I-WEST

Phase One Final Report | Detailed Chapter

Certification for Decarbonization Technologies

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About this report

The Intermountain West Energy Sustainability & Transitions (I-WEST) initiative is funded by the U.S. Department of Energy to develop a regional technology roadmap to transition six U.S. states to a carbon-neutral energy economy. I-WEST encompasses Arizona, Colorado, Montana, New Mexico, Utah, and Wyoming. Each state is represented in this initiative by a local college, university, or national laboratory. Additional partners from beyond the region were selected for their expertise in applicable fields. In the first phase of I-WEST, the team built the foundation for a regional roadmap that models various energy transition scenarios, including the intersections between technologies, climate, energy policy, economics, and energy, environmental, and social justice. This chapter presents work led by an I-WEST partner on one or more of these focus areas. A summary of the entire I-WEST phase one effort is published online at www.iwest.org.

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1 Certification: a social contract to improve quality, protect, and build trust

Consumers and industry are in a better place because of protocols, standards, and certification. We expect cars to not fall apart, outlets to not electrocute us, and food to be fit for human consumption. Every sector of the economy relies on protocols, standards, and certification to ensure materials, products, processes, and services are fit for their purpose. Protocols, standards, and certification together aim to provide standardization within industries to create equal playing fields, prevent consumer deception, ease logistical procedures, and improve quality. However, improvement in quality is not an automatic result of standardization. Quality will only be achieved when the advocated standard is a "high" standard, where the requirements are an improvement in relation to common practice. Standardization is also not always the goal of protocols, standards, and certification which may sometimes only aim to make improvements. For example, protocols, standards, and certification in agriculture are generally developed to improve customer choice on products that have an environmental and social sustainability quality such as being 'organic'.

Protocols, standards, and certification also have a wider purpose. In addition to preventing consumer deception and improving quality they can protect the public who is external to the product, process, or service. This is particularly salient in activities that may affect the environment and public safety because of their scale, supply chain, or waste production. Extractive industries, construction, agriculture, nuclear energy would be examples. In this context, protocols, standards, and certification are necessary to protect the public. Thus, they are a social contract that activities, products, and services are delivered properly acting on behalf of both purchasers and the public.

Protocols, standards, and certification are required to build trust and to meet legal obligations, which is critical for any industry (Lazarte, 2016). Trust is the basis of transactions, progress, and business performance. Trust can be fostered from many actions and behaviors that display integrity, social responsibilities, transparency, compliance, fairness, and meeting expectations. Industries that see low levels of trust often face significant backlash from the public and investors.

Lastly, it is worth noting that the failure to certify properly can have significant consequences. Inadequate standards can lead to mispricing of assets, wasting time and resources, scams and fraud, harm to communities and the environment, and general failures of the implicated industry. In the context of decarbonizing the economy, inadequate standards can lead, and have already led, to the proliferation of boondoggles, loss of credibility and investments[1], environmental destruction[2], human rights violations[3] as well as the potential failure of tackling climate change (**Figure 1**).

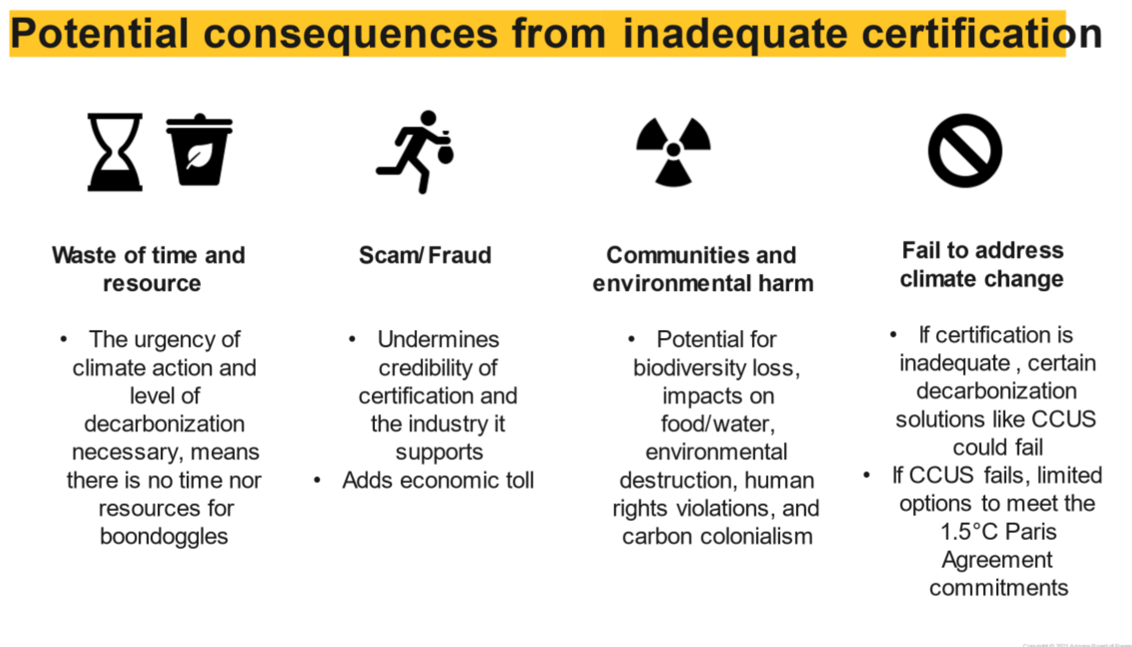

Figure 1. The potential consequences of inadequate certification of decarbonization solutions.

Not all products, services, or persons will need protocols, standards, and certification to guarantee quality. However, the least risky action would be to track and verify. Therefore, certification requires a level of verification which must be combined with remedial action for products/activities that do not meet the requirements. This is to reduce genuine mistakes, but also to minimize fraud. A product, service or activity that does not meet the requirements of certification by mistake and

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[1] Morton, A. (2022). Australia's carbon credit scheme 'largely a sham', says whistleblower who tried to rein it in. The Guardian, March 23, 2022. Available at: https://www.theguardian.com/environment/2022/mar/23/australias-carbon-credit-scheme-largely-a-sham-says-whistleblower-who-tried-to-rein-it-in

[2] Song, L. (2019). Why Carbon Credits For Forest Preservation May Be Worse Than Nothing. ProPublica, May 22, 2019. Available at: https://features.propublica.org/brazil-carbon-offsets/inconvenient-truth-carbon-credits-dont-work-deforestation-redd-acre-cambodia/

[3] Nelsen, A. (2011). Carbon credits tarnished by human rights 'disgrace'. Euractiv, October 3, 2011. Available at: https://www.euractiv.com/section/climate-environment/news/carbon-credits-tarnished-by-human-rights-disgrace/

remediates against it, is acceptable. Not remediating or not meeting the requirements by design is fraudulent behavior that is punishable through the courts if the legal standard from which "fraud" can be measured has been established. After all, the credibility of the certification and the industry it supports is dependent on it.

In the context of decarbonizing the economy, consumer and public trust in the industry and trust in protocols, standards, and certification have an important role. Technologies and activities proposed by the I-WEST initiative, including Point Source Capture and Sequestration (PSCS), Direct Air Capture and Sequestration (DACS), Biomass Carbon Removal and Sequestration (BiCRS), Hydrogen, and DAC to synthetic fuels, will all need to be fit-for-purpose and will all have environmental and safety considerations due to their anticipated large scale, infrastructure, material requirements, and waste production. Consumers and the public alike will want to ensure activities and products are fit-for-purpose in an environmentally and socially sound manner.

2 Definitions, organization, and actors

Protocols and standards are tightly linked and can reflect the interests of industry. Protocols are the technical specifications on how to perform measurements, exchanges, and behaviors. Standards are documented agreements containing protocols to be used consistently to ensure a desired outcome is reached. Standards are best thought of as mechanism architectures. Standards may be product or process based. Product standards set the outcome characteristics to be attained by a product. Process standards set the criteria for how products and services are performed. Process standards can be sub-categorized as management system standards, which set the management procedures, and performance standards, which set verifiable requirements. Protocols and standards are developed by standard developing organizations (SDO) which may represent or be the industry itself. SDOs may also be composed of environmental and social non-profit organizations who may develop standards independently or in collaboration with industry.

