Version 1.0

BCarbon Methane Capture and Reclamation Protocol

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Table of Contents

1. INTRODUCTION

BCarbon is a nonprofit organization creating pathways to net-zero goals that strengthen rural economies, and generate co-benefits including soil regeneration, improved water quality and water management, and increased biodiversity. With input from stakeholders including landowners, scientific experts, government officials, environmental organizations, and industry representatives, BCarbon develops standardized protocols to support the issuance and registration of carbon credits associated with carbon sequestration, protection, and permanent greenhouse gas ("GHG") emissions capture.

The BCarbon Methane Capture and Reclamation Protocol ("the Protocol") describes the technical approach required by BCarbon to certify GHG capture and associated land reclamation from plugging leaking abandoned oil and gas wells. As administrator of the Protocol, BCarbon's goal is to ensure the complete, consistent, transparent, accurate, and conservative quantification and verification of GHG emission reductions associated with a methane capture and reclamation project ("Project"). The Protocol is designed to operate within a digital measurement, reporting, and verification ("digital MRV" or "d-MRV") framework enabling automated, real-time data onboarding and data processing, quantification, and verifications. The BCarbon d-MRV framework is integrated with a registry that tracks the complete lifecycle of certified projects from project approvals, and issuance, serialization, transferring, and retirement of credits.

The Protocol also introduces important "co-benefits" of MCR Projects as described in section 7.0.

1.1. Methane Emissions from Oil and Gas Wells – Time is of the Essence

Measured from the start of the industrial revolution, methane is responsible for at least 25% of the rise in global temperatures. While methane's atmospheric lifetime is around 12 years vs. centuries for CO_2, it absorbs heat 200 times more efficiently than CO_2, making it 84 times more potent as a greenhouse gas on a 20-year time scale. In addition to its climate impacts, methane also affects air quality because it is an ingredient in the formation of ground level (tropospheric) ozone, a dangerous air pollutant. Rapid and sustained reductions in methane emissions are key to limit near-term warming and improve air quality.

According to the United Nations Environmental Program (UNEP), the oil and gas industry is one of the largest sources of anthropogenic methane emissions and is the sector with the greatest potential for emissions reduction. Furthermore, UNEP states that we cannot meet the Paris Agreement and avoid exceeding 1.5°C without achieving deep reductions in methane emissions from the global oil and gas industry.

Recent numbers released by the U.S. Environmental Protection Agency (EPA) in their Inventory of U.S. Greenhouse Gas Emissions and Sinks report estimate that there are about 3.7 million abandoned oil and gas wells (including orphaned wells and other non-producing wells) within the United States. Wells that have been plugged have average emissions of less than 1 kg CH_4 per well per year versus the over 100 kg CH_4 per well per year average emissions of unplugged wells (EPA 2023).[1]

Academic field surveys indicate that the majority of active wells have methane emissions (Omara 2022). These emissions are primarily due to maintenance issues (Deighton 2020). While there is little academic work specifically targeting inactive wells, these are expected to have even more severe maintenance inadequacies, driven primarily by a lack of funding and oversight. As a result, inactive wells are believed to be a significant source of methane emissions.

1.2. Definitions

Term	***Definition***
Abandoned Wells	Unplugged wells that are not currently in production and which have a known, solvent operator.
Additionality	An evaluation used in carbon markets to demonstrate that the results of a crediting initiative would not have occurred in absence of the incentive of carbon credits. A project is considered “additional” if it would not have happened in a business-as-usual scenario without the crediting project; it is “non-additional” if it would have still occurred.
American Petroleum Institute (API)	A national trade association that represents the interests of the United States oil and natural gas industry and sets standards for the industry.
Baseline Emissions	Emissions likely to occur if the Project is not implemented.
Carbon Dioxide Equivalent (CO_2e)	A standard unit of measure to express the impact of each different greenhouse gas in terms of the amount of CO_2 that would create the same amount of global warming.
Digital MRV (d-MRV)	An advanced methodology for Monitoring, Reporting, Verification (MRV) that applies digital technologies to streamline data collection, processing, and quality control in the issuance of GHG emission credits.

[1] MMTn = One Million Metric Tons

Term	*Definition*
Environmental Attribute	Greenhouse gas emission reduction recognition in any form, including verified emission reductions, voluntary emission reductions, offsets, allowances, credits, avoided compliance costs, emission rights and authorizations under any law or regulation, or under any emission reduction registry, trading system, or pursuant to any reporting or reduction program for greenhouse gas emissions that is established, certified, maintained, or recognized by any international, governmental, or nongovernmental agency.
Local Regulator	The government entity charged by the relevant state government with the oversight and regulation of oil and gas producing wells within that state.
Operator	The entity with authority to conduct oil and gas operations for an oil and gas well. The current or past Operator, or Operator's affiliates, of a well is not eligible to act as Project Developer for such well under this Protocol.
Orphaned Wells	Wells without a solvent operator, and that are not plugged or have been poorly plugged and require additional plugging measures to fully decommission the well.
Plug & Abandon Activity (P&A)	Any activity related to the plugging of an oil and gas well. P&A requirements vary by jurisdiction. For all P&A Activity related to a Project, Project Developers must demonstrate Regulatory Compliance.
Pre-Plugging Test	The test performed at each well to confirm the presence of methane in excess of 1,925 parts per billion, which is the globally-averaged mean atmospheric methane concentration for December 2022 as reported by NOAA (https://gml.noaa.gov/ccgg/trends_ch4/).
Project Developer	The entity that (i) has a demonstrated contractual right to receive environmental attributes related to the decommissioning of the target wells, and (ii) submits an application for project approval and quantification of emissions reduction with BCarbon per the terms of this Protocol. A well's current or past Operator, or Operator's affiliates, are not eligible to be Project Developer.

