects do not have negative impacts on ecosystem services or surrounding communities. If the avoidance of negative impacts is not possible, then mitigation and offset activities will aim to maintain the functionality of the impacted

ecosystem services. The impacted communities are required to be consulted and involved in the decision-making process.

*Invasive Species:* The UNDP requires that no invasive species will be brought into a foreign environment under any circumstances.

*Biosafety and Genetic Resources:* The UNDP requires a risk assessment to be conducted if a project involves a genetically modified organism or a living modified organism that could have a negative impact on biodiversity.

*Forests:* The UNDP requires that forest project activities be consistent with the natural conservation of the forest. Additionally, projects should incentivize and enhance the protection and management of the forests where possible. Projects should also contribute to the biodiversity and social benefit of surrounding communities.

*Water Resources:* The UNDP requires that projects which affect water resources avoid “significantly altering flow regimes in ways that prevent water resources” from reaching the communities that they currently serve. Additionally, a risk assessment should be conducted to determine the social and environmental risks, and how to mitigate them.

*Soil Management:* UNDP requires that projects avoid and/or reduce their negative impacts on soil and related ecosystems.

*Sustainable Management of Living Resources:* UNDP Requires that living natural resources are used and protected in a way that allows for present and future surrounding communities and/or Indigenous peoples to provide for their own “social, economic, and cultural welfare.”

*Access and Benefit Sharing:* The UNDP requires that projects which use genetic resources share their benefits equitably.

*Primary Suppliers:* UNDP requires that their projects, where possible, do not purchase their resources from suppliers that degrade the environment and critical habitats. They also encourage the use of eco-labels where possible.

### **Climate Change and Disaster Risks:**

*Climate change and disaster risk analysis, planning and implementation:* UNDP requires that all projects be evaluated for their potential to be impacted by climate change and disaster, as well as their potential to increase an area’s potential to be impacted by climate change and disasters. If significant potential is identified, then UNDP takes further steps to identify and mitigate these risks.

*Greenhouse gases:* UNDP attempts to reduce and where possible avoid the increase of greenhouse gas emissions through their projects. If a project does require a significant increase in greenhouse emissions, then the project is required to document the source of these emissions and take steps to mitigate and reduce those emissions where possible.

### **Community Health, Safety and Security:**

*Community health and safety:* UNDP requires their projects to protect local communities from the potential negative impacts caused or produced by the project. Both direct and indirect impacts of the project on the community are included by the UNDP in this characterization.

*Assessments and management plans:* The UNDP requires that their projects assess the potential risks and safety hazards that they might cause to the community around them during all stages of the project. They must then try to avoid or reduce as many of these negative impacts as possible. After all avoidance and/or reduction measures are taken, the project will be evaluated. All projects must also take appropriate health and safety measures.

*Community exposure to health issues:* UNDP requires that their projects avoid or minimize the health risks that the project could expose the community to.

*Infrastructure design and safety:* The UNDP requires that any construction or operation in a project be in line with the national and international requirements, as well as any industry standards set by professionals. The construction and operation of any technology or structure should not pose any significant risk of health issues to the community or workers.

*Universal Access:* The UNDP requires that the design and construction of facilities be accessible equally to all the public when possible.

*Hazardous materials management and safety:* The UNDP requires that the project avoid or reduce as much as possible the community's exposure to toxic or hazardous materials.

*Emergency preparedness:* The UNDP requires that their projects be prepared and have procedures to address emergencies (both anticipated and unanticipated). These plans should be periodically reviewed and revised if necessary.

*Risks associated with influx of project workers:* The UNDP requires that projects anticipate and address the issues associated with increasing the number of project-workers. This risk can span from the spread of diseases to threats of sexual violence, to training capacity.

*Impacts on ecosystem services:* The UNDP requires that projects understand and mitigate the impacts that they could have on ecosystem services that serve nearby communities. Projects must take measures to address the indirect negative impacts that they can have on the community.