Certification is a procedure by which a third party gives assurance that a product, process, or service is in conformity with certain standards. The certification programs are the system of rules, procedures, and management for carrying out certification, including the standards against which it is being certified. Certification bodies ought to always be independent from the industry, buyers, and standard developing organizations. If the SDO and certification body are the same, this can cause conflicts of interest and internal confusion as to the ultimate objectives. The SDO would like to see high implementation rates of its standard or have a bias against certain types of producers for ideological reasons, which can influence decisions. Certification bodies are usually accredited by an authoritative body which may be governmental or parastatal that they can carry out certification programs.

3 Certification characteristics pertinent to decarbonization technologies and activities

Certification programs can cover a range of product, process, and service characteristics. The main characteristics pertinent to decarbonization technologies and activities may be safety, performance, and origin. These would be in addition to more common measures pertinent to any industry, including quality management, occupational health and safety, and information security. Local and national regulations may also dictate additional certification requirements. Certification will involve methodological protocols as well as standards detailing the mechanism architecture to deliver specific outcomes.

3.1 Safety

Safety usually refers to the minimization of risk. Risks are often not zero but are usually minimized with the level of risk being a societal decision. When product or service risk is too high, safeguards can be implemented to reduce it to a tolerable level. For example, road fatalities in Germany decreased by 72% between 1994 and 2020 but decreased only by 24% in the US over the same period. Road fatalities even increased 17% between 2010 and 2020 in the US (OECD, 2022). In the US, road fatalities per 100,000 inhabitants only slightly trailed behind heart disease and cancer in 2020 (Murphy et al., 2021). The level of road fatalities represent a safety threshold that the American public has accepted as tolerable. The certification process may help determine that a product or service is within agreed safety levels, or that safeguards are adequately implemented.

In the context of decarbonization activities and technologies, safety may be a certifiable characteristic of carbon sequestration and its infrastructure as well as, for example, hydrogen storage. The Intermountain West's projected carbon sequestration volumes in geologic formations to reach carbon neutrality is on the order of 30 Gt over the next century. With such enormous volumes, safety in geologic sequestration cannot be compromised. Instances of safety compromise occurred with the Hutchinson, Kansas salt cavern natural gas storage incident (Bérest and Brouard, 2003). Pipes carrying CO_2 will need to be manufactured to meet higher standards than those for natural gas (National Petroleum Council, 2019), as displayed in the Satartia, Mississippi pipeline incident (Zegart, 2021). Equally large volumes of hydrogen are anticipated. Similarly, hydrogen production, transport, and storage come with significant safety risks (BARPI, 2020). The hydrogen explosion in 2019 at a filling station in Santa Clara, California, demonstrates that certification of personnel is as critical as technical protocols (Hydrogen Safety Panel, 2021). A thousand consumers lost access to hydrogen fuel and nearby businesses and homes were evacuated. Safety is an issue for both consumers and the public. Standard developing organizations are beginning to grapple with the question of safety in such activities, as will be discussed in section 4.

3.2 Performance

Performance refers to the specific level of quality or condition that is expected by consumers and the public through the lifetime of a product or service. Protocols describe the equipment and procedures to be followed. Standards use those protocols in addition to rules, guidance, and definitions to ensure there is minimal failure or replacement needed. This in turn improves efficiency and minimizes the waste of time and resources.

Performance has a time component which can be treated in various ways. For products, certification can be awarded following extensive testing over the product's lifetime. The consumer would then receive a form of guarantee of repair or replacement should the product fail to meet the certification standards. A new car's 3-year warranty is an example.

For ongoing services, certification can be conditional on the requirement of ongoing monitoring and verification. Monitoring would observe metrics that would indicate if the service were failing to meet the certification requirements. Verification from a third party, independent of the manufacturer, service provider, standard developer, or funder would ensure that the metrics are measured properly. Failures would trigger agreed remedial action. Another option is to require recertification through time. For example, LEED building certification must maintain their certification through time by going through a recertification process annually or at distinct intervals. Continuous monitoring, repeated verification, and remedial action would take care of certification for ongoing services.

In the context of decarbonization technologies and activities, performance is a certifiable characteristic of carbon sequestration. Carbon sequestration requires proof that a volume of carbon or CO_2 has been added to a reservoir and that this carbon will need to remain stored indefinitely or be remediated in the case of release. On-going monitoring of all reservoirs would observe potential changes in the reservoir content, verification from an independent party would ensure the measurements are accurate, and remedial action is triggered by the monitoring and verification. In this context, remedial action ought to be the remediation of the escaped carbon to ensure the integrity of the carbon that was paid for.

3.3 Origin

Finally, the origin of a product is another attribute that is certifiable. This is pertinent for the producer, purchaser, and the public. Certification of origin creates greater awareness, provides customers with the opportunity to choose, and signals this choice to the market. It also provides credible and verifiable documentation for auditing, fuel mix disclosures, and feed-in tariffs levelisation. For example, in France, agricultural products can be granted a certification of authenticity called "appellation d'origine contrôlée (AOC)". The AOC protects producers by only allowing products from a certain region and method to use a recognized name like "Roquefort" cheese, consumers by guaranteeing the product will meet expectations, and the public who may be attempting to eat local products and will want to know their behavior changes will be supporting a local industry.

The certification of origin can target a few narrow characteristics, such as the source of raw material. One example is the Forest Stewardship Council® which provides certification for wood produced in forests that are managed to preserve biodiversity and benefits the lives of local communities. Producers undergo certification, consumers expect their purchases to meet the certification requirements, and the public, in this case the local communities, the host country population, and the world are protected.

In the context of decarbonization solutions, certification of origin is called a Guarantee of Origin (GO) in the European Union[4] and are pertinent to renewable energy and biofuels. Certification of origin would also be pertinent to Carbon Dioxide Removal (CDR) approaches to guarantee carbon was captured from the environment to satisfy the promise of negative emissions; to hydrogen to guarantee its production from renewable energy; to DAC-to-fuels production to guarantee carbon was captured from the air and hydrogen was produced by renewable energy; and to BiCRS to guarantee the biomass came from sustainable sources.

4 Certification requirements and status

The I-WEST initiative is assessing several decarbonization activities and technologies that require certification programs. Most pertinent activities and technologies include carbon sequestration in the form of geologic formations, mineralization, forestry, and soils. Oceanic reservoirs are not

[4] The EU Renewable Energy Directive (2009/28/EC) refers to GOs as proof to the final consumer that a given quantity of energy was produced from renewable energy sources. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:en:PDF

considered given the intermountain states are landlocked. Whether the CO_2 is sourced from the environment or at the flue-stack will change the certification needs. Products that use carbon sourced from the environment either for sequestration or utilization will also need certification. Products used as reservoirs for sequestration will need to meet different requirements than products for utilization, particularly when it comes to synthetic fuels. Finally, hydrogen is another category of activities that will require certification. Here we analyze the certification needs for each of the aforementioned technologies and activities and review the current status of certification for each.

4.1 Sequestration

Sequestration concerns itself with the durable storage of carbon in oceanic, biotic, and geologic reservoirs or in products (IPCC, 2022). Carbon may be captured from the environment through CDR approaches which include the DAC technologies considered by the I-WEST initiative. Or, it may be captured from the flue-stack of industrial processes, referred to as Point Source Capture (PSC) including fossil fuel or biomass power generating stations, and heavy industries such as cement and steel; another technology considered by I-WEST. Sequestration has a multigenerational time commitment. All storage should be deemed temporary, or provisional, until they can be proven to sequester carbon durably.

The objective of the certification of carbon sequestration is not universally agreed. In carbon markets, a popular mantra is, certification *must ensure that the resulting carbon credits are real, measurable, additional, not resulting in leakage, not double-counted, and permanent* (McDonald et al., 2021). A supplemental objective is to achieve wide scale implementation to maximize potential impact on the climate (McDonald et al., 2021; Ruseva et al., 2020; Thamo and Pannell, 2016). The two objectives are often seen as a tradeoff between participation level and program stringency (Miltenberger et al., 2021; Ruseva et al., 2017). An alternative objective sees sequestration as a service which results in a commodity that can match an emission (past or future) and looks for a guarantee that carbon remains safely sequestered indefinitely to satisfy the polluter pays principle (Arcusa and Lackner, 2022). The principle of the polluter pays, also known as the producer's responsibility (Jenkins et al., 2021), would simply indicate that the producer of waste, or carbon in this context, has taken the necessary steps to dispose of the waste in a safe and permanent way (Khan, 2015). Satisfying the producer's responsibility, also implies that future generations will not be burdened by the waste, nor the maintenance of the disposal (Wong, 2014).