Term	*Definition*
Proof of Title to Environmental Attributes	Legally binding agreement demonstrating either (i) the right to perform the Project or (ii) title to the Environmental Attributes of the Project.
Regulatory Compliance	The adherence to laws, regulations, and statutes enforced by the governmental or regulatory bodies pertinent to a Project based on the jurisdiction in which it operates.
Regulatory Surplus Test	A test used to determine whether the plugging of a given well is surplus to existing governmental regulations pertaining to that well.
Roles-Based Access	The assignment of access rights to property for entities based on their role within a program. Such access allows transparency in the carbon credit buying and selling process.
Total Project Emissions (tCO_2e)	The carbon emissions accounted for during the production activities of a Project, measured in tons of Carbon Dioxide Equivalent, to be offset against the prevented emissions resulting from Project execution.

1.3. Protocol Purpose and Overview

The purpose of the Protocol is to incentivize the permanent capture of methane present in hydrocarbon reservoirs associated with leaking abandoned oil and gas wells and the reclamation of related surface sites. In addition to significant methane emissions, unplugged wells pose many health, safety, and environmental risks, including toxic water and air hazards (from hydrogen sulfide), flash fires, vapor cloud explosions, and pool fire hazards. Permanently plugging abandoned wells eliminates these hazards as well as the risk of further methane emissions.

This Protocol issues carbon credits for plugging eligible wells using historical production decline curve analysis combined with a leak estimation model. The key underlying observation is that leaking wells eventually completely exhaust the gas that is potentially available over long time-horizons. Field observations of long inactive wells indicate that the methane is exhausted somewhere within a time horizon of 50-60 years (Deighton 2020 and Townsend-Small 2016). The method of estimating a well's reservoir contents, as well as the method of estimating a well's leaks over time, are described in Section 5 and in the Appendix of this Protocol.

Carbon credits issued by BCarbon under this Protocol will be calculated by subtracting a Project's Total Project Emissions from its Baseline Emissions.

2. PROJECT ACTIVITIES

Figure 1 below illustrates the steps Project Developers and BCarbon will follow when completing Projects under this Protocol, including the issuance and registration of carbon credits.

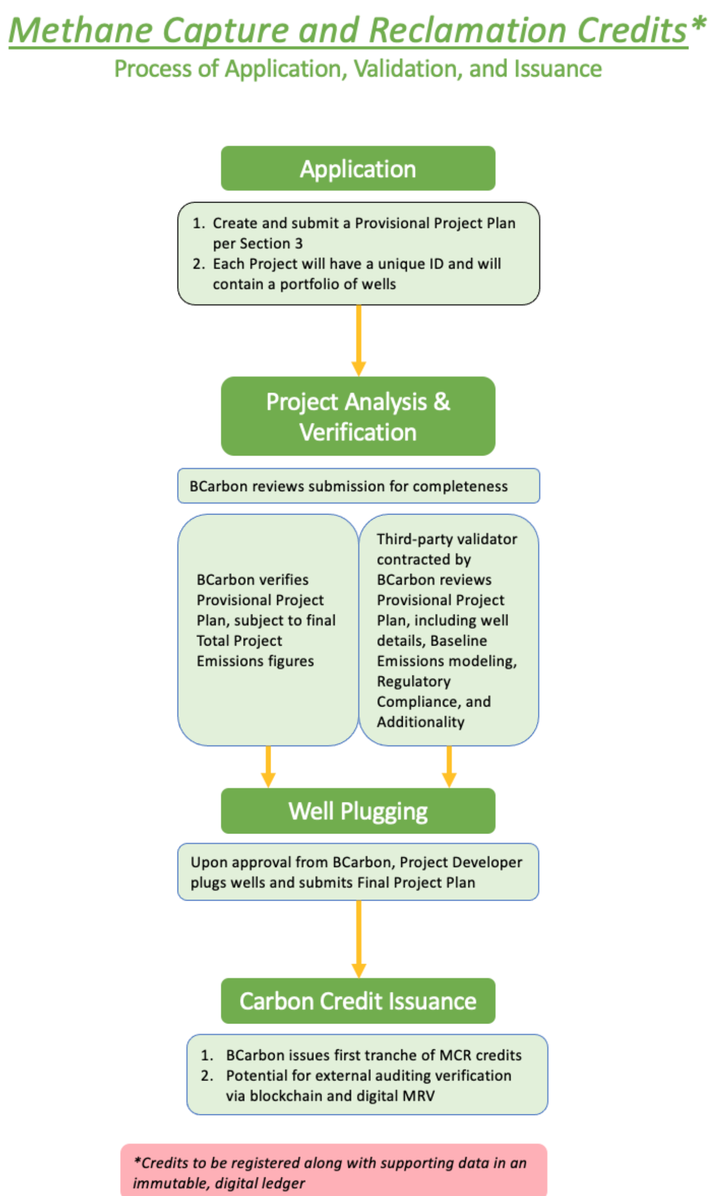

Figure 1 BCarbon Protocol Flowchart

3. APPLICATION OVERVIEW

3.1. Project Submission

Project Developer will submit to BCarbon:

