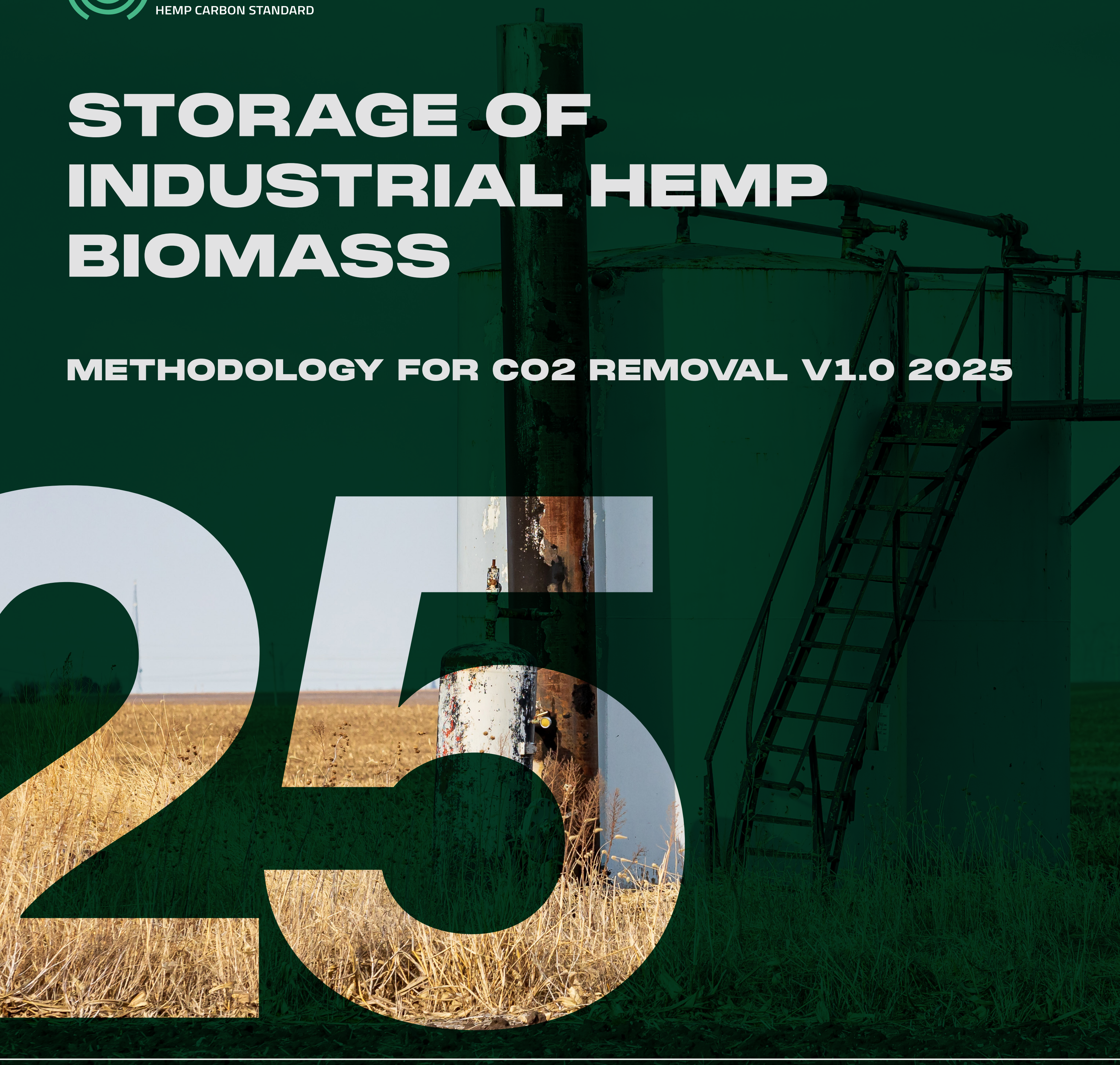
HCS
HEMP CARBON STANDARD

STORAGE OF INDUSTRIAL HEMP BIOMASS

METHODOLOGY FOR CO2 REMOVAL V1.0 2025



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1. INTRODUCTION

1.1 Overview of Industrial Hemp Biomass Burial

Introducing the innovative approach of "Industrial Hemp Biomass Burial," this methodology revolutionizes carbon sequestration by utilizing the inherent properties of industrial hemp. Esteemed for its swift growth cycle and robust biomass output, industrial hemp emerges as a formidable carbon sink, adeptly drawing CO_2 from the atmosphere through the natural process of photosynthesis. The essence of this methodology lies in the strategic burial of harvested hemp biomass, encased within layers of local clay or alternatively, utilizing orphaned oil wells—abandoned structures that can be repurposed for long-term carbon storage. Both methods significantly curtail the decomposition process, thereby sealing the carbon content securely within.

This meticulous process not only mimics the earth's organic carbon cycle but also amplifies the potential for long-term carbon storage, offering a dual advantage of ecological preservation and economic viability. By effectively halting the biomass decomposition, whether in subterranean clay layers or within the anoxic environments of oil wells, the method ensures the longevity of carbon sequestration. This positions it as a critical component in the global strategy to mitigate carbon footprint and combat climate change.

Moreover, the utilization of industrial hemp for carbon burial underscores a commitment to sustainable agricultural practices, highlighting the crop's versatility and its minimal requirement for chemical inputs. This aligns with broader environmental objectives, promoting biodiversity, soil health, and reducing water usage. The economic benefits are equally compelling, providing a new revenue stream for farmers through carbon credit markets, while also fostering innovation in green technologies and sustainable materials derived from hemp.

In essence, the "Industrial Hemp Biomass Burial" methodology is not merely a carbon sequestration tactic; it is a holistic approach to environmental stewardship, intertwining the benefits of agricultural sustainability with the imperative of climate action. Its implementation could signal a paradigm shift in how industries and communities view the role of agriculture in ecological balance, paving the way for a greener, more sustainable future. Incorporating orphaned oil wells into this methodology offers a novel recycling of industrial remnants for environmental benefit, further enhancing the sustainability of this innovative carbon sequestration approach.