4.1.1 Considerations

For carbon sequestration, the certification criteria that matter for performance, safety, and origin include evidence of carbon sequestration (including evidence of carbon source for CDR), mechanisms to support long-term sequestration, and implementation of safeguards against harm. These require methodological protocols as well as standards that detail the architecture of mechanisms to support the intended goals. The facets of certification meeting those criteria include (i) the demonstration of being fit-for-purpose, (ii) the origin of carbon, (iii) measurement protocols, (iv) monitoring plans, (v) safety protocols, (vi) mechanisms to ensure durable storage, (vii) verification mechanisms, and (viii) tracking. Each facet ought to be addressed for any reservoir, although the specific methods and equipment will vary by reservoir type and by site, with differences highlighted for PSC and CDR. We note that this analysis often does not reflect the current certification ecosystem which is explored in detail in **section 4.1.2**.

- Because CDR is a promise to clean up the environment, its **certification ought to consider the environmental impact of the entire proposed carbon removal activity**. Fit-for-purpose CDR will not damage the environment. Damage in this context may mean biodiversity loss, nutrient or water diversion, or pollution, amongst others. For example, enhanced weathering should not originate from rocks containing heavy metals; forestation should not be attempted in unsuitable locations or destroy species habitat; BiCRS should not source combustion materials from projects that cut forests or from projects that displace food production; the source of the wood for building material should not destroy mature forests. PSC activities do not have this requirement because PSC is part of the decarbonization phase and is an addition to existing activities that presumably have already met environmental regulations. The sequestration phase of PSC and CDR ought to consider the environment like any other industry would. Other fit-for-purpose requirements may consider whether the reservoir can spontaneously fill up or has large natural fluctuations, and whether the CDR approach can reach negative emissions in its design. Reservoirs that are not well understood ought to be researched further before being deemed fit-for-purpose. For example, the National Academy of Science, Engineering, and Medicine has begun targeting basic research with their reports (NASEM, 2022; NASEM, 2019).

  Whether the CDR activity can reach negative emissions in its design is critical. Consider the case of a system that captures carbon from the environment and sequesters it in a product that releases fossil carbon in its process. To result in a certifiable negative emission, emissions and removals from the whole CDR consequential process, from construction to operation to end of life, would need to be carbon negative (Brander et al., 2021). Thus, robust, standardized, consequential Life Cycle Assessments (LCA) is critical during the design phase to ensure the CDR activity will remove more carbon than it emits. However, although LCA is critical at the design phase, it is inadequate for the accounting of carbon removal due to its subjectivity and impossibility to standardize across CDR activities, as will be discussed in **section 4.1.2**. Activities that produce more emissions than they remove are not fit-for-purpose in a system that does not penalize for carbon emissions.

Alternatively, a system could be devised to require that carbon waste be safely disposed of. The Carbon Take Back Obligation[5] would require that carbon extraction and import would need to be matched by carbon removal (Jenkins et al., 2021) which ought to be done at the source to simplify the accounting as any product or use downstream would become carbon neutral (Lackner and Wilson, 2008). A transition period could be devised at the end of which 100% of all carbon extracted and imported would be matched by sequestration. The result of such a system would ensure that activities that produce more emissions than they remove would not become the norm.

- **The certification of CDR ought to consider the carbon source** for one obvious reason. CDR is a promise to dispose of carbon that has already been emitted by influencing the atmospheric carbon stock. It is impossible to reach a state of negative emissions if carbon is captured from activities that use fossil carbon. Carbon must be sourced from the environment to be considered a negative emission. Consideration of the carbon source also matters for environmental impact. For example, the origin of the biomass ought to be considered for BiCRS to avoid incentivizing the growth of energy crops instead of food, or incentivizing deforestation or habitat destruction. This ought to be a requirement if a policy like the CTBO is not implemented.

- **Both sequestration from CDR and PSC need robust, evidence-based measurement protocols**. The protocols ought to have specific methods and equipment for each reservoir but ought to meet certain uniform criteria. Protocols must include (i) a method to delineate the boundaries of the reservoir, (ii) a method to quantify the addition of carbon to the reservoir, (iii) a method to quantify the change in reservoir content on non-instantaneous, but rapid demand, and (iv) a method to quantify the measurement uncertainty. The level of sufficient measurement certainty would need to be

[5] Carbon Take Back Obligation. https://carbontakeback.org/about/

determined. Measurement protocols ought not to be based on LCA nor counterfactuals, to result in measurable and verifiable carbon sequestration.

- In addition to the measurement protocols, **sequestration from CDR and PSC both will need monitoring plans specific to the reservoir and site**. These plans ought to collect the measurements necessary to observe a change in the reservoir content. All reservoirs need ongoing monitoring for several decades, only after which monitoring frequency could be reduced if observations do not find significant changes in that time. Reservoirs that see a change in their carbon content should not be allowed to change the monitoring plan. Process times, the times when the carbon in the reservoir undergoes physical changes, ought to trigger a change in the monitoring plan. For example, in underground mineralization, the process time may be the transition from carbon in a supercritical state to carbonated mineral. The monitoring plans are one of two critical requirements to ensuring the durability of sequestration. The second requirement being remediation, as discussed in paragraph (vi).

- **Both sequestration from CDR and PSC need safety protocols and safeguards specific to the reservoir type**. Safety is a concept that can extend to safeguarding the environment from harm which was discussed above. Here safety is discussed in relation to minimizing risks to human life. For many types of reservoirs, the risks are likely minimal. For example, safety is a less applicable criteria for biotic and oceanic reservoirs where environmental harm will be more important, than for geologic reservoirs or products. Nevertheless, all reservoirs and their carbon removal operations should be considered from a safety lens. Extensive research and experience exist for sequestration in geologic formations. The EPA's Class VI wells put safety at the forefront. The National Energy Technology Laboratory's (NETL) Carbon Storage Program offers a wealth of information on best practices and risks assessments[6].

- **All sequestration will need to have mechanisms to ensure the durability of the sequestration**. Several constraints ought to be considered. First, the urgency of the climate crisis requires rapid, large-scale deployment of carbon sequestration activities (Lackner et al., 2012). Second, sequestration activities have different maturities, costs, and capacities (Bey et al., 2021; Fuss et al., 2018; McLaren, 2012). Third, to uphold the principles of the producer's responsibility and intergenerational equity, sequestration

[6] NETL Carbon Storage Program. Available at: https://netl.doe.gov/carbon-management/carbon-storage

duration ought to be commensurate to the residence time of CO_2 in the component of the climate system from which society wishes to avoid damages (Arcusa and Lackner, 2022). It is well understood that CO_2 will remain in the atmosphere for hundreds of thousands of years causing damage from temperature increases (Archer et al., 2009). The oceans will absorb some of it on millennia timescales causing ocean acidification (Hoegh-Guldberg et al., 2017). To avoid damages from ocean acidification, sequestration ought to continue for tens to hundreds of thousands of years to match the weathering and carbonation slow cycles (Archer et al., 1998; Arcusa and Lackner, 2022). Considered altogether, these constraints would suggest that all fit-for-purpose sequestration options ought to be considered, if mechanisms to guarantee durable storage are included in their deployment. These mechanisms can be implemented through the certification programs. One proposed mechanism is discussed below, and existing mechanisms are discussed in **section 4.1.2**.

The simplest solution to meet those constraints is to require the storage operators to monitor their reservoirs and to remediate any release (Arcusa and Lackner 2022). If a release is observed, the operator would simply be required to purchase new sequestration to cover the losses. These requirements ought to be included in the business plans of the storage activities before they can be allowed to be certified. Storage operators could be required to insure their activities, to protect themselves, investors, purchasers, and the public. The shift in responsibility from the buyer of sequestration to the storage operator allows for longer term management and removes the burden on the buyer who cannot control the reservoir.