1. A Provisional Project Plan that includes the following (See Appendix for Form Documents):
    a. Project Summary Table that includes summary details for every well included in the Project
    b. Well Details Summary that includes information for each well included in the Project, including Pre-Plugging Test to confirm the presence of methane
    c. Well Plugging Plan for each well that includes, at a minimum, all completed forms required by the Local Regulator to maintain Regulatory Compliance through the P&A process
    d. Well Additionality Summary for each well in the Project
    e. Proof of Title to the Environmental Attributes
    f. Emissions Reduction Report that includes all calculations for estimating Baseline Emissions, Project Emissions, and Post-Project Emissions (assumed to be zero) for each well in the Project
2. Final Project Plan (post-plugging) that includes:
    a. Updates to each section of the Provisional Project Plan, including the Post-Plugging Test confirming the well has been plugged.
    b. Final GHG Calculations
    c. d-MRV Details, including but not limited to demographic details listed below:
        i. # of aquifers within 5 miles of the well
        ii. # of water wells within 5 miles of the well
        iii. # of children, women of child-bearing age, and disadvantaged people within 5 miles of the well
        iv. # of hospitals, nursing/retirement homes, schools, churches, playgrounds, etc.
        v. List of endangered species within 5 miles of the well
        vi. Agricultural land acreage within 5 miles of the well
        vii. Total acreage of land reclamation across all wells
3. Co-Benefits Summary

3.2. BCarbon Review

Within 15 days of submitting the Provisional Project Plan to BCarbon, BCarbon will inform the Developer if they have a complete Provisional Project Plan. If not, BCarbon will request additional materials from the Project Developer.

Within 30 days of BCarbon acknowledging they have a complete Provisional Project Plan, BCarbon will notify the Developer that they either have 1) an approved project or 2) they will notify the Developer of the deficiencies in the Developer's Provisional Project Plan.

Submissions and notifications regarding the Final Project Plan will follow the same timeline used for the Provisional Project Plan outlined above.

The internal review by BCarbon's team will assess all Project submissions, including GHG calculations, well Additionality, and Regulatory Compliance. This review will also include working with contracted engineers to verify and validate each Provisional and Final Project Plan.

Process of Validation, Approval, Development, and Issuance of Carbon Credits

1. Pre-Plugging Submission to BCarbon contains:

   Provisional Project Plan including d-MRV
2. BCarbon reviews Provisional Project Plan for completeness
3. BCarbon selects and contracts with a third-party validator to review the Provisional Project Plan. Project Developer is responsible for such validation costs and will be notified of the estimated costs of validation prior to an agreement.
   a. Validator reviews and returns a Validation Certificate to BCarbon
   b. Review process timeline is 30 days
   c. Validation Certification includes:
      i. Confirmation that the Provisional Project Plan is complete
      ii. Confirmation that the number of carbon credits to be allocated to the Project (and on a per well basis) is complete and accurate, subject to final Total Project Emissions figures
      iii. Confirmation of Additionality
4. BCarbon receives Notice to Proceed from d-MRV and uploads from the Provisional Project Plan the Validation Certificate from Validator

   BCarbon issues carbon credits for Project, such carbon credits to be held on the BCarbon Registry within a Lock-Box Account to be released to the appropriate Project Developer account upon BCarbon receiving the Final Project Plan with final Total Project Emissions figures
5. Project Developer submits Final Project Plan to BCarbon's d-MRV direct access and notifies BCarbon
6. BCarbon receives Final Project Plan and reviews it with a third-party validator, following the same contracting process as outlined for the Provisional Project Plan. Once the Final Project Plan is approved by BCarbon and the validator, BCarbon automatically releases carbon credits from the Lock-Box Account to the appropriate Project Developer's account
   a. Project Developer pays a per carbon credit fee to BCarbon of $0.10
   b. Project Developer pays [$100] per well processing fee

4. PROTOCOL SUMMARY AND PROJECT REQUIREMENTS

This Protocol provides the quantification and accounting frameworks for carbon offset credits generated from the capture of methane emissions by plugging leaking abandoned and orphaned oil and gas wells and reclamation of the associated surface site. The Protocol provides for the estimation of the remaining methane in the reservoir and allocates offset credits for preventing the potential release of that gas into the atmosphere.

In this methodology, the term “abandoned wells” will refer to unplugged wells with no recent production which have a known, solvent operator.

4.1. Eligibility

1. Geographic scope:
   Projects must be located in the United States. At this time, BCarbon has received requests to include Canadian projects in the Protocol and is currently evaluating the issue of and the feasibility of doing so. Once completed, BCarbon will make a recommendation to stakeholders.
2. Accepted well types:
   On-land or onshore wells (over freshwater) registered with the appropriate Local Regulator as oil or natural gas producing wells
3. Well with proof that either:
   a. The well has been transitioned to a non-producing status in filings with the Local Regulator or attestation from a certified engineer; or
   b. There has been no net production in the past 3 months
4. Presence of Methane:
   The Pre-Plugging Test confirms the presence of methane at the wellhead in excess of 1,925 parts per billion, which is the globally-averaged mean atmospheric methane concentration for December 2022 as reported by NOAA (https://gml.noaa.gov/ccgg/trends_ch4/)

4.2. Regulatory Compliance

Wells must be in compliance with the Local Regulator or, in the course of the project, be brought into compliance with the Local Regulator.

At the conclusion of the project, the wells covered must receive approval from the Local Regulator that they have been appropriately plugged and decommissioned, including removal of any equipment and suitable remediation of the site surface soil and vegetation, as required to maintain Regulatory Compliance.

4.3. Earning of Credits

Fifty percent of total issuable credits will be issued upon completion of BCarbon’s review of the Final Project Plan, as described in Section 3. Ten percent of total issuable credits will be issued on the second anniversary of first credit issuance and then annually until 100% of credits have been issued, as illustrated below.