*Security-related issues:* The UNDP requires that projects take security measures to protect sensitive or dangerous property or information from the public. Projects must mitigate the risks that can be created by sensitive information or property landing in the wrong individual's hands.

### **Culture Heritage:**

*Avoidance, assessment, and mitigation of adverse impacts:* The UNDP requires relevant projects to provide an assessment of the impact they will have on the cultural heritage of a community. Then, the project must work to avoid having any impact on their cultural heritage if possible and reduce their impact to the minimum if not.

*Chance find procedures:* The UNDP requires their projects to include "chance find procedures." These procedures will determine how chance finds of cultural heritage will be addressed and managed prior to the chance find itself.

*Community participation, stakeholder consultations and use of experts:* The UNDP requires that all projects with potential for impacting a community's cultural heritage must use Cultural Heritage experts and relevant stakeholders to assist in the identification, handling, and documentation of affected cultural heritage.

*Continued access:* UNDP requires that projects do not restrict access to Cultural Heritage if possible. If it is not feasible then the Cultural Heritage will be accessible through stakeholder consultations and other alternative methods.

*Confidentiality and restricted access by communities:* With the relevant stakeholders and experts, UNDP projects should determine whether information regarding Cultural Heritage would be considered sensitive information, and if it should or should not be disclosed to the public. If it is determined that the information should not be disclosed, then the project should respect and maintain the practice of the relevant communities as it relates to the Cultural Heritage in secret.

*Integration and use of Cultural Heritage:* The UNDP requires projects that wish to integrate and/or use Cultural Heritage as a part of their project to meaningfully engage with the relevant communities and inform the affected communities of their rights, the scope of the project, how their participating will impact the project, and the potential consequences for them. The project should respect the community's culture, and work to make sure that the meaning of the cultural Heritage is not impacted or distorted.

#### **Displacement and Resettlement:**

*Prohibit forced evictions, allowing evictions in exceptional circumstances only:* UNDP projects should not force individuals or families to move out of their home or land. Evictions in general (not forced) should only be allowed in rare circumstances where the eviction meets specific criteria.

*Avoid, minimize, and mitigate physical and economic displacement:* UNDP projects should work to avoid physical and economic displacement by considering all other feasible options. When displacement cannot be avoided, the project should work to minimize the impacts of displacement on the displaced people and provide them with timely access to effective remedies.

*Develop plans for displacement:* When physical or economic displacement is unavoidable, UNDP projects should develop and include an action plan, which should be created with the input of the displaced parties, which addresses the displacement impacts in a way that is proportional to the risks. Additionally, a resettlement plan should also be developed and included in the project plan.

*Addressing prior displacement:* If displacement has occurred prior to project taking place, and in preparation for the project, then the standards set by the UNDP to create action and resettlement plans still apply.

*Monitoring and completion analysis:* UNDP projects with significant displacement impacts will have to put in place monitoring procedures to determine the effectiveness of the action and resettlement plans. If they are not having the desired effect as determined by the UNDP, then the plans will be revised. A completion analysis will also be conducted to determine whether the lives of displaced parties were at least restored if not improved.

#### **Indigenous Peoples:**

*Respect for domestic and international law:* The UNDP requires that their projects do not violate the human rights of Indigenous peoples under international law.

*Identification of Indigenous peoples:* UNDP projects must acknowledge that “Indigenous peoples” does not refer to one group of people, but rather diverse groups of people who have diverse cultures, values, and identities. UNDP projects will treat diverse groups of Indigenous peoples differently and equally while respecting their cultures.

*Land, territories and resources:* UNDP projects should acknowledge that Indigenous peoples have the right, as a group, to use their lands (which they have traditionally owned) as they see fit. UNDP projects will not conduct activities that undermine Indigenous peoples’ right to their land. Indigenous people will be consulted and take part in the decision-making process for any processes that happen on their land.

*Involuntary resettlement:* UNDP projects will not cause the “forcible removal of Indigenous peoples from their lands and territories.”