1.2 Rationale and Importance

The urgency to combat climate change underscores the critical role of carbon sequestration, a natural or artificial process that captures atmospheric carbon dioxide (CO_2) and stores it long-term to mitigate or defer global warming. Within this context, industrial hemp emerges as an exceptional candidate for carbon sequestration due to its distinct advantages. Characterized by its rapid growth rate, industrial hemp is capable of absorbing CO_2 at a higher velocity compared to many other crops or forestry initiatives, effectively turning these plants into efficient, living carbon sinks. Industrial hemp not only thrives across various climates with minimal water and fertilizer requirements but also produces a significant amount of biomass, which translates into substantial CO_2 capture and storage potential per hectare. Its versatility extends beyond environmental benefits, offering economic opportunities through the production of sustainable materials, thus promoting a circular economy. The rationale behind prioritizing industrial hemp for carbon sequestration efforts is embedded in its ability to deliver dual benefits: mitigating climate change impacts while fostering sustainable agricultural and industrial practices.

By capitalizing on industrial hemp's high carbon capture rate and integrating it within the broader carbon sequestration strategy, we can leverage a natural, efficient means to draw down excess atmospheric CO_2. This, combined with hemp's sustainability credentials, positions it as an excellent material for tackling the pressing challenge of climate change, highlighting the importance of innovative, ecologically sound solutions in our global carbon management efforts.

1.3 Methodology Objective

The core objective of this methodology is to establish a rigorous framework for measuring the net CO_2 removed from the atmosphere, achieved through the burial of industrial hemp biomass over a century. This approach is rooted in the understanding that by burying hemp biomass in conditions that significantly impede decomposition, we can effectively lock away carbon for prolonged periods. To this end, we meticulously engineer both subterranean burials in local clay and the utilization of orphaned oil wells, which offer anoxic environments ideal for long-term carbon storage. These conditions are designed to mirror natural geological processes that lead to the long-term sequestration of carbon, akin to the formation of fossil fuels and minerals.

This methodology not only seeks to quantify the carbon sequestered but also to validate the effectiveness and reliability of using industrial hemp as a sustainable solution to climate change challenges. By incorporating the use of orphaned oil wells, we expand the potential for securely storing carbon in abandoned infrastructures, thus repurposing industrial remnants for environmental benefits. This dual approach aims to contribute substantively to global carbon reduction efforts, providing a scalable, verifiable, and environmentally beneficial strategy for capturing and storing atmospheric CO_2. Through this innovative integration, the methodology reinforces the importance of adaptive reuse in environmental conservation strategies, enhancing the sustainability and impact of our carbon sequestration efforts.

1.4 Suitability of Biomass

Within the scope of this methodology, the lignocellulosic biomass (LCB) that qualifies must possess both a robust structure and significant lignin content, with a carbon to nitrogen (C:N) ratio exceeding 80 (refer to rule 4.1.2 and the glossary definition for Eligible biomass). These chemical and structural characteristics render the biomass resistant to microbial decay.

To be more precise, LCB is comprised of a durable matrix of cellulose, hemicelluloses, and lignin. This contrasts with plants like grasses and lichens, which are typically rich in starch, sugars, and proteins that degrade more easily and are therefore excluded from this methodology.

The essence of this approach is centered on the enduring biomass of Industrial Hemp and its inherent carbon content. Table 1 summarizes the principal components of LCB found in different materials.

Table 1

Raw Material	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Grasses	25-40	25-50	10-30
Softwoods	45-50	25-35	25-35
Hardwoods	45-55	24-40	18-25

The cellulose, hemicellulose, and lignin content in industrial hemp can vary depending on the part of the plant analyzed and the method used for analysis. Here are some findings:

- Hemp fibers have been reported to have a cellulose content of 57.5% (MDPI).
- Hemp shives, another part of the plant, contain 49% cellulose, 21% hemicellulose, and a lignin content of approximately 23.9% (Springer) (MDPI).
- In hemp hurds, the alpha-cellulose content is around 44.0%, hemicellulose 25.0%, and lignin 23.0% (BioResources).
- Hemp bast fibers, used in the production of high-quality textiles, have even higher cellulose content, ranging from 70–74%, and lower lignin content, ranging from 3.5–5.7% (MDPI Res).
- The alpha-cellulose content in hemp bast fiber is particularly high, sitting at 92–96.2%, which is favorable for feedstock in the manufacturing of lyocell fibers (MDPI).

Comparing these metrics to the table provided for softwoods, which have a cellulose content of 45-50%, hemicellulose content of 25-35%, and lignin content of 25-35%, industrial hemp generally shows a higher percentage of cellulose, particularly in the bast fibers. The hemicellulose and lignin content can be comparable or even lower than that of softwoods, especially in the bast fibers. This high cellulose content and the favorable ratio of cellulose to lignin make industrial hemp a promising candidate for carbon sequestration when considering biomass burial, given cellulose's stability and resistance to decomposition.

Table 2 details the carbon content across various plant types, concerning the organic carbon within the biomass.

Table 2

Type of Plant	No of Samples (%)	Carbon Content (%)
Herbaceous Plants	162	42.4
Crop	69	43.2
Woody Plants	3461	48.1
Deciduous broad-leaved	1581	47.6
Evergreen broad-leaved	1212	47.8
Conifers	502	50.5
Vine	82	46.7
Bamboo	39	49.2
All	**3754**	**47.9**

The carbon content in industrial hemp stems can account for up to 44.46% of the stem's dry weight. This implies that for every ton of industrial hemp stems, there's a capture of approximately 0.445 tonnes (~0.49 tons) of carbon directly from the Earth's atmosphere. When converting this carbon to CO_2, the data shows that a single ton of hemp can absorb about 1.63 tonnes (~1.8 tons) of CO_2 (Hemp.inc).

Comparing this to the figures in your provided table for other plant types, industrial hemp's carbon content percentage is competitive. It's particularly notable when compared with crops (43.2%) and even deciduous broad-leaved plants (47.6%). This high carbon content makes industrial hemp an effective tool for carbon sequestration efforts.

As scientific understanding progresses, alternative biomass sources might be contemplated for future methodological adaptations. While many forms of biomass could be durably stored under ideal conditions—for example, those maintaining a low equilibrium relative humidity—non-lignin-containing biomass degrades more rapidly without these conditions. This methodology, therefore, restricts inclusion to lignocellulosic biomass that inherently resists decomposition as a measure against re-emission risks, ensuring time for restoration of proper storage conditions should a breach occur.