After a certain number of decades of monitoring, it may be conceivable to transfer the responsibility of the storage operator to a willing party at a fee paid upfront. The willing party could be for example, a nation state or parastatal entity. The willing party would then take over the responsibility of the sequestration system until the next transfer. In some reservoirs, after a certain number of decades of monitoring without observation of release, monitoring frequency may reduce and eventually the storage operator may make the scientifically supported and accepted case that the carbon should be deemed durable. Durable storage in this context would thus be defined as a condition where the probability weighted damage (risk) of full or partial reversal during the required sequestration duration falls below a threshold of concern, e.g., the expected average loss from a reservoir must less than a few percent of the amount stored over tens of thousands of years. Both the duration and threshold of concern would need to be determined but this solution would treat all reservoirs equally and allow for the immediate deployment of sequestration without sacrificing the future. Other mechanisms have been proposed over the past decades (Moura Costa and Wilson, 2000; Whitmore and Aragones, 2022) but fail to meet the constraints outlined above, for reasons detailed in **section 4.1.2**.

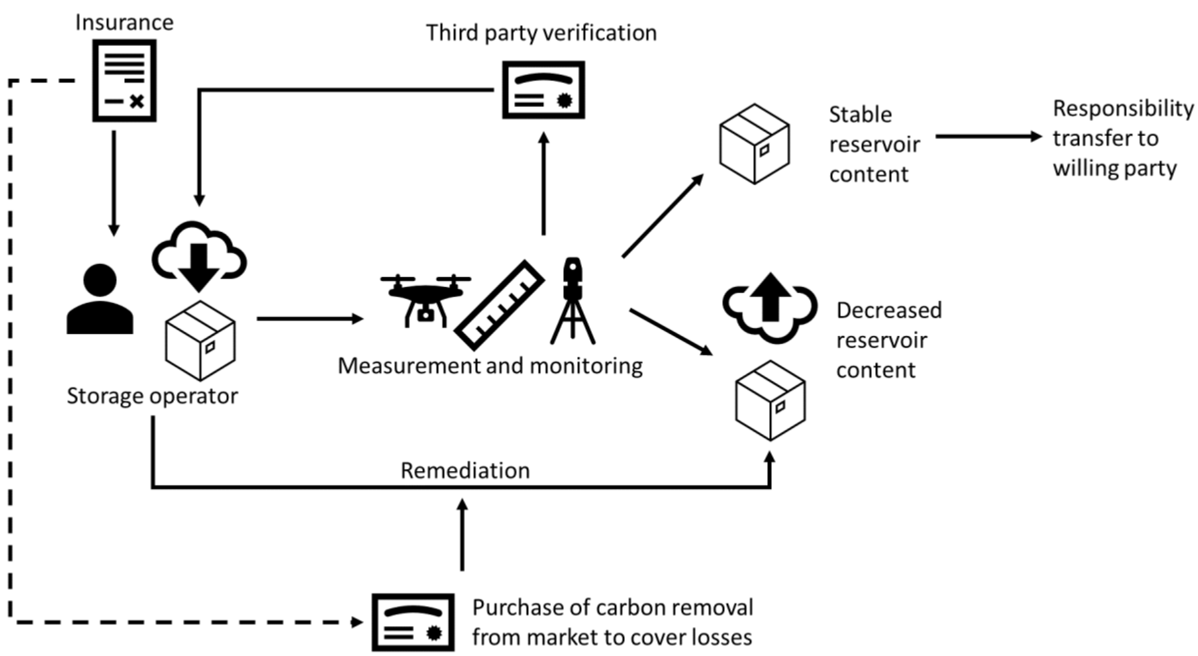

Figure 2. Simplified depiction of the certification program.

- **All measurements need reporting to a central database and verification from an independent entity**. Reporting is usually considered a minimum requirement in multilateral agreements because of the perceived low burden (Breidenich and Bodansky, 2009). Verification usually refers to independently checking the accuracy and reliability of reported information or the procedure to report that information (Breidenich and Bodansky, 2009). Strong verification regimes are important to build confidence. The verification regimes for arms control and nuclear non-proliferation are two examples of the essentiality of verification (Breidenich and Bodansky, 2009). In the context of certifying carbon sequestration, the data that standards rely on to issue certification need to be made available for verification purposes. Verification and eventual certification will need to assign a unique digital identifier to each ton of carbon removed for the purpose of tracking (**paragraph viii**). Verification cannot be performed by the entity receiving the certification nor the entity producing the standards. Verification must be independent and free from conflicts of interests, or even the appearance of conflict. This means that carbon sequestration accounting must use data that can be measured, reported, and verified. It also means that a strong and independent verification regime must be included.

- **Once carbon removal is verified by a third party and certified, it will need to be tracked.** Tracking is the traceability of each ton of carbon removed, from production to purchase including the metadata associated with the sequestration activity. The metadata will need to include incidences of release and remediation. To increase efficiency and transparency, tracking could be done through digital ledger technology and an open-source and centralized double ledger. An international system that works across jurisdictions would help ensure that double counting is eliminated.

4.1.2 State of certification

We restrict the summary of available standards and certification to voluntary or compliance, regulated or unregulated, state, U.S. national or voluntary international programs for the CDR that may be applicable to the Intermountain West region. Programs that are developed in other countries for compliance purposes are not listed, e.g., the Alberta Emission Offset Program. This summary draws from Arcusa and Sprenkle-Hyppolite (2022) who collected a more complete database of available standards and certification worldwide.

The availability of standards and certification schemes depends on the reservoir type and whether the activity is developing for compliance or voluntary purposes, and whether it is regulated or not (**Table 1**). More standards exist for agriculture for soil carbon than any other reservoir. No standard currently exists for enhanced weathering and only one for sequestration in long-lived plastics. The availability of more than one standard for a certain reservoir allows for comparisons, resulting in the conclusion that the programs do not certify the same outcome. For example, CarbonPlan reviewed 14 soil carbon certification protocols, finding wide variety in the rigor of measurements, treatment of durability, and safeguards along other metrics (Zelikova et al., 2021). Similarly, McDonald et al. (2021) reviewed 12 standards across carbon reservoirs and found significant differences in methodologies even for the same reservoirs. These studies raise questions regarding quality, and further, whether standardization across standards ought to be the logical next step to ensure integrity of the certification foundation of the carbon sequestration industry (Arcusa and Sprenkle-Hyppolite, 2022).

Performance, safety, and origin are three key criteria for the certification of carbon sequestration from CDR, with only the first two mattering for PSC except in the case of BiCRS. Above we listed that evidence of carbon sequestration (including evidence of carbon source for CDR), mechanisms to support long-term sequestration, and implementation of safeguards against harm are three facets that ought to be considered for the certification of sequestration. The facets and principles discussed in the previous **section 4.1.1** do not align well with existing research that analyzes the quality of standards and certification programs (e.g., EDF-Oko Institute[7], McDonald et al., 2021; Plastina, 2021; Zelikova et al., 2021). The reason being that the underlying objectives and criteria of certification are perceived differently. Our criteria focus on the demonstration of measurability at the stage of standard development; the existing research focuses on working within the system. However, some commonalities can be drawn in that transparency through reporting and independent verification are important.

Two aspects that deserve special attention in our analysis of existing standards and certification programs are measurements and durability. On the former, current standards for nature- or technology-based reservoirs generally estimate removals from Life Cycle Analysis (LCA) compared to a counterfactual baseline. Although efforts have been made to standardize LCAs (e.g., NETL's LCA Toolkit[8], the International CCU Assessment Harmonization Group[9], ISO 14040:2006[10]), LCA remains a subjective analysis when applied to accounting (Ekvall, 2020). Similarly subjective is setting a counterfactual baseline (Lohmann, 2009). Meanwhile, the counterfactual baseline represents an alternative world where the sequestration project is absent, or business as usual practices continue. Counterfactuals are by nature unverifiable and unmeasurable (Lohmann, 2005), which do not lend to robust carbon sequestration accounting. As detailed in the previous section, measurement protocols for carbon sequestration ought to be designed to be rigorous by including (i) a method to delineate the boundaries of the reservoir, (ii) a method to quantify the addition of carbon to the reservoir, (iii) a method to quantify the reservoir content on (non-instantaneous, but rapid) demand, and (iv) a method to quantify the measurement uncertainty to result in measurable and verifiable carbon removal. As discussed in **paragraph (i) in section 4.1.1**, LCAs remain important at the stage of activity design, but not for accounting.