*Relocation:* UNDP projects will not relocate Indigenous peoples without the “free, prior and informed consent” of the Indigenous peoples in question. Additionally, if relocation does take place, then the relocated peoples will be compensated fairly, and given the option to return to their original lands if possible.

*Full, effective, and meaningful participation and FPIC:* UNDP projects should engage relevant Indigenous communities early and continuously throughout the design, construction, and implementation of the project. This engagement should be meaningful and effective, and the information gained from the engagement should be used throughout the decision-making process.

*Documentation:* UNDP projects should document all engagement and outcomes of engagement with Indigenous communities throughout the duration of the project.

*Prior social and environmental impact study:* UNDP requires that all projects which have the potential to impact Indigenous peoples, culture, or land, perform a prior review to assess the potential for negative and positive impacts. UNDP projects should work to minimize and mitigate all negative impacts of the project, and enhance any impacts desired by the affected Indigenous communities.

*Appropriate benefits:* UNDP projects that use the resources, lands, or knowledge of Indigenous peoples should equitably share the benefits of the project with those involved communities.

*Indigenous Peoples Plan:* Indigenous communities will be affected by a UNDP project, then the UNDP requires that the project develop and implement an “Indigenous Peoples Plan,” which will be developed in coordination with the affected Indigenous communities. This plan will identify the potential negative and positive impacts that the UNDP project will have on the Indigenous community, and provide sufficient risk avoidance measures, community engagement pathways, and continuous monitoring procedures to evaluate the effectiveness of the plan.

### **Labor and Working Conditions:**

*Terms and Conditions of Employment:* UNDP requires all their projects to have clear and understandable written procedures that establish the terms and conditions of employment, compensation and benefits for all worker positions, and the health and safety protocols for all workers.

The UNDP also requires their projects to have fair wages, reasonable hours, and detailed breakdown of wages, bonuses, and deductions. Workers should also be allowed maternity and family leave, as well as sick leave. Prior to termination, workers should receive a severance package, and a written notice.

*Non-Discrimination and equal opportunity:* UNDP projects should treat all their employees equally and make personnel decisions based on job performance alone. Additionally, hiring practices should be non-discriminatory. Appropriate measures should be taken and enforced by management to prevent any forms of harassment or abuse in the workplace.

*Workers Organization:* UNDP projects should recognize the workers' right to organize (in countries where it is allowed) to collectively bargain without consequences from the project. Additionally, in countries where it is not allowed, the project should not hinder worker's attempts to collectively air grievances and protect their rights.

*Forced Labor:* UNDP Projects will not use, or knowingly support the use of forced labor. If the project determines that forced labor is being used to support their work, then they will immediately take steps to fix the situation.

*Child Labor:* UNDP Projects will not use or knowingly support the use of child labor, defined as the labor of people under the age of eighteen. If it is determined that child labor is or could be being used, the project will take immediate steps to fix the situation.

*Occupational Health and Safety:* UNDP Projects will take steps to protect workers' health and safety through the design and implementation of the project. The project will work to fix and address any reported situations where the workers' health and safety is not being prioritized, or if there is a potentially dangerous situation.

#### **Pollution Prevention and Resource Efficiency:**

*Pollution Prevention:* UNDP Projects should avoid releasing pollutants as much as possible. If avoidance is not possible, then they should work to reduce the release of pollutants to the minimum.

*Ambient considerations:* UNDP projects will seek to maintain ambient conditions surrounding the project as much as possible.

*Wastes:* UNDP projects should keep the waste production to a minimum. The waste that is produced will be disposed of in a manner that is safe for human and environmental health.

*Pesticide use and management:* UNDP projects will work to avoid the use of pesticides as much as possible. If pesticide use is deemed as necessary after thorough review by UNDP, then the project will use the pesticides in a safe and efficient manner and keep the environmental impact to a minimum.

*Resource Efficiency:* UNDP projects should use resources as efficiently as possible. This includes financial, natural, and human resources.

*Water Usage:* UNDP Projects should keep water usage to a minimum and be mindful of the surrounding communities which use the same water source as the project. The Project should also use appropriate wastewater cleanup and management practices.