Plant biomass recalcitrance (PBR) is multifaceted, influenced by the biomass matrix's structural integrity and its chemical composition. Of particular importance to PBR is the nitrogen content within the biomass. Additionally, PBR depends on the configuration and chemical attributes of the primary components within the biomass cell walls: hemicellulose, cellulose, and lignin. For an extensive evaluation of the factors affecting the recalcitrance of lignocellulosic biomass, see reference [7].

A high nitrogen content fosters rapid microbial degradation as it is essential for the production of microbial enzymes that break down biomass. Therefore, a C:N ratio under 25 facilitates microbial processing of biomass into CO2 or methane. A C:N ratio of 25 indicates a nitrogen composition of approximately 4% relative to the carbon mass. This ratio underpins the superior recalcitrance of LCB over herbaceous biomass due to its lower nitrogen content (C:N > 80, or less than 1.2% nitrogen content).

1.5 Significance of Industrial Hemp Biomass

Within the framework of this methodology, industrial hemp represents a pivotal category of lignocellulosic biomass (LCB) due to its robust structure and notable lignin content, though the decompositional traits differ from wood. Notably, industrial hemp has been recognized for its resistance to decay under various conditions, thanks to its dense cellulose network and high lignin concentration.

Industrial hemp's resilience, particularly under anaerobic conditions, stems from the composition of its lignocellulose, wherein cellulose and hemicellulose fractions may be broken down while lignin remains largely unaffected. The substantial C:N ratio found in industrial hemp, much like wood, contributes to its recalcitrance; it's sufficiently low in nitrogen to resist rapid decomposition without external nitrogen sources. Hemp biomass, with a C:N ratio exceeding 80, indicates minimal nitrogen content and, as a result, a decreased propensity for natural decay.

Moreover, when considering the burial of industrial hemp for long-term carbon storage, it's essential to draw on methods that optimize preservation. Submerging hemp biomass below the water table and encasing it with native clay has emerged as a promising approach. This technique draws inspiration from historical applications where organic materials are known to persist for extended periods when kept in low-oxygen environments, shielded by clay layers that prevent microbial activity and oxidation.

Observations of hemp's durability under such conditions are encouraging, mirroring the longevity seen in wood applications, where wood chips and sawdust have successfully served as stable fill in infrastructure projects, enduring for decades. Employing this method for industrial hemp could effectively transform it into a long-standing carbon store, leveraging its innate properties to contribute significantly to carbon sequestration goals.

1.6 Innovative Storage Solutions for Industrial Hemp:

The potential of Industrial Hemp as a sustainable carbon sink is not only rooted in its rapid growth and carbon absorption capabilities but also significantly influenced by the methodologies employed for its long-term storage. Industrial Hemp offers a remarkable opportunity for carbon sequestration when coupled with advanced storage solutions designed to mitigate degradation and promote carbon containment over extended periods exceeding a century. This analysis delves into three pivotal storage strategies tailored for Industrial Hemp, each engineered to harness its ecological benefits while addressing the critical challenge of biomass decay.

I. Burial Below the Water Table Covered with Native Clay:

The burial of Industrial Hemp below the water table, safeguarded by a layer of native clay, stands as a testament to leveraging natural geological features for carbon storage. This method capitalizes on the anoxic conditions prevalent beneath the water table, where the absence of oxygen significantly slows down the decomposition process. The native clay acts as a natural barrier, further inhibiting oxygen penetration and ensuring the Hemp remains in an environment less conducive to microbial activity. This synergy between the water table's natural anoxic conditions and the protective qualities of native clay provides a robust framework for the long-term preservation of Hemp's carbon content.

II. Engineered Below Ground Storage Chambers:

Engineered below ground storage chambers represent a leap in precision and control for Hemp storage. Designed to maintain either an anoxic or a dry oxic environment, these chambers are constructed with specific attention to inhibiting decomposition. The tailored environment within these chambers can replicate the natural anoxic conditions found below the water table or offer a controlled, dry oxic setting akin to above-ground solutions. The key advantage lies in the ability to design and engineer these chambers to meet exact specifications for humidity, temperature, and other parameters critical to preserving Hemp's integrity and carbon sequestration capabilities.

III. Above Ground Storage Chambers:

Above ground storage chambers offer a versatile and accessible solution for Hemp storage. These purpose-built structures are engineered to maintain low relative humidity, shield the Hemp from UV radiation, pests, and other external factors that could promote decomposition. By providing a controlled environment that minimizes moisture and blocks sunlight, these chambers effectively slow down the degradation process, ensuring that the carbon captured by the Hemp remains sequestered over the long term.

IV. Orphaned Oil Well Utilization:

Incorporating orphaned oil wells as a novel storage solution offers a unique opportunity to repurpose these existing infrastructures for carbon sequestration. By filling these abandoned wells with hemp biomass, we can utilize the naturally anoxic conditions deep underground to significantly reduce the decomposition rate. This method not only prevents methane escape but also leverages the geological stability of the wells to ensure long-term carbon containment.

Monitoring and Optimization:

All storage solutions require diligent monitoring and optimization of internal conditions such as humidity, temperature, and gas exchange to ensure the integrity of the stored Hemp. Continuous refinement based on empirical data and ongoing research will further enhance the efficacy of these storage methods, making Industrial Hemp an even more viable option for carbon sequestration.

The strategic storage of Industrial Hemp using the outlined methods not only maximizes its potential as a carbon sink but also aligns with ecological, social, and economic objectives. By adopting innovative storage techniques such as burial below the water table covered with native clay, engineered below ground storage chambers, and repurposing orphaned oil wells, we can significantly advance our capabilities in carbon sequestration, leveraging Industrial Hemp's inherent benefits to combat climate change effectively.

1.7 Biomass decomposition and methane emissions:

In the context of Industrial Hemp storage and its implications for carbon sequestration and methane emissions, it's vital to assess and refine storage methodologies that curtail the initial decomposition and subsequent methane generation. Industrial Hemp, recognized for its environmental benefits, also necessitates strategic storage approaches to optimize its role in carbon capture and minimize its environmental footprint. This analysis extracts key insights from the provided document to focus on tailored storage solutions for Industrial Hemp: burial below the water table covered with native clay, engineered below-ground storage chambers, above-ground storage chambers, and utilization of orphaned oil wells. These methods are evaluated for their effectiveness in mitigating methane emissions and ensuring the long-term integrity of stored biomass.