Tranche 1: Upon Completion of BCarbon's review of the Final Project Plan	50% of credits
Tranche 2: Two years from the date of Tranche 1 issuance	10%
Tranche 3: Three years from the date of Tranche 1 issuance	10%
Tranche 4: Four years from the date of Tranche 1 issuance	10%
Tranche 5: Five years from the date of Tranche 1 issuance	10%
Tranche 6: Six years from the date of Tranche 1 issuance	10%

4.4. Project Boundaries

4.4.1. Geographic Boundaries

The geographic boundaries will include the surface wellhead, surface equipment, and surface pad associated with the registered well. Any surface area considered by the Local Regulator to be within scope of their authority by virtue of the presence of the project well will be considered within the geographic boundaries of the project.

4.4.2. GHG Assessment Boundaries

Qualified offsets occur in scenarios where methane would, if not for the enactment of the Project, be released from target wells into the atmosphere. Furthermore, in cases where methane is being released from any surface equipment attached to target wells, such emissions may also be measured and reported for net emission reductions.

5. QUANTIFICATION OF GHG EMISSIONS REDUCTIONS

5.1. Baseline Reference Case

The baseline reference case is a scenario where the methane being emitted from target wells into the atmosphere is not restricted by the Project. The baseline against which the post-plugging calculation is compared is established by the predicted emissions that would have been released without the Project Developer's implementation of the MCR Project.

Pre-plugging reservoir estimation is required to obtain an estimate of baseline, business-as-usual, Baseline Emissions. Pre-plugging reservoir estimates shall approximate current active leaks as well as future potential leaks by estimating how much methane is in the well's reservoir, and how much methane will leak out over time. The method required for estimating reservoir contents is the standard industry decline curve analysis, supplemented with additional gas composition sampling, if needed. The method required for estimating leaks over time is the leak probability model. These methods are detailed in section 5.2 and in the Appendix.

For wells without a history of natural gas production, BCarbon may entertain alternative methods of estimating reservoir contents and future leak rates. Project Developers with such Projects should present such alternative methods to BCarbon for eligibility consideration.

5.2. Production Decline Curve Analysis and Leak Estimation

This method follows the industry standard for estimating the remaining reservoir natural gas, similar to the methods originally outlined by J.J. Arps (Arps 1944 and Arps 1956.) For each individual well:

1. Estimate the decline rate:
    a. Source at least 42 months of production history for each individual well from two credible, independent sources, sorted by production date.
    b. In cases where the two sources of non-zero production history differ, the lower of the two cases will be used if it is not an outlier under (g) below.
    c. Drop records with 0 producing days and zero monthly production. These would otherwise distort indications of production.
    d. Calculate average production per day for each month with non-zero producing days, defining each of these averages as P_i for month i.
    e. Keep the last 36 records (if available) or all production records (if fewer than 36)
    f. For each of the three 12-record periods $\{P_1, \ldots, P_{12}\}$, $\{P_{13}, \ldots, P_{24}\}$, $\{P_{25}, \ldots, P_{36}\}$, calculate the mean (m) and standard deviation (s) of production.
    g. Within each of these three 12-month periods, drop records with production P_i where ABS(P_i – m) > 2s, for the m and s of that 12-month period.
    h. Take the 6-month moving average of the production, denoted as $\{Q_1, \ldots, Q_{36}\}$. This smooths the data.
    i. Estimate a regression line: ln(Q_i) against time (T) measured in producing days. This regression estimates parameters A and B in the model ln(Q) = A * T + B. Coefficient A is the decline rate per day. This is fitting an exponential decline curve to the production rates.
    j. Calculate the estimated annualized decline rate EADR = $(1+A)^{365.25}-1$
    k. Determine the effective annualized decline rate, ADR, as the greater of -30% or the smaller of -3% or the EADR: ADR = max(-30%, min(-3%,EADR)). The decline rate is bounded from above and below to eliminate results that are inconsistent with industry experience for end-of-life wells.
2. Calculate fitted last production FLP = e^{ZN+B} where N is the number of producing days between the first and last production records (normally P_0 and P_{36}) and Z is the minimum of A*365.25 and -3%
3. Determine the last production estimate, LPE:
    a. If EADR is less than -3%, set LPE = FLP
    b. If EADR is greater than -3%, set LPE to the mean calculated (in 1.f above) for the latest 12-record period
4. Estimate the methane fraction of the gas. Project Developers may follow either of two approaches to determine the methane fraction of gas (MFG):
    a. Table based on the Gas Research Institute survey "Chemical Composition of Discovered and Undiscovered Natural Gas in the Lower-48 United States; Volume 3: Associated/Dissolved Gas Data" as updated in 1993 and published by the US Department of Commerce: Identify the table associated with the region and the vertical depth for the well. Use the mean value of methane from the table as the MFG.

b. Sample 1 liter of gas from the well and determine the gas composition using a third-party laboratory service using a gas chromatograph. The percentage of methane in the sample can be used as the MFG.

5. Calculate the expected leaks over the target time horizon:
   a. Use the BCarbon Leak Probability Model. This model incorporates the following:
      i. Input characteristics of the well: completion date, shut-in date, sour/non-sour production mix
      ii. Input state of the well (existing leaks, current pressure in the wellbore)
      iii. Fault tree incorporating industry reference estimates of mean service life to determine the probability of the well transitioning into a small leak or large leak state
      iv. Forecast flow rates under multiple leak-states (i.e., large leak, small leak, no leak)
   b. Run the leak model with three standardized parameters:
      i. Flow rate reference for large leaks of 50 years
      ii. Decline time horizon for small leaks of 100 years
      iii. Offset crediting time horizon of 20 years
   c. will be the total gas leaked, TGL.
6. Methane available to leak (MAvail) will be the probability weighted-sum of the amounts of gas leaked in each state over 20 years.