[7] Carbon Credit Quality Initiative. Available at: https://www.edf.org/climate/carbon-credit-quality-initiative

[8] National Energy Technology Laboratory Life Cycle Analysis Toolkit. Available at: https://netl.doe.gov/LCA/CO2U

[9] Global CO2 initiative. International CCU Assessment Harmonization Group. Available at: https://www.globalco2initiative.org/evaluation/

[10] ISO. Environmental management — Life cycle assessment — Principles and framework. Available at: https://www.iso.org/standard/37456.html

On the topic of storage durability, what is meant by durable storage has been debated for decades without satisfying resolution (Dornburg and Marland, 2008; Dynarski et al., 2020; Fearnside, 2002; Fearnside et al., 2000; Herzog et al., 2003; Kirschbaum, 2006; Ruseva et al., 2020; Thamo and Pannell, 2016). Durable storage has been left undefined by the Intergovernmental Panel on Climate Change (2022). The term also varies greatly across existing standards (Arcusa and Sprenkle-Hyppolite, 2022). The reasons for why durable storage matters also remain inadequately articulated and inadequately treated in certification (Arcusa and Lackner, 2022). **Section 4.1.1** argued that durable storage is the point at which the producer of carbon emissions can be lifted the responsibility for their carbon waste in a manner that does not sacrifice future generations. This implies that all carbon reservoirs must meet this aim, and certification ought to be the mechanism to implement this objective. Current practices use long project durations varying between 10 and 100 years, discounting, buffers, or legal approaches (McDonald et al., 2021), but none of these approaches internalize the potential failure of sequestration to be permanent (Arcusa and Lackner, 2022). The few that attempt to internalize impermanence are the Kyoto Protocol's Joint Implementation[11] and Clean Development Mechanism[12] which require perpetual liability on the part of the buyer to remediate for any carbon release.

The carbon sequestration industry moves odorless, colorless gas into reservoirs. For this reason, and the additional safety concerns, the public's trust is primordial. Certification (measurement, tracing, and verification) is key to providing support for the industry. Therefore, ensuring that certification is robust, measurable, and verifiable is a critical endeavor for carbon sequestration.

[11] Joint Implementation Guidelines. Available at: http://unfccc.int/resource/docs/2005/cmp1/eng/08a02.pdf#page=2

[12] Clean Development Mechanism modalities and procedures. Available at: https://cdm.unfccc.int/Reference/COPMOP/08a01_abbr.pdf

Table 1. Available certification schemes for carbon reservoirs pertinent to I-WEST.

PSC and sequestration in geologic formations	DAC and sequestration in geologic formations	Soil carbon – biochar burial or in products	Soil carbon – agriculture for soil carbon	Enhanced weathering	Afforestation, reforestation, or forest restoration	Long-lived products – wooden building material	Long-lived products – plastics	Long lived products – carbonated building materials
Environmental Protection Agency[13] (national, compliance, regulated)	California Air Resource Board Low Carbon Fuel Standard[14] (state, compliance, regulated)	Puro.earth[15] (international, voluntary, unregulated)	Puro.earth[16] (international, voluntary, unregulated)	Under development – Open Natural Carbon Removal Accounting[17] (international, voluntary, unregulated)	PlanVivo[18] (international, voluntary, unregulated)	Puro.earth[19] (international, voluntary, unregulated)	Verra[20] (international, voluntary, unregulated)	Puro.earth[21] (international, voluntary, unregulated)
American Carbon Registry[22] (national, voluntary, regulation approved)	Verra CCS+ [23] (international, voluntary, unregulated)	Ithaka Institute[24] (international, voluntary, unregulated)	Food and Agriculture Organization of the United Nations[25] (international, voluntary, unregulated)	Verra CCS+ [26] (international, voluntary, unregulated)	Regional Greenhouse Gas Initiative[27] (regional, compliance, regulated)	Under development – Open Natural Carbon Removal Accounting[28] (international, voluntary, unregulated)		Verra[29] (international, voluntary, unregulated)
Verra CCS+ [30] (international, voluntary, unregulated)	International Organization for Standardization[31] (international, voluntary, unregulated)	Verra[32] (international, voluntary, unregulated)	BCarbon[33] (international, voluntary, unregulated)		Climate Action Reserve[34] (national, voluntary, unregulated)			Gold Standard[35] (international, voluntary, unregulated)
DNV [36] (international, voluntary, unregulated)		Climate Action Reserve[37] (national, voluntary, unregulated)	Nori[38] (international, voluntary, unregulated)		American Carbon Registry[39] (national, voluntary, unregulated)			
			Regen Network[40] (national, voluntary, unregulated)		California Air Resource Board Cap-and-trade[41] (state, compliance, regulated) *			
			American Carbon Registry[42] (national, voluntary, unregulated)					
			Climate Action Reserve[43] (national, voluntary, unregulated)					
			Verra[44] (international, voluntary, unregulated)					
			PlanVivo[45] (international, voluntary, unregulated)					
			Gold Standard[46] (international, voluntary, unregulated)					

[13] Environmental Protection Agency (EPA) Class VI wells. https://www.epa.gov/uic/class-vi-wells-used-geologic-sequestration-carbon-dioxide
[14] California Air Resource Board (CARB) Low Carbon Fuel Standard. https://ww2.arb.ca.gov/sites/default/files/2020-03/CCS_Protocol_Under_LCFS_8-13-18_ada.pdf]
[15] Puro.Earth [https://static.puro.earth/live/uploads/tinymce/Puro_Documents/Puro-Rules-CO2-removal-marketplace_v2.0_final.pdf]
[16] Puro.Earth https://puro.earth/articles/introducing-corc20-and-the-soil-amendment-methodology-647]
[17] Open Natural Carbon Removal Accounting (ONCRA). https://climatecleanup.org/accounting/
[18] PlanVivo [https://www.planvivo.org/Handlers/Download.ashx?IDMF=5b30948b-26f3-4d7a-803f-0fcce593acbd]
[19] Ibid 16.
[20] Verra. [https://verra.org/methodology/vm0040-methodology-for-greenhouse-gas-capture-utilization-plastic-materials/]
[21] Ibid 16.
[22] American Carbon Registry (ACR). [https://americancarbonregistry.org/carbon-accounting/standards-methodologies/carbon-capture-and-storage-in-oil-and-gas-reservoirs]
[23] Verra CCS+. https://www.ccsplus.org/
[24] Ithaka Institute. [https://www.european-biochar.org/en/ct/139-C-sink-guidelines-documents]
[25] Food and Agriculture Organization of the United Nations (FAO). [https://www.fao.org/3/cb0509en/cb0509en.pdf]
[26] Ibid 24.
[27] Regional Greenhouse Gas Initiative (RGGI). [https://www.rggi.org/sites/default/files/Uploads/Design-Archive/2012-Review/2013-later-materials/Forest_Protocol_FINAL.pdf]
[28] Ibid 18.
[29] Verra. [https://verra.org/wp-content/uploads/2021/07/Methodology-for-CO2-Utilization-in-Concrete-Production-Carbon-Cure.pdf]
[30] Ibid 24.
[31] International Organization for Standardization (ISO). [https://www.iso.org/obp/ui/#iso:std:iso:tr:27915:ed-1:v1:en]
[32] Verra. [https://verra.org/request-for-proposals-development-of-a-vcs-biochar-methodology/]
[33] BCarbon. [https://static1.squarespace.com/static/611691387b74c566a67f385d/t/622f8af172db6730a9a21db7/1647282930779/031422_Soil_Metrics_Protocol.pdf]
[34] Climate Action Reserve (CAR). [https://www.climateactionreserve.org/wp-content/uploads/2014/07/Urban_Tree_Planting_Project_Protocol_V2.0.pdf]
[35] Gold Standard. [https://globalgoals.goldstandard.org/432_cdr_carbon-sequestration-through-accelerated-carbonation-of-concrete-aggregate/]
[36] DNV. DNV-SE-0473, DNV-RP-F104, DNV-RP-J203, DNV-RP-J201. https://www.dnv.com/oilgas/download/dnv-rp-j201-qualification-procedures-for-carbon-dioxide-capture-technology.html https://www.dnv.com/oilgas/download/dnv-rp-f104-design-and-operation-of-carbon-dioxide-pipelines.html https://www.dnv.com/oilgas/download/dnv-se-0473-certification-of-sites-and-projects-for-geological-storage-of-carbon-dioxide.html https://www.dnv.com/oilgas/download/dnv-rp-j203-geological-storage-of-carbon-dioxide.html

* CARB uses standards from CAR and ACR for this type of reservoir. PSC = point source capture. CCS+ = carbon capture and storage plus.