I. Burial Below Water Table Covered with Native Clay:

This storage technique leverages the natural anoxic conditions present below the water table, which are instrumental in slowing the decomposition process of Industrial Hemp. By covering the buried hemp with native clay, an additional barrier is created, further minimizing oxygen exposure and, consequently, the potential for decomposition. This method not only harnesses the innate properties of the subsurface environment but also capitalizes on the clay's ability to act as a physical and biochemical shield, significantly reducing the risk of methane production.

II. Engineered Below-Ground Storage Chambers:

Designed to replicate the anoxic conditions found naturally below the water table or to create a controlled dry environment, engineered below-ground storage chambers offer a customizable solution for Hemp storage. These chambers are meticulously constructed to prevent moisture accumulation and ensure a stable environment, thereby minimizing the conditions favorable for methane-producing microbial activity. The adaptability of these chambers to specific site conditions and requirements makes them a viable option for effectively controlling the rate of biomass decomposition and associated methane emissions.

III. Orphaned Oil Well Utilization:

Utilizing orphaned oil wells as an innovative storage solution capitalizes on their deep underground, naturally anoxic conditions to minimize decomposition. By filling these abandoned wells with hemp biomass, we can significantly reduce the risk of methane emissions due to reduced microbial activity. The geological stability and isolation provided by these wells also contribute to the long-term containment of carbon.

IV. Above-Ground Storage Chambers:

Above-ground storage chambers provide a versatile and potentially more accessible option for storing Industrial Hemp. These structures are engineered to maintain low humidity levels and protect the biomass from external factors that could accelerate decomposition, such as UV radiation and pests. By creating a controlled environment that minimizes the key drivers of biomass breakdown, these chambers play a critical role in reducing the potential for methane generation and ensuring the carbon sequestered in the hemp remains locked away from the atmosphere.

Monitoring and Mitigation of Methane Emissions:

Regardless of the storage method employed, it is crucial to monitor the conditions within the storage site actively to manage and mitigate the risk of methane emissions. Techniques such as the construction of methane oxidation systems or the use of soil probes for methane testing can be integrated into storage solutions to track and address any methane generation. This proactive approach is essential not only for quantifying the effectiveness of the storage methods in containing carbon but also for ensuring that methane, with its potent short-term climate impact, is effectively captured or converted, thus safeguarding the net environmental benefit of using Industrial Hemp for carbon sequestration.

The strategic storage of Industrial Hemp, through methods such as burial below the water table covered with native clay, engineered below and above-ground storage chambers, and the innovative use of orphaned oil wells, represents a pivotal step in maximizing its utility as a carbon sink while addressing the critical concern of methane emissions. By adopting and refining these storage techniques, the full potential of Industrial Hemp in contributing to carbon sequestration efforts can be realized, ensuring its role in mitigating climate change is both effective and environmentally responsible.

2. PRINCIPLES FOR AUTHENTICATING CO2 REMOVAL WITHIN THE HEMP CARBON STANDARD

2.1 Guiding Principles

This document underpins the framework for verifying and quantifying carbon dioxide removal efforts, specifically within the context of Industrial Hemp projects under the Hemp Carbon Standard. It emphasizes a structured approach, fostering innovation and learning through experimentation within a scientifically rigorous and transparent environment. The principles highlighted are transparency, evidence-based practices, rigorous monitoring, reporting, and verification (MRV), and the iterative refinement of methodologies based on empirical data. This structured approach aims to build trust, reduce market transaction costs, and ensure the integrity and efficacy of carbon sequestration projects.

In adapting these principles to the context of Industrial Hemp and focusing on specified storage methods—burial below the water table covered with native clay, engineered below-ground, and above-ground storage chambers—there's a clear directive to prioritize direct measurement and robust evidence in monitoring carbon storage efficacy. The document advocates for a transparent process that involves public consultation, the application of scientific evidence, detailed MRV protocols, and the continuous improvement of carbon accounting practices based on field data and scientific advancements.

Transparency in Industrial Hemp Carbon Sequestration:

Transparency is crucial in establishing trust and confidence among stakeholders in the carbon market. For Industrial Hemp carbon sequestration projects, this involves detailed documentation of storage methodologies, carbon capture quantities, and the operational practices employed. A public registry and a thorough verification process ensure that the projects deliver on their promises and adhere to the highest standards of accountability.

Evidence-Based Storage Practices:

The document encourages the application of direct measurements over simulations or estimates, highlighting the importance of grounding project methodologies in empirical evidence. For Industrial Hemp, this means rigorously documenting the carbon capture capacity of the biomass and the effectiveness of chosen storage methods in preserving this capacity over time.

Monitoring, Reporting, and Verification (MRV):

Detailed MRV requirements are essential for tracking the performance of Industrial Hemp sequestration projects. This encompasses the long-term monitoring of storage conditions, the periodic reporting of carbon capture volumes, and third-party verification to validate reported outcomes. The approach ensures the accuracy of carbon accounting and fosters an environment of continuous improvement based on verified data.

Refinement Over Time:

Acknowledging the evolving nature of scientific understanding, the document supports the refinement of methodologies based on new insights and field data. For Industrial Hemp carbon sequestration, this iterative process involves updating storage techniques, MRV practices, and carbon accounting models to reflect the latest scientific evidence and operational learnings.

These guiding principles shape a robust framework for Industrial Hemp carbon sequestration projects, ensuring they are transparent, evidence-based, accurately monitored, and continuously refined to enhance their contribution to carbon dioxide removal efforts. This approach not only aligns with the immediate goals of the Hemp Carbon Standard but also contributes to the broader mission of combating climate change through innovative and sustainable practices.

2.2 Alignment with Core Carbon Principles

The Integrity Council for the Voluntary Carbon Market (ICVCM), is an independent governance body for the voluntary carbon market. Their objective is to build integrity, so that high-quality carbon credits efficiently mobilize finance towards urgently needed mitigation and climate resilient activities. The Hemp Carbon Standard is following the Core Carbon Principles (CCPs) issued by the ICVCM.