5.3. Pre-Plugging Emissions Calculations

Baseline Emissions will be set according to the following formula:

1. Determine the MAvail in units of MCF CH_4 as described above in section 5.2
2. Determine the equivalent amount of atmospheric carbon dioxide (Est_tCO_2e) as
   a. Est_tCO_2e = MAvail * Density * GWP20, where
   b. Density = the metric density of methane at STP = 0.0418 MT/MCF
   c. GWP20 = the 20-year global warming potential for methane as reported in the most recent Intergovernmental Panel on Climate Change (IPCC) Assessment Report (AR.) As of 25 November 2022, GWP20 is 84, as reported in the IPCC AR5 Working Group 1, Chapter 8, Table 8.7.
3. Determine the project pre-plugging baseline emissions (BE) as
   a. BE = min(Est_tCO_2e, P_Max), where
   b. P_Max = Protocol maximum allowance = 63k tCO_2e

5.4. Post-Plugging Emissions Calculations

Post-plugging emissions are expected to be negligible for a well that has been decommissioned correctly and each site must comply with all local requirements for regulatory recognition that the well has been plugged and abandoned.

5.5. Project Emissions

The following categories of project emissions sources must be assessed and reported:

1. Materials emissions from concrete used for plugging
2. Fuel for equipment and materials transport to project site
3. Fuel for rig operation during plugging activity
4. Methane vented during baseline measurement
5. Project Developers shall use the current version of the U.S. Environmental Protection Agency's Emission Factors Hub (GHG Emission Factors Hub | US EPA) to determine the correct factors to use for their equipment. For diesel fuel, use No. 2 Fuel Oil.

Define TPE to be the total project emissions in terms of tCO_2e.

5.6. Uncertainty Discount

An uncertainty discount will be deducted from granted offsets as a buffer against failed plugs from any wells for which offsets have been granted in this Protocol. The uncertainty discount for each Project will be 5% of measured gross offsets: $D = 5\%$

5.7. Net Emissions Reductions

Define the gross emissions reduction as: $G = (BE - TPE) * (1 - L)$.

The number of offset credits issued will be the net emissions reductions once project emissions are deducted from gross emissions reductions.

5.8. Plugging Confirmation

Prior to credits being issued, Project Developers must demonstrate that the well has been designated as "plugged", or equivalent, by the Local Regulator. Also prior to credits being issued, a post-plugging test is required (see Section 5.9.1, item 6), confirming that emissions have been reduced to at or below the 1,925 parts per billion threshold.

5.9. Data Collection

5.9.1. Well Identifiers Reported

The following material is to be prepared by the Project Developer for submission to the Validator:

1. API Well Number for each target well
2. GPS Coordinates (Lat/Long) for each target well
3. Photograph(s) of the well at surface level, including any surface equipment
4. Evidence that each target well is in regulatory compliance (abandoned wells only)

5. Evidence that both the Project Developer and whoever will be plugging each well have a legal right to conduct plugging activities
6. Post-plugging methane detection test at or below the Pre-Plugging Test

5.10. Quality Assurance and Control

5.10.1. Offset Ownership

The Project Developer must demonstrate a contractual right to receive environmental attributes related to decommissioning of the target wells from a contractual chain originating with the current operator of the wells.

5.10.2. Plugging and Surface Reclamation Standards

In the absence of plugging requirements set by local and state authorities, Project Developers are required to follow guidelines for design, placement, and verification of cement plugs as set by the American Petroleum Institute (API) Recommended Practice (RP) 65-3 – Wellbore Plugging and Abandonment Standard. Where applicable, plugging, abandonment and restoration must meet contractual requirements within existing mineral leases should those requirements exceed regulatory minimums. Such requirements are out of the purview of BCarbon and are solely within the Project Developer's responsility.

5.10.3. Accounting Framework

Submissions will be made on the basis of the entire portfolio of wells in the Project.

Credit issuing: Issued upon completion of BCarbon's review, which is limited to 60 days.

Project Developer Offset ownership: Offsets will be issued either to the Project Developer or a designated third-party Project Developer with a duly confirmed contract transferring the right to receive issued offsets.

5.10.4. Digital MRV Recording

The MCR Project is assigned a Unique ID which allows access to "digital MRV" (d-MRV) and asset data that records:

1. the complete crediting "lifecycle" of the Project including credit issuances, transfers and retirements;
2. relevant information from field monitoring, emission factors, data refinements, verifications, and other relevant inputs;
3. the complete profile of physical and environmental attributes of the Project including the environmental conditions determined from the site analysis

"Roles-based" access to d-MRV asset data is provided through a 3rd party registry that is integrated with BCarbon to participants in the generation and market application of the BCarbon credits including owners of primary data (e.g., landowners, operators, and Project Developers) and secondary data refiners, and 3rd party auditors.

6. DEMONSTRATING ADDITIONALITY

A well is Additional if, at the time of plugging, no person or entity has a firm, non-extendable legal obligation to plug it either (a) by law, regulation, statute, court order or other government requirement, or (b) by private contract (e.g., pursuant to a lease, service, or other agreement with a third party).

No offsets will be granted for a well that is included in a project registered under another carbon offset protocol, whether with BCarbon or another carbon registry.