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[37] Climate Action Reserve (CAR). [https://www.climateactionreserve.org/how/protocols/biochar/dev/]

[38] Nori. [https://nori.com/documents]

[39] American Carbon Registry (ACR). [https://americancarbonregistry.org/carbon-accounting/standards-methodologies/afforestation-and-reforestation-of-degraded-lands]

[40] Regen Network [https://regen-registry.s3.amazonaws.com/Methodology+for+GHG+and+Co-Benefits+in+Grazing+Systems.pdf]

[41] California Air Resource Board (CARB) cap-and-trade. . [https://ww2.arb.ca.gov/our-work/programs/compliance-offset-program/compliance-offset-protocols/us-forest-projects/2015]

[42] American Carbon Registry (ACR). [https://americancarbonregistry.org/carbon-accounting/standards-methodologies/methodology-for-avoided-conversion-of-grasslands-and-shrublands-to-crop-production]

[43] Climate Action Reserve (CAR). [https://www.climateactionreserve.org/wp-content/uploads/2020/10/Soil-Enrichment-Protocol-V1.0.pdf]

[44] Verra. [https://verra.org/methodology/vm0042-methodology-for-improved-agricultural-land-management-v1-0/; https://verra.org/methodology/vm0017-adoption-of-sustainable-agricultural-land-management-v1-0/; https://verra.org/wp-content/uploads/2021/06/VM0026-Methodology-for-Sustainable-Grasslands-Management-v1.1.pdf; https://verra.org/wp-content/uploads/2018/03/VM0021-Soil-Carbon-Quantification-Methodology-v1.0.pdf; https://verra.org/wp-content/uploads/2018/03/VM0032-Meth-for-the-Adopt-of-Sustain-Grasslands-through-Adj-of-Fire-and-Grazing-v1.0.pdf]

[45] PlanVivo [https://www.planvivo.org/Handlers/Download.ashx?IDMF=5b30948b-26f3-4d7a-803f-0fcce593acbd]

[46] Gold Standard. [https://globalgoals.goldstandard.org/402-luf-agr-fm-soil-organic-carbon-framework-methodolgy/; https://globalgoals.goldstandard.org/402-1-luf-agr-am-soc-module-improved-tillage/; https://globalgoals.goldstandard.org/402-2-luf-agr-am-soc-activity-module-application-organic-soil-improvers/]

4.2 Utilization

The utilization of carbon refers to the use of CO_2, at concentrations above atmospheric levels, directly or as a feedstock in industrial or chemical processes, to produce valuable carbon-containing products (Metz et al., 2005). Feedstocks including non-fossil carbon from the air, biomass, or algae can be transformed into short life products including chemicals and fuels (Hepburn et al., 2019) for various usage, including sustainable aviation fuels and alternative fuels for land transportation. These pathways have limited potential to sequester carbon as the carbon is released upon use. However, they have the potential to reduce emissions and create a circular carbon economy, and therefore have an important role to play in decarbonization.

4.2.1 Considerations

To support the role of carbon utilization, the criteria that need consideration in its certification are origin, performance, and safety. In the transition to a zero or net negative emission economy, the origin of carbon will matter. Purchasers and the public will need to be able to differentiate between fossil and non-fossil-based products. This is pertinent for all carbon products, including synthetic fuels and chemicals and short-lived materials. For example, technologies that combine renewable energy, clean hydrogen, and carbon from air to produce synthetic fuels will want to be certified in the origin of each, proving to consumers and the public that the technology is non-fossil.

In the context of utilization, performance would refer to the net decrease in emissions from using the substitution. Until the transition to a net zero or negative emissions world is complete, the production of non-fossil carbon products has the potential to produce more emissions than continuing with the fossil-based product. This is because the production process may use unabated fossil fuels. As discussed in the section on **Sequestration**, the whole consequential process would need to be carbon neutral, or the activity would need to take responsibility for the fossil carbon it did use. Regulation akin to the Carbon Take Back Obligation[47] at the source of carbon extraction (Lackner and Wilson, 2008) would have to take effect to be rid of this burden on each product and process.

Safety in carbon utilization would refer to analyzing that the substitute product is fit for purpose and that the source of the non-fossil carbon is not damaging the environment. An example of the former, alternative aviation fuels are often designed to be “drop-in” fuels that can be used in

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[47] Carbon Take Back Obligation. https://carbontakeback.org/about/

existing aircrafts and infrastructure. ASTM International has been developing certification programs for this purpose (e.g., ASTM D7566, Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons[48]). An example of the latter is the EU's negative impact on food, the environment, and land through first generation bioenergy crops (Hein and Leemans, 2012; Rulli et al., 2016). Certification of safety criteria is supposed to consider environmental harm - if that criterion is not considered at other points in the certification program.

As concluded by National Academies of Sciences, Engineering, and Medicine (2016), only with verifiable data on carbon utilization can economic value, reliability, safety requirements and climate targets be ensured to stakeholders. The certification of performance, origin, and safety is one system.

4.2.2 State of certification

Certification of carbon utilization in the context described above is limited in the US to fuels and to the Environmental Protection Agency (EPA) and California's Air Resource Board's (CARB) Low Carbon Fuel Standard (LCFS). The EPA administers the Renewable Fuel Standard which requires a minimum volume of renewable fuels to be sold in the US. The renewable fuels are biomass-based, and the certification of performance is determined through a Life Cycle Analysis compared to a 2005 petroleum baseline. The EPA tracks compliance using a Renewable Identification Number[49], like a certificate of origin. Targets have not been met since 2014 met due to underproduction of advanced biofuels (Bracmort, 2022).

California's regulation certifies the performance, safety in terms of responsible biomass sourcing, and origin to some extent of alternative fuels. To certify performance, the California's Air Resource Board's (CARB) Low Carbon Fuel Standard (LCFS)[50] uses Life Cycle Assessments to examine the direct and indirect greenhouse gases associated with the production, transportation and use of alternative fuels expressed as a carbon intensity compared to gasoline and diesel fuels. A declining benchmark assigns credit generations and deficits. Since its inception, the LCFS has reduced the carbon intensity of California's fuel pool by about 7% (2011-2020)[51]. The LCFS offers pathways to

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[48] ASTM International. ASTM D7566: Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons. Available at: https://www.astm.org/d7566-21.html

[49] Renewable Identification Number in the Renewable Fuel Standard. More information available at: https://afdc.energy.gov/laws/RIN.html

[50] CARB's Low Carbon Fuel Standard Program basics. Available at: https://ww2.arb.ca.gov/sites/default/files/2020-09/basics-notes.pdf

[51] CARB Data Dashboard. Available at: http://www.arb.ca.gov/fuels/lcfs/dashboard/dashboard.htm

certify the carbon intensity for common low carbon fuels (e.g., landfill gas, cooking oil biodiesel, corn ethanol, gasoline blend stock) as well as next-generation fuels including DAC. Regarding safety, the LCFS contains regulation on the types of crops and residues that can be used in fuel production, for example used cooking oil, tallow, corn extracted from distiller grains and oils from fish processing. With the certification, the LCFS offers a form of guarantee of origin. Certification of origin is more prevalent in the EU where every member state must have a Guarantee of Origin system under the Renewable Energy Directive (2009/28/EC)[52].

Other standards and certification programs relevant to carbon utilization may include standards for fair comparisons between products (e.g., ASTM International), and the LCA standardization efforts referred in the previous section (e.g., NETL's LCA Toolkit, the International CCU Assessment Harmonization Group, ISO 14040:2006).

The certification of non-fossil carbon utilization meets similar issues as the certification of carbon sequestration discussed previously. Similar issues with LCA's apply for carbon sequestration as well as carbon utilization: without regulation such as the CBTO applied upstream, products may not be carbon neutral and the accounting will continue to be challenging in its attribution of ownership and responsibility. Guarantees of origin have also been criticized for their lack of environmental integrity, having no or worse impact on emissions, and double counting (Jansen, 2017).

Table 2. Certification programs available for carbon utilization.