Principles for carbon-crediting programs

1. Effective governance (CCP 01)

The carbon-crediting program shall have effective program governance to ensure transparency, accountability, continuous improvement and the overall quality of carbon credits.

2. **Tracking (CCP 02)**

The carbon-crediting program shall operate or make use of a registry to uniquely identify, record and track mitigation activities and carbon credits issued to ensure credits can be identified securely and unambiguously.

3. **Transparency (CCP 03)**

The carbon-crediting program shall provide comprehensive and transparent information on all credited mitigation activities. The information shall be publicly available in electronic format and shall be accessible to non-specialized audiences, to enable scrutiny of mitigation activities.

4. Robust independent third-party validation and verification (CCP 04)

The carbon-crediting program shall have program-level requirements for robust independent third-party validation and verification of mitigation activities.

5. Sustainable development benefits and safeguards (CCP 09)

The carbon-crediting program shall have clear guidance, tools and compliance procedures to ensure mitigation activities conform with or go beyond widely established industry best practices on social and environmental safeguards while delivering positive sustainable development impacts.

Principles for projects (mitigation activities)

6. **Additionality (CCP 05)**

The greenhouse gas (GHG) emission reductions or removals from the mitigation activity shall be additional, i.e., they would not have occurred in the absence of the incentive created by carbon credit revenues.

7. **Permanence (CCP 06)**

The GHG emission reductions or removals from the mitigation activity shall be permanent or, where there is a risk of reversal, there shall be measures in place to address those risks and compensate for reversals.

8. Robust quantification of emission reductions and removals (CCP 07)

The GHG emission reductions or removals from the mitigation activity shall be robustly quantified, based on conservative approaches, completeness and sound scientific methods.

9. No double counting (CCP 08)

The GHG emission reductions or removals from the mitigation activity shall not be double counted, i.e., they shall only be counted once towards achieving mitigation targets or goals. Double counting covers double issuance, double claiming, and double use.

10. Contribution to net zero transition (CCP 10)

The mitigation activity shall avoid locking-in levels of GHG emissions, technologies or carbon-intensive practices that are incompatible with the objective of achieving net zero GHG emissions by mid- century.

3. POINT OF CREATION OF THE CO2 REMOVAL UNIT (CRU)

3.1 The CO2 Removal Supplier

- **3.1.1 Role and Responsibility:** The CO2 Removal Supplier is the authorized entity responsible for overseeing the end-to-end supply chain of activities associated with the terrestrial storage of biomass using burial techniques and orphaned oil wells. This encompasses all stages from biomass sourcing to final storage and monitoring.
- **3.1.2 Data Provision and Accessibility:** The CO2 Removal Supplier is tasked with ensuring that all data relevant to the storage process is available and accessible for third-party verification. This includes data necessary to assess the eligibility of the activities, quantify the predicted net carbon removal, and monitor the actual rate of carbon stability within the storage sites.

3.2 Point of Creation

- **3.2.1 Definition and Criteria:** The point of creation of the CO2 Removal Unit (CRU) occurs when the eligible biomass is securely enclosed within the designated storage system, which may be subterranean burial chambers lined with clay or repurposed orphaned oil wells. The exact specifications of a "storage chamber" will vary depending on the individual project design and the storage methodology employed.

- **3.2.2 Proving Stability of Storage Conditions:** For a CRU to be issued, proven stable storage conditions within the filled and completed chamber or well are required. The CO2 Removal Supplier must provide convincing evidence to demonstrate the long-term stability of these conditions. This evidence must be detailed and robust, giving a high degree of confidence in the permanence of the carbon sequestration.

    - **Evidence Requirements:** Detailed monitoring data and validation reports that confirm the absence of significant decomposition or carbon leakage must be submitted. This may include, but is not limited to, sensor data showing consistent environmental conditions, integrity assessments of the storage chamber or well, and any other relevant geological or environmental impact assessments.

- **3.2.3 Issuance Delays and Additional Data:** The issuance of CRUs may be postponed until the stability of the storage conditions can be thoroughly verified. If initial submissions are insufficient, the Hemp Carbon Standard may request additional data or impose further monitoring to ensure compliance with storage stability requirements.

Process Integration

The point of creation of CRUs in the HCS Biomass Burial Methodology underlines the rigorous standards required for carbon storage using advanced burial techniques and orphaned oil well methodologies. It emphasizes the need for meticulous planning, robust engineering, and comprehensive monitoring to ensure that the carbon sequestered is effectively and permanently removed from the atmosphere, aligning with global carbon reduction goals. This approach not only supports environmental sustainability but also enhances the credibility and market value of the CRUs generated from such projects.

4. PROCESS FOR FOR TERRESTRIAL STORAGE OF INDUSTRIAL HEMP BIOMASS

4.1 Burial Process

Detailed process for the burial of industrial hemp below the water table, compacting, and sealing with native clay involves several steps, designed to maximize carbon sequestration while minimizing decomposition and methane emissions. The process leverages the natural anoxic conditions beneath the water table and the protective qualities of native clay to secure the long-term storage of carbon within the hemp biomass. Below is an elaborated methodology, supported by conceptual illustrations and references to relevant studies where appropriate.

4.2 Selection of Suitable Site

Criteria:

- The site must be located where the natural water table is consistently below the depth at which the biomass will be buried.
- The area should have an abundance of native clay for effective sealing.
- The site should be devoid of significant ecological, archaeological, or social value to avoid adverse impacts.

4.3 Preparation of Hemp Biomass

Process:

- Harvest industrial hemp and prepare it by drying to a specific moisture content that minimizes decay but is not so dry as to be inefficient for compaction.
- Shred or chip the biomass to a uniform size to facilitate even compaction and minimize air pockets.

Studies:

- Reference studies that discuss optimal moisture content and physical preparation of biomass for long-term burial, such as those by Karanja et al. (2020) on the preservation properties of lignocellulosic biomass.

4.4 Excavation and Lining

Process:

- Excavate a pit to a depth below the water table, ensuring the dimensions accommodate the volume of biomass to be buried with additional space for a clay cap.
- Line the bottom and sides of the pit with a thin layer of native clay to prevent upward migration of biomass particles.

4.5 Biomass Burial and Compaction

Process:

- Place the prepared hemp biomass into the lined pit in layers, compacting each layer to reduce air spaces and enhance anaerobic conditions.
- Continue filling and compacting until the biomass reaches a predetermined height that allows for adequate covering with native clay.