7. ENVIRONMENTAL AND COMMUNITY CO-BENEFITS

MCR Projects have many co-benefits, including:

1. Soil regeneration:

   As part of the required surface reclamation process when a well is plugged, the surrounding soil will be brought back to its native state, which will dramatically improve the soil's organic matter, which in turn improves drainage, water retention, and nutrition for plants and other species. Soil regeneration also further mitigates climate change.

2. Increased biodiversity:

   The removal of the well, well equipment, and the reclamation of the surface will regenerate the area to its native state and increase the variety of plants, animals, fungi, bacteria, and other organisms. This process:

   i. allows native plants and other species to repopulate the area
   ii. helps to regulate the climate and clean the air and water
   iii. reverses the effects of habitat loss and fragmentation

3. Improved water quality:

   Well plugging and land reclamation improves local water quality by removing the risk of additional contamination to groundwater aquifers, allowing them to recharge naturally.

4. Improved air quality:

   MCR Projects improve air quality by preventing future emissions of air pollutants from each well, which emit a variety of toxins, including volatile organic compounds, particulate matter, nitrogen oxides, and other poison gases. When a well is plugged, it is no longer possible for these pollutants to be emitted into the air. In addition, soil and plant regeneration made possible by surface reclamation will further improve air quality.

5. Job creation:

   a. As part of the plugging of a well, human resources are required to:

      i. plan and design the plugging process
      ii. prepare the well pad for plugging
      iii. perform plugging

iv. repair and maintain equipment associated with the plugging process
v. prepare and deliver materials to each plugging site
vi. verify that the well has been plugged properly
vii. perform equipment removal and surface reclamation

b. Furthermore, site reclamation expands the land use opportunities for additional economic activity, such as farming, ranching, and development

6. Improved human health conditions:
   Living near leaking oil & gas wells poses several significant health risks, including air pollution and water contamination and the associated exposures to dangerous toxins.

7. Removal of significant potential future liabilities for state governments, local communities and taxpayers:
   The cost of plugging an oil & gas well is high, and in some cases, can exceed over $1,000,000. This high cost of plugging wells is one of the reasons there is such a significant number of shut-in wells that eventually end up becoming orphan wells, which are a liability for the community and state in which they are located. Not only does this Protocol encourage and accelerate the plugging of abandoned wells, it also fully removes the potential for abandoned wells to become a liability for the related communities and states.

REFERENCES

Deighton, J. A., Townsend-Small, A., Sturmer, S. J., Hoschouer, J. & Heldman, L. Measurements show that marginal wells are a disproportionate source of methane relative to production. J. Air Waste Manag. Assoc. 70, 1030–1042 (2020). https://pubmed.ncbi.nlm.nih.gov/32776822/

Nichol, J.R., Kariyawasam, S.N. “Risk Assessment of Temporarily Abandoned or Shut-In Wells,” prepared for the US Department of the Interior, Minerals Management Service (2000). http://www.wellintegrity.net/Documents/MMS%20Report%20on%20SI%20Wells.pdf

Omara, Mark and Zavala-Araiza, Daniel and Lyon, David R. and Hmiel, Benjamin and Roberts, Katherine A. and Hamburg, Steven P. “Methane Emissions from Low Production Oil and Natural Gas Well Sites.” Nature Communications (2022). https://www.nature.com/articles/s41467-022-29709-3

Townsend-Small, A., Ferrara, T., Lyon, D., Fries, A. & Lamb, B. Emissions of coalbed and natural gas methane from abandoned oil and gas wells in the United States. Geophys. Res. Lett. 43, 2283–2290 (2016). https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2015GL067623

Williams, J. P., Regehr, A. & Kang, M. Methane emissions from abandoned oil and gas wells in Canada and the United States. Environ. Sci. Technol. 55, 563–570 (2021). https://pubmed.ncbi.nlm.nih.gov/33322902/

United Nations Environmental Programme (UNEP). https://www.unep.org

Appendix A: Engineering Support Letter

RALPH E. DAVIS
AN OPPORTUNE COMPANY

Overview

We (Ralph E. Davis Associates or “RED”) have been asked to evaluate the method described in the attached spreadsheet and documentation (the “Proposed Method”) devised for estimating the amount of methane gas that can be expected to leak in future years from a portfolio of wells, given certain general premises and well-specific data.

The well-specific data include the last 36 months of historical production volumes, the year the well was shut-in, the presence of an intact surface casing (or “bradenhead”) valve, the detection of methane leaking from the well and the presence of sustained casing pressure. The general premises include no change to existing laws and regulations or the way they are enforced, and no change to current operations for each well in the portfolio, including no plugging and abandonment.

Opinion of the Proposed Method

It is our opinion that the Proposed Method provides a reasonable means of estimating the future methane emissions, its specifications are reasonable, and the methods it employs are consistent with standards and principles generally accepted in the petroleum industry (where such industry standards exist).

The scope of our review and basis for our opinion is shown in Exhibit A.

Disclaimer

Our opinion does not in any way constitute or make a guarantee or prediction of results, and no warranty is implied or expressed that any actual outcome will conform to any outcome based on the Proposed Method.

The opinions expressed herein are subject to and fully qualified by the generally accepted uncertainties associated with the interpretation of geoscience, engineering and production data and do not reflect the totality of circumstances, scenarios and information that could potentially affect actual results and/or decisions made that rely on this report.

There are numerous uncertainties inherent in estimating hydrocarbon resources and in projecting future methane emissions. Oil and gas resources assessments must be recognized as a subjective process of estimating subsurface accumulations of oil and gas that cannot be measured in an exact way.