Organization	Certification program	Certification criteria	Reference
CARB	Low Carbon Fuel Standard	Fuel carbon intensity – performance and safety	https://ww3.arb.ca.gov/regact/2009/lcfs09/lcfs09.htm
EPA	Renewable Fuel Standard	Biofuel market penetration -origin	https://www.epa.gov/renewable-fuel-standard-program/overview-renewable-fuel-standard
ASTM International	ASTN E3066-20: Standard Practice for Evaluating Relative Sustainability Involving Energy or Chemicals from Biomass	Comparison practice	https://www.astm.org/e3066-20.html
ISO	Environmental management — Life cycle assessment — Principles and framework	LCA	https://www.iso.org/standard/37456.html

52 Ibid 4

National Energy Technology Laboratory	Life Cycle Analysis Toolkit	LCA	https://netl.doe.gov/LCA/CO2U
Global CO2 initiative	International CCU Assessment Harmonization Group	LCA	https://www.globalco2initiative.org/evaluation/

4.3 Hydrogen

4.3.1 Considerations

Safety and origin are two criteria that matter for the certification of hydrogen. Hydrogen has ignition, combustion and pressure characteristics that make safety a priority, despite being a promising energy efficient and clean fuel. Safety concerns arise during production, transmission, use, and storage (Najjar, 2013). Hydrogen can be produced in various ways (e.g., from hydrocarbons, coal, nuclear energy, wind energy by electrolysis, thermos-chemical biomass processing, solar energy and hydrogen separation and purification), each having their own hazards. In general, the main hazard is through leakage (Najjar, 2013), although combustion also may be a safety hazard.

Because hydrogen can be produced from many sources, the origin of the energy used and the process to produce the hydrogen matters in the context of decarbonizing. Hydrogen can be used to reduce emissions in sectors with no other pathways, for example steel making. In a world of negative emissions, hydrogen production must either not produce emissions or emissions will have to be removed using CDR. Hydrogen produced from steam methane reform will need to be successfully fitted with CCS technology. However, the Rocky Mountain Institute found that in many natural-gas economies, such as the US, the predominantly SMR (small modular reactor)-based existing hydrogen production plants are quickly on track to become less CO_2-efficient than electrolysis[53]. Therefore, using the cleanest energy possible in hydrogen production could avoid stranded assets and accelerate decarbonization. Certifying the source of the energy will play a critical part to tracking this clean hydrogen, and support decarbonization claims.

[53] Koch Blank, T. and P. Molly (2020). Hydrogen's Decarbonization Impact for Industry. Rocky Mountain Institute Insight Brief, January. Available at: https://rmi.org/wp-content/uploads/2020/01/hydrogen_insight_brief.pdf

4.3.2 State of certification

Certification programs for hydrogen origin and safety exist (**Table 3**). The only available certification of energy origin for hydrogen is from the organization TÜV SÜD, an international and independent testing, inspection, and certification organization[54]. TÜV SÜD's Production of Green Hydrogen Standard is based on European Union legislation but is in principle applicable worldwide. TÜV SÜD can issue a GreenHydrogen certificate if the basic requirements are met, and the hydrogen has a greenhouse gas reduction potential of at least 70 % compared to a fossil fuel benchmark for fuels or combustibles. If additional requirements are met, TÜV SÜD can issue a GreenHydrogen+ certificate and this is proposed to promote greater use of renewable energy. The TÜV SÜD standard will eventually be superseded by the CertifHy™ GO (Guarantee of Origin) but will remain as an additional quality scheme. CertifHy™ was formed in response to EU legislation to reduce emissions continent wide with hydrogen a key technology. The mission of CertifHy™ is to develop an EU-wide system with a unique registry and unique standard compliant with the EU's Guarantee of Origin regulation (Art. 19 from RES Directive 2018/2001/EC (REDII)). The CertifHy™ will not be available outside of the EU.

More standards and certification are available regarding safety (**Table 3**). Organizations such as the National Institute of Standards and Technology (NIST), the American Society of Mechanical Engineers (ASME), the SAE International (SAE), and the International Organization for Standardization (ISO) provide hydrogen safety standards at the various stages of hydrogen production. For example, NIST has statutory responsibility under the US's Pipeline Safety Act of 2002 to develop research and standards for gas pipeline integrity, safety, and reliability for hydrogen. ASME expanded on data gathered by NIST to design pipeline construction code. The PSC certification programs identified in the previous section would provide the standards (e.g., pipelines and storage) which are pertinent to CCS for biomass or fossil-based hydrogen.

Table 3. Certification programs available for hydrogen.

Organization	Certification program	Certification criteria	Reference
TÜV SÜD	Production of Green Hydrogen Standard	Renewable energy origin	https://www.tuvsud.com/de-de/-/media/de/industry-service/pdf/broschueren-und-

[54] TÜV SÜD. Available at: https://www.tuvsud.com/en-us

			flyer/is/energie/tv-sd-standard-cms-70_grund–und-zusatzanforderungen-deutsch-englisch.pdf
CertifHy™	EU Voluntary Scheme for the certification of hydrogen as RFNBO (Renewable Fuel of Non-Biological Origin) according to the European Renewable Energy Directive	Renewable energy origin "Guarantees of Origin"	https://www.certifhy.eu/
NIST	Measurement Quality in Hydrogen Storage R&D	Storage measurement	https://www.nist.gov/programs-projects/measurement-quality-hydrogen-storage-rd
ASME	Hydrogen Piping and Pipelines B31.12 – 2019	Pipeline safety	https://www.asme.org/codes-standards/find-codes-standards/b31-12-hydrogen-piping-pipelines
ISO	ISO 14687:2019 Hydrogen fuel quality — Product specification	Fuel quality	https://www.iso.org/standard/69539.html
ISO	ISO 13984:1999 Liquid hydrogen — Land vehicle fueling system interface	Fueling interface safety	https://www.iso.org/standard/23570.html?browse=tc
ISO	ISO 13985:2006 Liquid hydrogen — Land vehicle fuel tanks	Fuel tanks	https://www.iso.org/standard/39892.html?browse=tc
ISO	ISO/TR 15916:2015 Basic considerations	Basic safety	https://www.iso.org/standard/56546.html?browse=tc

	for the safety of hydrogen systems		
ISO	ISO 16110-1:2007 Hydrogen generators using fuel processing technologies — Part 1: Safety	Generator safety	https://www.iso.org/standard/41045.html?browse=tc
ISO	ISO 19880-1:2020 Gaseous hydrogen — Fuelling stations — Part 1: General requirements ISO 19880-3:2018 Gaseous hydrogen — Fuelling stations — Part 3: Valves ISO 19880-5:2019 Gaseous hydrogen — Fuelling stations — Part 5: Dispenser hoses and hose assemblies ISO 19880-8:2019 Gaseous hydrogen — Fuelling stations —	Fueling station safety	https://www.iso.org/standard/71940.html?browse=tc https://www.iso.org/standard/64754.html?browse=tc https://www.iso.org/standard/73787.html?browse=tc https://www.iso.org/standard/69540.html?browse=tc https://www.iso.org/standard/80272.html?browse=tc

	Part 8: Fuel quality control ISO 19880-8:2019/AMD 1:2021 Gaseous hydrogen — Fuelling stations — Part 8: Fuel quality control — Amendment 1: Alignment with Grade D of ISO 14687		
ISO	ISO 19881:2018 Gaseous hydrogen — Land vehicle fuel containers	Fuel containers (vehicles)	https://www.iso.org/standard/65029.html?browse=tc
ISO	ISO 26142:2010 Hydrogen detection apparatus — Stationary applications	Detection apparatus	https://www.iso.org/standard/52319.html?browse=tc
SAE International	J2719 Hydrogen Fuel Quality for Fuel Cell Vehicles	Vehicle safety	https://www.sae.org/standards/content/j2719_202003/