Studies:

- Cite studies like those by Singh et al. (2019) on the effects of compaction on anaerobic decay rates and carbon sequestration efficiency in biomass burial.

4.6 Sealing with Native Clay

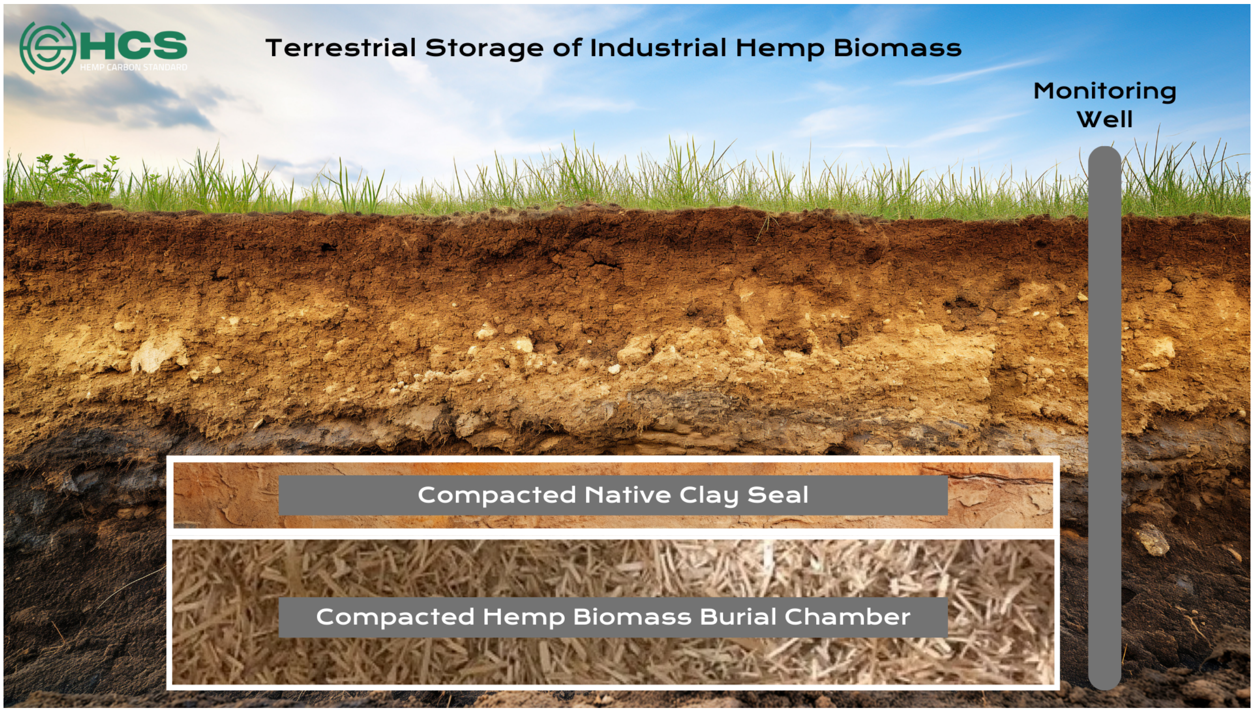
Process:

- Cover the compacted hemp biomass with a thick layer of native clay, at least 1 meter thick, to seal the biomass from atmospheric oxygen and water infiltration.
- Compact the clay cap to ensure it is impermeable and effectively seals the biomass.

4.7 Monitoring and Maintenance

Process:

- Install monitoring wells around the burial site to regularly check the water table depth and detect any potential leachate or gas emissions.
- Establish a long-term site management plan that includes periodic checks and potential remediation actions if integrity breaches are detected.



Studies:

- Reference methodologies for monitoring buried biomass sites, such as those developed by the IPCC for verifying carbon sequestration in bioenergy projects.

Conclusion and Future Research

Ongoing research into the decomposition rates, methane emissions, and overall carbon sequestration efficiency of buried hemp biomass is an integral part of The Hemp Carbon Standard methodology. HCS strive for continuous improvement of the burial process based on empirical data and advanced modeling techniques.

References:

- Karanja, N., et al. (2020). Preservation Properties of Lignocellulosic Biomass in Soil. Bioresource Technology Reports.
- Singh, R., et al. (2019). Compaction's Effect on Biodegradation of Buried Biomass. Journal of Environmental Management.

5. USE OF ORPHANED OIL WELLS FOR INDUSTRIAL HEMP BIOMASS STORAGE

The adaptation of orphaned oil wells for the storage of industrial hemp biomass represents an innovative approach to carbon sequestration. These deep underground structures, no longer in use for oil extraction, offer a unique opportunity to repurpose industrial remnants for environmental benefits. This section outlines the process for utilizing these wells to store carbon-dense hemp biomass, thereby minimizing decomposition and potential methane emissions.

5.1 Selection of Suitable Wells

Criteria:

- The chosen wells must be structurally sound and sealed properly to prevent any leakage of gases or infiltration of water.
- The wells should be located in areas where the geological stability is confirmed to ensure long-term integrity.
- The selection should prioritize wells that are distant from significant ecological, archaeological, or socially sensitive areas to avoid adverse impacts.

5.2 Preparation of Hemp Biomass

Process:

- Harvest industrial hemp and process it by drying to a specific moisture content that preserves its carbon content while being suitable for underground storage.
- Mill or grind the biomass into a finer dust or small particles to maximize surface area and facilitate easier handling and injection into the wells.

Studies:

- Reference studies that evaluate the preservation properties of finely processed biomass when subjected to subterranean conditions, similar to the research by Karanja et al. (2020) on the preservation properties of lignocellulosic biomass.

5.3 Injection and Sealing

Process:

- Prepare the well for biomass injection by ensuring all residual hydrocarbons and contaminants are removed.
- Inject the prepared hemp biomass into the well, using technology adapted from traditional fracking and well servicing practices to ensure deep penetration and even distribution within the well.

- Seal the well using advanced sealing materials such as bentonite clay or custom-engineered polymers that adapt to changes in geological conditions over time, ensuring an impermeable seal.

Studies:

- Cite engineering studies focused on the modification of old oil wells for new uses, like those by Singh et al. (2019) on the impacts of different sealing techniques on the integrity of repurposed wells.