Projections of methane emissions that are prepared by other parties or measured at the well may differ, perhaps materially, from those estimated by the Proposed Method. Any projection of methane emissions for a given well necessarily involves substantial uncertainty regarding its accuracy. Such uncertainty is based on the availability and quality of the well information, how such information is interpreted and the variability of the population of wells with characteristics similar to the given well.

Statement of Independence

In performing this study, RED is not aware of any conflicts of interest. As an independent consultancy, RED provides impartial technical, commercial, and strategic advice within the energy sector. In the preparation of this document, RED has maintained, and continues to maintain, a strict independent consultant-client relationship with the Client. RED's remuneration was not in any way contingent on the contents of this report.

The management and employees of RED have no interest in any of the methods evaluated or related to the analysis performed, as part of this report. Staff members who prepared this report hold appropriate professional and educational qualifications and have the necessary levels of experience and expertise to perform the work. This report was prepared for public disclosure in its entirety in conjunction with the promulgation of a carbon offset protocol.

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Exhibit A

Summary of RED's Review of the Proposed Method

Proposed Method Parameter	How addressed in the Proposed Method	RED's Review
Amount of gas that is available to leak	Best-fit estimate of exponential decline of last 36 months of gas production data (subject to minimum and maximum declines of 3 and 30%) for 30 years	RED back-tested the method against the actual results of approximately 5000 randomly selected producing gas wells in selected basins in the Onshore US, and found that it generated, in the aggregate, estimates of volumes produced over five years that were within approximately 10% of the actual volumes. Individual well results varied, however.
Point in time the well began leaking	Date of last production according to public records	The actual date a well began leaking is typically unknown. This is a conservative assumption that reduces the amount of methane available to be leaked in the future
Gas leak rate	The weighted average between a "large" leak and a "restricted" leak	This is an approach to account for uncertainty in the leak rate
Probability of a "large" leak	10%	Based on "Risk Assessment of Temporarily Abandoned or Shut-in Wells", prepared for the US Department of the Interior, Minerals Management Service, October 2000
"Large" leak rate	50% of the forecasted rate obtained from the exponential decline forecast	This is a specified value in the Protocol.
"Large" leak volume	The volume that would have been produced over 30 years using the extrapolated best-fit exponential decline parameters	The 30-year period is a specified value in the Protocol.
"Large" leak decline rate	Calculated to match the "large" leak volume over a 50- year period, in combination with the "large" leak rate. Minimum value of 0%.	The 50-year period is a specified value in the Protocol.

"Restricted" leak rate	20% of the “large” leak rate, used to match the “large” leak volume, in combination with the “restricted” leak decline rate over the extended time window.	This is a specified value in the Protocol.
“Restricted” leak decline rate	Calculated to match the “large” leak volume over a 100- year period, in combination with the “restricted” leak rate. Minimum value of 0%.	The 100-year period is a specified value in the BCarbon Methane Capture and Reclamation Protocol.

Methane concentration of leaked natural gas	Based on actual gas analysis from the well or within the field; if unavailable, based on published literature	Although a sample from the well (or another well in the field) is the best estimate, there are numerous other sources that can provide reasonable estimates of methane concentration in natural gas. One example is "Chemical Composition of Discovered and Undiscovered Natural Gas in the United States, 1993 Update: Volume 3" prepared for the US Department of Commerce
Methane Greenhouse Gas 20 Year Equivalency (GWP20)	84 tons CO_2 equivalent/tons methane	The Intergovernmental Panel on Climate Change (IPCC) estimates this value to be between 84 and 87

Appendix B: Decline Curve Model

An illustrative example of the decline curve analysis described in Section 5.2 is included in the attached Microsoft Excel spreadsheet “Decline_Curve_Model.xlsx.”

Appendix C: Leak Model

The Leak Model is attached as a Microsoft Excel spreadsheet titled "Leak_Rate_Model.xlsx." This section is a user guide to understanding and applying this model.

Model Inputs

For each well, enter the following well-specific inputs, all on the primary sheet "Leak Rate:"

Input	Cell location	Type	Example
Sour / non-sour?	'Leak Rate'!B4	Binary drop-down	non-sour
Bradenhead valve present?	'Leak Rate'!B5		yes
Sustained casing pressure?	'Leak Rate'!B6	Binary drop-down	yes
Methane detected?	'Leak Rate'!B7	Binary drop-down	yes
Year drilled	'Leak Rate'!B10	Four-digit integer	2006
Year shut-in	'Leak Rate'!B11	Four-digit integer	2010
Plugging year	'Leak Rate'!B12	Four-digit integer	2023
Last rate, mcfpd	'Leak Rate'!B17	Floating point number	8.87
Exponential decline rate, %pa	'Leak Rate'!B18	Floating point number, expressed as a positive percent	3.00%
Methane concentration, %	'Leak Rate'!B21	Floating point number, expressed as a positive percent	75%
"Large" leak decline rate %pa	'Leak Rate'!B26 (see further discussion below)	Floating point number, expressed as a positive percent	0.98%
Restricted rate decline rate %pa	'Leak Rate'!B27 (see further discussion below)	Floating point number, expressed as a positive percent	0.001%

Model outputs

The model produces both intermediate and final outputs. The key intermediate outputs are the forecast of flows under the three states over the forecasting time horizon (located in 'Leak Rate'!F:M.) The final outputs are:

Output	Cell location	Type	Example
CH_4 Volume leaked pre-plugging	'Leak Rate'!B44	Floating point number, expressed as MCF	3,997
CH_4 Volume leaked post plugging in the crediting window	'Leak Rate'!B35	Floating point number, expressed as MCF	6,332
CO_2 Mass leaked pre-plugging	'Leak Rate'!D44	Floating point number, expressed as tCO_2e	6,368
CO_2 Mass leaked post plugging in the crediting window	'Leak Rate'!D45	Floating point number, expressed as tCO_2e	10,087

Model overview

The model forecasts expected leaks based on a three-state model:

- No leak
- "Large" leak
- "Restricted" leak

The model uses the most recent flow and the estimated production decline rate to extrapolate a counterfactual "as-if producing" gas flow vector. For this extrapolation, the flow starts at a daily rate equal to the Last Production Estimate (LPE.) For each future year, this rate declines exponentially following the decline rate estimated from the historical production data (see section 5.2.). The sum of the values from the years from the shut-in date until the end of the "Volume Window" (from cell 'Leak Rate'!B19) in that vector is the reference potential volume of gas, This appears, in cumulative form, as DCA Forecast in column 'Leak Rate'!P.

For each of the two leak states, the model forecasts a potential flow rate over time that is similar to the DCA forecast, but with adjustments for the starting value, the number of years in the time window, and the decline rate. In each case, the associated decline rate is estimated to produce a total volume of gas equal to the reference potential volume from the DCA Forecast. This is described in more detail below.

For the "large" leak state, the starting daily rate is equal to the Last Production Estimate (LPE) multiplied by the "Large" leak factor. From that starting year, the forecast leak flow rate decays exponentially at the calculated implied rate in cell 'Leak Rate'!B26..

The forecast flows in the "Restricted" leak state are similar, though there is an additional adjustment to the starting flow rate and the associated decay rate. The starting rate is the "large" leak starting rate multiplied by the "Restricted" leak factor in cell 'Leak Rate'!B31. The decay rate for the restricted state is the calculated implied rate in cell 'Leak Rate'!B33.

From the year in which the well was shut-in, the model estimates a probability that the well is in each of the three leak states. These probabilities are used to calculate a weighted sum of the expected volume of leaked gas in that year. This weighted sum is then added for the years in the crediting window to arrive at an expected volume of leaked gas. This is then adjusted to account for the methane fraction and then converted to an equivalent mass of CO_2 under standard conditions set at 60°F and 14.5 PSIA.

Leak Decline Rates

The leaks from the well are expected to flow at a slower rate than in the counterfactual producing state used to estimate the DCA Forecast. The key underlying observation is that leaking wells eventually completely exhaust the gas that is potentially available over long time-horizons. Field observations of long inactive wells indicate that the methane is exhausted somewhere within a time horizon of 50-60 years (Deighton 2020 and Townsend-Small 2016). Based on this observation, the two leak sub-models are calibrated to emit the same volume of gas as the DCA Forecasts, but at slower initial rates, with a longer time horizon, and a slower flow decay rate.

Leak sub-model parameters

For generating potential flows in the restricted leak state, the key parameters are:

Parameter	Value or Calculation Method	Notes
Initial "Large" leak rate	50% of the “large” leak rate	This is a specified value in the Proposed Method
“Large” leak time window	50 years	Set conservatively to fully cover the window from field observations.
“Large” leak decline rate	A positive value calculated to reproduce the DCA Forecast volume over the “Large” leak time window (for example, using excel solver or goalseek so that cell ‘Leak Rate’!B29 is as close to 0 as possible.) In cases where no positive value will produce a match with the DCA forecast volume, use 0.001% as a default value.	Implied by the assumption that the total volume of leaks will eventually match the DCA Forecast volume.
Initial "Restricted" leak rate	20% of the “large” leak rate	This is a specified value in the Proposed Method
“Restricted” leak time window	100 years	Set conservatively to fully cover the window from field observations.

“Restricted” leak decline rate	A positive value calculated to reproduce the DCA Forecast volume over the “Restricted” leak time window (for example, using excel solver or goal-seek so that cell ‘Leak Rate’!B36 is as close to 0 as possible.) In cases where no positive value will produce a match with the DCA forecast volume, use 0.001% as a default value.	Implied by the assumption that the total volume of restricted leaks will eventually match the large leak volume

Example Calculation

For illustrative purposes, consider a well with the following characteristics:

Input	Value
Sour/non-sour?	non-sour
Bradenhead valve present?	yes
Sustained casing pressure?	yes
Methane detected?	yes
Year drilled	2006
Year shut-in	2010
Plugging Year	2023
Last rate, mcfpd	8.87
Exponential decline rate, %pa	3.00%

Based on these input values, the DCA forecast estimates a total volume of emissions of 64,042 MCF. To match that volume with the standard leak state parameters, the implied decline rate for the large leak is 0.98%pa and, for the restricted leak flows, the implied decline rate is 0.001%pa (the default value, as no positive value will allow a match with the DCA forecast volume.).

For this example well, the model forecasts a total volume of methane leaked in the crediting window of 6,332 MCF and a CO_2 equivalent mass of 10,087 tCO_2e.

Sensitivity

To evaluate the standard reference value of the "large" leak factor, it is useful to analyze the sensitivity of the implied large leak decline rate and the total estimated volume of expected gas leaked under a range of alternative restricted leak rate values.

The following sensitivity table is based on an illustrative well with the input values from the example calculation (above.)

Alternative Large Leak Factor	Implied Large Leak Decline Rate	Expected total gas leaked (MCF)
0.4	0.04%	5,420
0.45	0.53%	5,880
0.5 (Protocol Standard Parameter)	0.98%	6,332
0.55	1.40%	6,776
0.6	1.80%	7,215