5 Gaps, needs, and recommendations in the context of I-WEST

5.1 Carbon sequestration (including long-lived products)

5.1.1 Gaps

- The situation with the certification of carbon sequestration currently depends on the reservoir type. The certification of sequestration ought to result in an equal outcome that ought to be clearly stated, which may require different treatments for each reservoir type. Guidelines on how this could be done do not currently exist and the considerations in **section 4.1.1** may offer a starting point.
- The region's main consideration is point source capture into geologic reservoirs. For this type of decarbonization solution, the EPA's Class VI wells permitting is available. The main issues have so far been related to the time and effort needed to get through the process, exacerbated by the limited staffing. Lessons learned from the Illinois Basin – Decatur Project are detailed in Van Voorhees et al. (2021). The remedial action requirements of the Class VI wells may not be consistent with ensuring the integrity of the sequestration as a decarbonization solution, i.e., by requiring an equal amount of re-sequestration to match lost carbon, and may need further exploration.
- For other carbon sources injected into geological reservoirs, a few protocols are available (e.g., the California Air Resource Board Low Carbon Fuel Standard allows for carbon from DAC whereas Verra CCS+ initiative is developing voluntary, unregulated standards for DAC, CO_2-rich gases, biogenic sources, and oil and gas production into aquifers and depleted oil and gas fields[55]). Protocols ought to result in the certification of the same outcome to be considered equivalent. Guidance on what that ought to be is generally lacking, unless the EPA's Class VI Guidance also applies to CO_2 streams that are not captured from an emission source.
- Protocols are available for Enhance Oil Recovery activities through the California Air Resource Board and the American Carbon Registry. However, it remains unclear whether EOR is fit-for-purpose as a sequestration activity.
- Emission accounting that relies on LCAs and counterfactuals are inadequate for delivering measurable and verifiable estimations of sequestration. Alternative approaches that use direct measurements are limited, except for certain standards covering geologic sequestration.

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[55] Verra CCS+ Initiative. Available at: https://verra.org/wp-content/uploads/2021/10/Verra-RFP-Meth-CCS.pdf

- Most standards of sequestration do not internalize the potential failure that sequestration will not be durable. Guidance on what is satisfactory is generally lacking.

5.1.2 Recommendations

The I-WEST initiative is explicitly focused on geologic sequestration in the intermountain West. Thus, the following recommendations are pertinent to that focus and location.

- As recommended elsewhere, support the streamlining of EPA permitting process and increase of EPA staffing.
- Determine if bio-oil injection is a fit-for-purpose CDR approach.
- Develop standards that safeguards against poorly sourced biomass.
- Develop certification of origin for biomass used for BiCRS.
- Regulate voluntary standards in geologic formations to meet criteria as stringent as EPA.
- Require that standards internalize the potential that sequestration will not be permanent.
- Ensure the EPA Class VI permit includes CO_2 streams from non-point sources such as DAC and BiCRS.

Although I-WEST is not explicitly assessing forestry, soils, enhanced weathering, and mineralization in the decarbonization pathways, a plethora of protocols are available on a voluntary basis for these types of reservoirs. For these, there is no coherency in the protocols either in terms of performance, safety, or origin. Many are of questionable integrity in terms of their rigorousness of measurement, monitoring plans, and remedial action. They also have limited oversight and restricted verification activities. Recommendations for non-geologic reservoir certification are the following.

- Create independent oversight of standards development to ensure standards represent the same outcome.
- Develop an independent system for verification that eliminates conflicts of interests.
- Develop accounting protocols that use direct measurements to meet measurability and verification requirements.
- Require that standards internalize the potential that sequestration will not be permanent.
- Identify what reservoirs need further research and target basic research towards reservoirs with large uncertainties or costly measuring equipment.
- Require the separation of certification and verification from the financial gain of the activity or product.
- Support the development of a framework for the certification of carbon sequestration that is equal across reservoirs, produces measurable and verifiable accounting of sequestration, and allows deployment today without compromising the future.

5.2 Utilization

5.2.1 Gaps

- The LCFS and the EPA's RFS are the only two standards covering carbon utilization as a fuel. The EPA narrowly focuses on biofuels demand, whereas the LCFS offers some opportunities to expand to DAC-to-fuel production.
- The LCFS is for now restricted to California, although it does provide for the import of fuels into the state. This could benefit alternative fuel production in the intermountain west.
- Existing standards are focused on land and air transport, with none appearing to exist for watercrafts, which are important to support recreational activities, a lucrative sector for the intermountain west.
- No standard appears to exist for fuels outside of the transport sector. For example, to replace residential and commercial heating fuel.
- No standard appears to exist for carbon utilization in other non-fuel, short-lived products.
- Criticisms of GO systems are similar to those of the carbon sequestration: poor environmental credibility, over supply, and double counting will weaken the system.
- Carbon accounting at the product level is challenging in terms of attribution, has large uncertainties in terms of quantification, and is a burden on product manufacturers. It is unclear how the current strategy would support an expansion of carbon neutral or negative products.

5.2.2 Recommendations

- Expand a standard like the LCFS to the intermountain west.
- Develop an independent verification regime.
- Support regulation like the CBTO and require that accounting be done at the point of carbon extraction or import to create a demand and simplify accounting systems, respectively.

5.3 Hydrogen

5.3.1 Gaps

- The scaling of clean hydrogen will require adequate certification infrastructure which is inexistent or nascent. Buyers will want to report their purchases of clean hydrogen either for reporting or to make claims towards sustainable practices and clean hydrogen production will need to be tracked to target hard infrastructure development and market development.

- A portion of the challenge is the various naming designation for hydrogen based on the source. In some cases the naming of the hydrogen (green, blue, etc.) serves to obfuscate the origin and as such hide the actual CO_2 impact of the hydrogen, both its formation and application.
- No standard for hydrogen energy origin currently exists to do that for the US, but the TÜV SÜD standard is a priori applicable.

5.3.2 Recommendations

The certification of hydrogen activities ought to be a priority to support the development and scaling of the hydrogen industry in the US to the extent envisaged by the I-WEST initiative. Recommendations to do so are the following.

- Like the CertifHy Initiative, create a unique hydrogen Guarantee of Origin registry that would span across states.
- Build on the TÜV SÜD standard.
- Adopt one hydrogen Guarantee of Origin standard.
- Develop a strategy using certification to reach 100% renewable energy hydrogen source.
- Develop an independent verification regime.
- Develop a naming system that identifies the source of the hydrogen and the CO_2 created by the different sources.

6 Conclusions

Certification is the social contract that protects the public and consumers. Certification will be critical for decarbonization activities to gain and keep the public's trust. Some decarbonization activities have the added complexity of being invisible to the consumer, either because they are far removed, or because they move gases without physical properties that can be sensed and have limited immediate impacts on the public. For these reasons, certification is important for decarbonization with the understanding that certification must be actively shielded from the potential to be gamed in its development but also in its verification. Strong verification regimes ought to be developed for all the decarbonization activities that require certification.

The I-WEST so far only concerns itself with geologic storage, which is largely governed by the EPA Class VI well permitting process. The process has limitations as discussed but provides a robust procedure that results in measurable and verifiable data, along with long-term commitments to monitor. Ensuring that released carbon would be remediated by re-sequestration would continue the integrity of the sequestration as a decarbonization solution.

Alternative sequestration options may be sought by the region in the future, including mineralization, enhanced weathering, soil carbon, and forestation. For these types of activities, the status of certification highlights several urgent needs that ought to be addressed before implementation begins. These include a need for oversight so the plethora of unequal protocols are reformed to meet a minimal level of quality that can be trusted, a need for the establishment of independent certification without financial link to decarbonization products or activities or to the standards, and a need for independent verification that can make sure the certification is applied properly.

Other decarbonization activities, such as synthetic fuels, hydrogen, and biomass utilization, have either nascent or inexistent certification programs, particularly when it comes to certification of origin. To support the development of these industries, there is thus a need for urgent development of rules in a U.S. context, which could be borrowed from the European model.

Targeted basic research will support the development of certification programs. For carbon sequestration, basic research on the various reservoirs and technology cost reduction will add additional suitable reservoirs, will help protect communities and the environment, and will reduce the cost of certification. For hydrogen, basic research should focus on reaching the DOE targets for hydrogen systems[56].

In the end, the intermountain west would need to implement regulation like the Carbon Take Back Obligation, where each ton of carbon extracted is a ton that must be matched by sequestration. This needs to be applied at the source to simplify the accounting. When CBTO is applied upstream with a transition mechanism, robust certification will then support the transition to a carbon neutral or even carbon negative intermountain west economy.

[56] DOE Hydrogen Shot Program. Available at: https://www.energy.gov/eere/fuelcells/hydrogen-shot

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