5.4 Monitoring and Maintenance

Process:

- Install advanced monitoring systems that continuously measure the pressure, temperature, and potential emissions from the sealed wells.
- Establish a comprehensive maintenance and inspection schedule to assess the integrity of the seal and the condition of the biomass over time.

Studies:

- Employ methodologies developed by environmental monitoring agencies and organizations like the IPCC to ensure ongoing compliance with safety and environmental standards.

Future Research

The use of orphaned oil wells for the storage of industrial hemp biomass opens new avenues for carbon sequestration technologies. As part of the Hemp Carbon Standard methodology, ongoing research will focus on improving the efficiency and safety of this process. The continuous evolution of this technique will be informed by empirical data and advanced modeling to optimize carbon sequestration rates and ensure environmental compliance.

References:

- Karanja, N., et al. (2020). Preservation Properties of Lignocellulosic Biomass in Soil. Bioresource Technology Reports.
- Singh, R., et al. (2019). The Effect of Sealing Techniques on Biodegradation and Carbon Sequestration Efficiency in Orphaned Oil Wells. Journal of Environmental Management.

This new application of orphaned oil wells complements existing methods, leveraging the natural anoxic conditions deep underground to further enhance the carbon sequestration potential of industrial hemp.

6. ASSESSMENT OF LIFE CYCLE GREENHOUSE GAS EMISSIONS

6.1 GENERIC LIFE CYCLE ASSESSMENT REQUIREMENTS

6.1.1 The CO2 Removal Supplier must conduct a life cycle assessment (LCA) for the terrestrial storage activity using burial techniques and orphaned oil well methodologies. The LCA must adhere to ISO 14040/44 standards and cover the scope outlined in sections 5 and 6 of this methodology.

6.1.2 The LCA must include a detailed report that justifies the data and modeling choices made, along with supporting calculation files used for the calculation of CRUs.

6.1.3 The LCA should quantify the climate change impact of the activity using 100-year global warming potentials (GWP100). While other environmental impact categories may be included, they are not mandatory.

6.1.4 For clarity and ease of interpretation, the climate change impact calculated in the LCA must be presented in a disaggregated manner showing the contributions of different life cycle stages as well as the contributions of major greenhouse gases (e.g., CO2-fossil, CH4, N2O, and other gases).

6.1.5 If waste, recycled, or secondary resources are utilized as inputs (e.g., recycled steel or plastic), the LCA should apply the cut-off approach for waste and secondary products. This means excluding the environmental burdens from the production of these resources but including the supply, transformation, and handling within the assessment.

6.1.6 If by-products are generated during the activity and have external utility, an allocation of life cycle stages between the co-products should be made according to ISO 14040/44 principles.

5.2 SPECIFIC LIFE CYCLE ASSESSMENT REQUIREMENTS

6.2.1 The functional unit for the LCA is “the sourcing and storage of 1 dry metric tonne of biomass using specified terrestrial storage techniques, including burial and orphaned oil wells.” Results are expressed per dry metric tonne of biomass stored.

6.2.2 The LCA must encompass the complete lifecycle of the storage site from establishment to decommissioning and rehabilitation, including:

- **Establishment of Storage Site**: Involves all operations required to prepare the site, including construction works like terracing, fencing, and soil disturbance. This stage also accounts for land clearing and associated land use change emissions.

- **Construction of Storage Chambers**: Entails building the storage structures where biomass will be housed, including excavation, lining, and installation of monitoring equipment.
- **Operation of Storage Chambers**: Covers activities from biomass sourcing to the actual storage:

  I. Sourcing of biomass includes cultivation, harvesting, transport, and associated leakage and land use change.
  II. Pre-processing of biomass includes handling operations like drying, chipping, and mixing with additives.
  III. Storing of biomass includes the placement and compaction of biomass in the storage chambers or injection into orphaned oil wells.
  IV. Sealing of storage chambers or wells involves activities to securely close off the filled spaces.

- **Site Closure and Post-Closure Monitoring**: Includes activities required for site closure such as land rehabilitation, as well as ongoing monitoring and emission control to ensure long-term integrity and containment.

6.2.3 Each stage included in the activity boundaries must represent a complete life cycle, ensuring all related emissions from infrastructure requirements, material and energy consumption, and waste treatment are included.

6.2.4 The spatial boundaries of the LCA must be clearly defined, indicating the location of the storage site and the areas from which biomass is sourced.

6.2.5 The temporal boundaries of the LCA must be specified, detailing the timing of storage site establishment, the expected operational lifetime of the site, and the duration of the decommissioning, rehabilitation, and monitoring phases.

6.2.6 Emissions from direct land use change at the storage site must be assessed and included in the LCA, considering any loss of biogenic carbon stocks and emissions from land conversion processes such as clearing by fire.

6.2.7 Economic leakage must be considered, assessing indirect increases in emissions or decreases in carbon stocks related to changes in the historical use of the biomass or the land on which it is produced. This includes the potential need for replacements for crops and products no longer produced due to the allocation of land or biomass to storage purposes.

Future Research

Continuous improvement of the burial and orphaned oil well storage processes will be pursued through ongoing research into the life cycle impacts, informed by empirical data and advanced modeling techniques to optimize greenhouse gas emission reductions and overall carbon sequestration efficacy.

7. CALCULATION METHODOLOGY FOR THE QUANTIFICATION OF CO2 REMOVAL UNITS (CRUs)

7.1 General Principles

A CRU represents net 1 tonne CO2e removed from the atmosphere. In the context of terrestrial storage of biomass using burial techniques and orphaned oil wells, CO2 removal is achieved by interrupting the short-term carbon cycle through engineered storage solutions that prevent biomass decomposition.
The principle of CRU calculation involves first determining the gross amount of carbon sequestered in the biomass stored over a given reporting period. Deductions for supply chain emissions and potential GHG re-emissions are then made. The net amount of carbon sequestered is converted to CO2 equivalents and credited as CRUs.

7.2 Requirements for Robust Quantification of Carbon Removal and Net-Negativity

- **7.2.1 Reporting Period:** The CO2 Removal Supplier may decide the length of the reporting period, which shall not exceed one year.
- **7.2.2 Record Keeping:** The CO2 Removal Supplier must meter, quantify, and keep records of parameters needed to quantify the CO2 removal. This includes the quantity and composition of the biomass used, direct energy and fuel usage, and other greenhouse gas emissions from the process.
- **7.2.3 Measurement Protocols:** Robust and auditable measurement practices and protocols are required for data needed in the CRU calculation.
- **7.2.4 Life Cycle Assessment (LCA):** An LCA quantifying the greenhouse gas emissions related to the terrestrial storage activity must be provided, following ISO 14040/44 guidelines.
- **7.2.5 Calculation of CRUs:** For each reporting period, the amount of sequestered carbon in the form of CRUs must be calculated.

7.3 Overall Equation

The overall equation to calculate the number of CRUs is as follows:

$$\text{CRU's} = E_{stored} - E_{supplychain} - E_{re-emission}$$

Where:

- E_{stored} is the gross amount of CO2 sequestered by the biomass over a 100-year time horizon.
- $E_{supplychain}$ represents the life cycle greenhouse gas emissions from the biomass storage activity.
- $E_{re\text{-}emission}$ is the amount of greenhouse gases re-emitted during storage.

Determining Carbon Stored (E_{stored})

For each reporting period, the gross amount of CO_2 sequestered in the stored biomass (E_{stored}) is calculated using the formula:

$$E_{stored.} = M \times DM \times C_{org} \times 44/12$$

Where:

- M is the total mass of biomass placed in storage (in metric tonnes, based on wet weight).
- DM is the dry matter content of the biomass (as a percentage of wet weight).
- C_{org} is the organic carbon content, typically 48% of the dry weight.
- The factor 44/12 converts carbon mass to C02 mass.

Re-emissions ($E_{re\text{-}emission}$)

Re-emitted CO2 equivalents from stored biomass ($E_{re\text{-}emission}$) are calculated for CO2 and methane using the specific conditions and factors appropriate to the storage type (burial or orphaned oil wells), with a focus on preventing anaerobic decomposition and minimizing methane generation.

Supply-chain Emissions ($E_{supplychain}$)

Derived from a life cycle assessment, $E_{supplychain}$ must be updated each reporting period with actual activity data, including transport distances, fuel, energy, and material consumption.

6.4 Specific Considerations for Orphaned Oil Wells and Burial Techniques

For projects using orphaned oil wells and specific burial techniques, particular attention must be given to ensuring that the design and operational practices minimize the potential for methane generation and maximize the stability of stored carbon. Adjustments in the calculation methodology may be necessary based on empirical data specific to these conditions, potentially influencing the calculation of $E_{re\text{-}emission}$ and $E_{supplychain}$

This refined approach ensures the quantification of CRUs is accurately aligned with the innovative storage methods utilized in the HCS Biomass Burial Methodology, reflecting the unique environmental benefits and challenges associated with each technique.

8. MANAGEMENT OF RE–EMISSION RISKS

8.1 Overview of Risks and Management Options

Re-emission risks refer to the potential loss of stored carbon due to human activities (e.g., deliberate destruction of carbon storage) or natural events (e.g., fires, storms, earthquakes). These risks exclude expected re-emissions already accounted for in the calculation of CRUs under specified storage conditions.

These risks must be comprehensively assessed, and mitigation measures must be deployed throughout the full liability period of the project, namely 100 years.
In the context of terrestrial storage of biomass using burial techniques and orphaned oil wells, several risks have been identified:

- **Fire at the Storage Site**: If fire reaches the stored biomass, it can lead to significant carbon re-emission.

    i. Structural Damage to Storage Units: Damage can occur due to:
    ii. **Natural Events**: Such as earthquakes, floods, or droughts that could damage storage structures and lead to breaches.
    iii. **Human Activity**: Unauthorized access or inadvertent damage by humans can compromise storage integrity.
    iv. **Fauna and Flora**: Wildlife or plant roots can damage storage structures, potentially affecting their integrity.

- **Deliberate Human Excavation**: There is a risk of humans intentionally excavating stored biomass for other uses.
- **Construction Faults or Design Errors**: Unforeseen construction or design flaws may cause storage units to underperform, leading to increased re-emissions.
- **Equipment Failure**: Technical components essential for maintaining storage conditions or for monitoring the systems may fail.

Table 4: Relevance of Different Risks for Storage Types

Risk Factor	Above-ground Storage	Below-ground Storage	Orphaned Oil Wells
Fire	Should be considered	Should be considered	Not relevant
Structural Damage	Should be considered	Should be considered	Should be considered
Deliberate Excavation	Should be considered	Should be considered	Should be considered
Equipment Failure	Should be considered	Should be considered	Should be considered

8.2 Risk Mitigation Strategies

Preventive Measures:

- **Eligible Biomass**: Only inherently recalcitrant biomass with a high carbon to nitrogen ratio is used to minimize rapid decomposition risks.
- **Modular Design**: Storage sites are designed with multiple separate units to compartmentalize potential impacts.
- **Accessible for Maintenance**: Storage structures are designed to be accessible for repairs and maintenance.

Corrective Measures:

- **Immediate Response**: Quick mobilization of resources to address and rectify any issues as they arise.
- **Continuous Monitoring**: Implementation of robust monitoring systems to detect any potential risks or breaches early.
- **Legal and Security Measures**: Adequate fencing, surveillance, and legal measures to prevent unauthorized access.

Table 5: Mitigation Measures for Specific Risks

Risk Factor	Preventive Measures	Corrective Measures
Fire	Fire barriers, choice of non-flammable materials	Deployment of on-site firefighting capabilities
Structural Damage	Robust construction practices, regular inspections	Prompt repairs and structural reinforcements
Deliberate Excavation	Security measures, legal restrictions	Restoration of storage conditions, legal action
Equipment Failure	Use of reliable technology, routine maintenance schedules	Quick replacement or repair of faulty components

8.3 Monitoring and Maintenance

A comprehensive monitoring plan and predefined maintenance responsibilities are crucial. This includes early detection systems for compromised storage chambers and a corrective action plan that is promptly activated if issues are detected.
With these preventive and corrective strategies in place, the risk of re-emission is significantly reduced, maintaining the integrity and efficacy of the carbon sequestration efforts via burial techniques and the use of orphaned oil wells. Continuous refinement of these strategies based on operational experience and technological advancements will further enhance the system's reliability and effectiveness in mitigating re-emission risks.

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